AN INVESTIGATION INTO THE FEASIBILITY AND POTENTIAL BENEFITS OF INTEGRATING MICROALGAE CULTURE WITH LIVESTOCK FARMING IN NIGERIA

By

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Abstract

Nigeria continues to struggle to meet the demand for animal sourced protein despite its sizeable livestock population. In fact, the average daily intake of 0.75 gram of protein per kilogram of body weight recommended by the Food and Agriculture Organisation (FAO) for developing countries, is met by only 31% of the nation's population. The high-priced and poor quality of the feeds currently available in Nigeria causes high animal mortalities, stimulates low productivity and as a result, produces a low rate of return on investment. An efficient animal *cum* feed production system is therefore vital to the sustainability of viable livestock and aquaculture production enterprises in Nigeria. The purpose of this interdisciplinary research was to determine the status of animal feeds in Nigeria, and to investigate the country's livestock farmers ability to adopt animal *cum* microalgae farming as a potential solution to the low-quality feed materials challenges. Survey of the existing livestock and aquaculture market in Nigeria was undertaken to capture farmer's expectations, preferences, and aversions with regards to feeds and feed materials. It was found that animal farmers in Nigeria fed livestock and fingerlings (in aquaculture) with imported commercial feed brands at the beginning of the farming cycle and then switch to local brands or on-farm formulation to save on cost. Farmers' are also in desperate need for affordable protein and lipids rich feed materials to supplement and/or balance the readily available low nutrient feed materials. It was also found that sufficient credit and/or loan facilities are not made available to livestock farmers in Nigeria and thus, there is the need for better access to credit facilities through non-private government sources. Finally, the results of the market survey indicate that despite their willingness to undertake trainings and other learning programmes, animal farmers are lacking in basic education and thus limited in their ability to adopt innovative farming practices and technologies such as microalgae culture.

The aforementioned findings offer the voice of the customer and defines the farmer's needs with regards to feeds and feed materials in Nigeria. These were key inputs for setting up the appropriate process and design specifications for the case study analysis of an open pond microalgae farm. A conceptual framework based on the DMAIC (Define, Measure, Analyse, Improve and Control) model was developed as a roadmap for the process improvement case study analysis. The case study analysis focuses on both the potential causes of failure and process capability (in terms of repeatability, reproducibility and/or transferability) with regards to human capability/manpower. It was found that the sun drying process of the microalgae biomass is the only "off-centred" process that exhibits special causes of variation due its reliance on the weather. The study also found that microalgae culture contamination rate is higher during the scaling-up process of the inoculate from the mother culture to higher concentration in the ponds. In addition, it was found that the cultivation medium composition can be diluted up to five times (depending on the type of water supply used) the prescribed Zarrouk's medium requirement, which could reduce the cost of nutrients.

The study concludes that adequately funded training programmes and a shift of the animal industry focus from imported overpriced commercial feed products to an animal *cum* microalgae (plant) culture systems integration could off-set the current cost of feedstuff in Nigeria. This is particularly true for protein source feed materials like fishmeal. This study provides a comprehensive examination of the existing feed market in Nigeria and the opportunities and challenges for the implementation of microalgae cultivation systems.

Keywords: *Microalgae, Spirulina, Livestock, Feeds, Nigeria, Lean 6 Sigma, DMAIC, Market Analysis*

Dedication

To the memory of my beloved sister, Hassana Bature.

Table of Contents

List of Figures

List of Tables

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Declaration

I declare and affirm that this thesis is my genuine work and that all the sources of materials used for the research has been duly acknowledged through citation. I have followed all the ethical and technical principles of scholarship in the preparation, data gathering and analysis as well as compilation of this thesis.

This thesis has been submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy at Birmingham City University. I solemnly declare that this thesis has not been submitted to any other institution for any academic degree or certificate.

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Name: **Aminu Bature** Signature……………..A_B…………………

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Faculty: **Computing, Engineering and the Built Environment**

Acronyms

ARCN	Agricultural Research Network
CtQ	Critical to Quality
DMAIC	Define, Measure, Analyse, Improve and Control
EFA	Essential Fatty Acids
FAO	Food and Agriculture Organization
FCR	Feed Conversion Ratio/Feed Conversion Rate
FMEA	Failure Mode and Effects Analysis
GNP	Gross National Product
IFAD	International Fund for Agricultural Development
LCL	Lower Control Limits
LM	Lean Manufacturing
LPD	Lean Product Development
LSS	Lean Six Sigma
NIRSAL	Nigeria Incentive-Based Risk Sharing System for Agricultural Lending
NPD	New Product Development
PESTEL	Political, Economic, Social, Technological, Environmental and Legal factors
PUFA	Polyunsaturated Fatty Acids
QFD	Quality Function Deployment
RBT	Resource-Based Theory
RBV	Resource-Based View
SCA	Sustainable Competitive Advantage
SCD	Solar Conduction Dryer
SCP	Single Cell Proteins
SDG	Sustainable Development Goal
SIPOC	Suppliers, Inputs, Process, Outputs, and Customers
TQM	Total Quality Management
UCL	Upper Control Limits
VoC	Voice of the Customer
VRIO	Value Rarity Imitability and Organization

Chapter One: Introduction

1 Country Background: Nigeria

Nigeria is a large country in the Guinea Coast of West Africa, covering a total geographical area of 356,668 square miles, which makes it three times larger than the United Kingdom (Falola & Heaton, 2008). It lies between the longitudes 2° and 15°E' and latitudes 4° and 14°N occupying a land area of 923,768 km^2 (Ugbah, *et al*., 2019). Nigeria is the most populous country in Africa with about 195 million people (The World Bank, 2018; Udo & Umanah, 2017) and ranked seventh most populous country in the world (The World Bank, 2017). According to Marais *et al*. (2014), the population of Nigeria is projected to reach between half a billion to a billion people by the year 2100. In 2014, as the most populated country in Africa, Nigeria emerged as the biggest economy in the continent (REO, 2015). The country has 36 states, each of which has its own political administration headed by a governor, and a federal capital territory (FCT) where the federal government is based (Bourne, 2015). The country experiences variable pattern of rainfall from North to South due to ITD (Inter-tropical discontinuity) movement, which is the meeting zone of the dry CT (Continental Tropical) air mass from the Sahara Desert and the MT (Maritime Tropical) winds from the Atlantic Ocean (Eludoyin, *et al*., 2014). The rainfall pattern over Nigeria are also modulated by equatorial easterlies (Odekunle, *et al*., 2008). Subsequently, the country is characterised by two seasons wet and dry. The former is as a result of northward movement of the ITD in January from its lowest position of about 4°N to its highest position of about 23°N in August, which lead to the flow of moist MT air mass from the Atlantic Ocean that predominates and favours rainfall. The later season, however, is triggered by southward retreat of the MT air mass to the initial lowest position due to dry CT air mass coming from the Sahara Desert (Ugbah, *et al*., 2019). These explains why rainfall stops earlier in the Northern states and starts earlier in the Southern states. In the same vein, annual mean rainfall is lower in the Northern states (400-1100 mm) and higher in the South (1200-3000 mm). According to Ismaila *et al*. (2010), Northern Nigeria experiences unimodal pattern of rainfall that peaked in/around the month of August while the South experiences bimodal rainfall and peaked in June and September, which makes the country adequate for agriculture.

1.1.1 The Agriculture and Livestock Sector

In spite of major government focus on the oil and gas sector, agriculture remains one of the pillars of the Nigerian economy, contributing 22% of the nation's GDP (NBS, 2018). The sector although mostly underdeveloped (largely due to high cost of feed) provides; employment opportunities for 36.38% of the rural households (The World Bank, 2019; USDA, 2019), foreign exchange opportunities for the economy, food and raw material for the shoe, clothing and cosmetic industry (Bamaiyi, 2013). The livestock subsector in particular “contributes around 1.7% to the national GDP and around 9% to the agriculture value added” (FAO, 2019b). It is influenced by high demand for animal products driven by population growth, rising disposable income, urbanisation, and changing customer service needs from the demand driven capital-intensive non-ruminant market and the resource driven labour-intensive ruminant subsector. For instance, except for poultry and aquaculture, the domestic production of animal products is less than 50% of the demand for livestock products such as mutton, beef, goat meat, pork and milk (FAO, 2019c). Growth in population without a corresponding rise in agricultural productivity and/or successful implementation of favourable policies is leading to food insecurity, poverty, and unemployment in Nigeria (Fasoyiro & Taiwo, 2012). Consequently, protein consumption in the country is far lower than the recommended animal protein of 0.75 gram per kilogram of body weight per day per citizen (Campbell, *et al*., 2008), or “less than 9 grams of animal protein per capita per day” (Bamaiyi, 2013). This is because the animal industry is still underdeveloped due to insufficient access to feeds, conflicts among pastoralist, poor processing facilities and low technical inputs in animal management *vis-à-vis* diseases and waste (FAO, 2019c). Moreover, despite the fact that the country has abundant natural resources and (therefore high potential for increasing the volume of livestock and crop production to meet the nutritional requirements for the fast-growing population), approximately 30% of animals slaughtered in Nigeria are imported from surrounding countries like Niger. In the same vein, the country’s average yield of milk has been static for the last two decades, at about 0.8 litres per cow per day, making Nigeria highly dependent on imported milk. Likewise, fish production per annum is not sufficient to meet the need of the current population (Udo & Umanah, 2017). Based on the aforementioned issues, an average citizen of Nigeria is malnourished due to an inadequate number of proteins and essential amino acids in their diets. To alleviate these problems, it is important to increase the production of livestock and aquaculture based agricultural products by improving crop and animal farming systems for farmers to adopt.

One of the major factors influencing the success of livestock and aquaculture production in Nigeria is feed production and quality (Becker, 2008). The cost of feeds currently constitutes about 60 – 70% of the total operational cost in aquaculture, and 20 – 30% in poultry and pig production (Fagbenro & Adebayo, 2011; Ayinla, 2007). This has been attributed to the lack of readily available and/or affordable feedstuff as well as low literacy rates among farmers. One of the goals of this research is to appraise the factors militating against animal production in Nigeria, and to investigate means by which microalgae cultivation could improve the livestock and aquaculture growth performance and reduce operational cost. Microalgae are a large group of photosynthetic aquatic organisms, capable of converting CO_2 to produce organic materials such as foods, feeds or high-value bio-actives (Chisti, 2007). They are abundant in nature and grow in various climates and geographical locations including polar areas (Kirst & Wiencke , 1995). Moreover, microalgae have the potential to provide feedstock for animal feed, because they contain relatively high concentration of protein and essential amino acids as well as grow 10 - 30 times faster than terrestrial oilseed crops like soybean and groundnuts (Sheehan, *et al*., 1998; Miao & Wu , 2006). Studies have also shown that microalgae could provide waste management opportunities for farmers because they are capable of bio-remediating waste matter such as animal waste effluents into organic matter using energy from the sun (Chaiklahan, *et al.*, 2010; Ramírez, *et al.*, 2018).

1.2 What are Microalgae?

With over 40,000 species characterised thus far, algae refer to a large group of "photosynthetic, aquatic organisms that lack the true roots, stems, and leaves of higher plants. Eukaryotic algae are generally divided into the multicellular "macro-algae" (such as seaweeds) and the unicellular "microalgae" (such as *Spirulina* and *Chlorella*). The basic concept of exploiting algae like *Chlorophyceae* (green algae) and *Bacillariophyceae* (diatoms) for their oil accumulation properties has been around for over half a century (Meier, 1955). Although it is generally accepted in the literature that the technology is very promising, cultivation of microalgae as a feedstock for biofuel production requires further development in order for it to be economically viable and environmentally sustainable. (Milbrandt & Jarvis, 2010). Consequently, in recent years attention has been directed towards the production of high-value, low-volume food and feed supplements as well as nutraceuticals. Commercial microalgae biomass production facilities such as Cyanotech Corp., in Hawaii, Earthrise Nutritionals, LLC, in California, and Martek Co., in Maryland uses both open ponds and closed tubes or photo-bioreactors cultivation systems. Although each of the aforementioned cultivation systems have their advantages and disadvantages, photo-bioreactor have been criticised in the literature for being too expensive to build for small-scale algae production by say rural farmers and will never compensate for the added initial and operational cost (Huesemann & Benemann, 2008). Other challenges of cultivation associated with photo-bioreactors systems include effective agitation or mixing, reactor construction materials, gas exchange complexities, temperature control, CO_2 administration, and optimal cultivation scale (Darzins & Pienkos, 2010). On the other hand, open pond systems made from shallow artificial ponds lined with plastic or clay (to prevent percolation at the bottom) offers a relatively cost-effective way of cultivating microalgae. However, productivity is highly affected by effective agitation and quality of the culture medium (Narala, *et al.*, 2016). Consequently, paddlewheels are utilised in raceway designs to provide laminar flow of the culture medium to keep the culture suspended and increase productivity (Milbrandt & Jarvis, 2010). Although open ponds remain the most widely adopted commercial scale system for producing microalgae for high volume, lower value products it is constrained by evaporation losses, contamination and land area requirements (Mata, *et al*., 2010).

In this research, one of the most cultivated microalga utilised in developing countries - *Spirulina* (*Arthrospira platensis* and/or *Arthrospira maxima*) (Khan, *et al*., 2005; Delrue, *et al*., 2017) is examined as a potential feedstock for animal feed formulation and/or supplementation. *Spirulina* is a "multicellular and filamentous blue-green microalgae belonging to two separate genera *Spirulina* and *Arthrospira* and consists of about 15 species" (Habib, *et al*., 2008). It is a filamentous cyanobacterium with diversity in its biological activities and has nutritional significance due to high natural nutrient concentration that gives it immune-modulatory and bio-modulatory functions. These species is commonly found in Africa (for example adjacent to Lake Chad in the *Kanem* region) and the alkaline lakes of Mexico, where it grows naturally in the warm climates (Khan, *et al.*, 2005). In 1940, the French phycologist Dangeard was the first to report a traditional algae-based food eaten by the *kanembu* people around Lake Chad called *dihé*. Moreover, in the mid-1960s the botanist Jean Léonard discovered in the native markets of N'Djamena (formerly Fort-Lamy) an edible greenish cake made from blooming algae near Lake Chad (Leonard, 1966). *Spirulina* is currently cultivated commercially in nutrient rich medium to produce nutritionally rich biomass for food (Holman & Malau-Aduli, 2013; Shimamatsu, 2004). It yields more protein per hectare than other traditional livestock feed types including corn, wheat, and soybeans. Furthermore, unlike other species of algae, the cell walls of *Spirulina* does not contain cellulose that results in better digestibility (Šimkus, *et al*., 2013), which is a key determining factor for high quality feed ingredient (Winter, 1929). In line with Belay *et al*. (1996) and Holman (2013), the issue of malnutrition among both livestock and human beings in Nigeria could be lessened by adopting microalgae cultivation with animal production for their high protein and lipids content. However, the operational cost and price of microalgae in comparison to other feedstuff is significantly higher and consequently challenging for large-scale livestock production operations (Holman & Malau-Aduli, 2013). In addition, its palatability, smell and dried powdery form have also been criticised in the literature (Becker, 2007).

This research presents the results of a market survey carried out in Nigeria to determine animal farmers' requirements for feed products, which provides the basis for the case study analysis of a small to medium size microalgae farm in India using lean six-sigma DMAIC cycle. Analysis of the market survey indicates that although there is some evidence that suggest steady increase in conventional animal feeds over the years, feed quality remains a major problem for the growth and profitability of the intensive poultry and aquaculture subsectors in Nigeria. Likewise, the ruminant's industry of cattle, goats and sheep still depends on free grazing on rangelands, while pig farmers keep their livestock in traditional piggeries (Ayinla, 2007). The market segmentation undertaken in the present research also shows that poultry farmers followed by aquaculture dominate the animal feed marketplace and thus, provides the best target segment for microalgae feed development in Nigeria. In the same vein, cost of feed materials varies in the country, due to state purchases of feedstuff and inflation as found by exploring the country's agricultural macro-environment, which calls for on-farm feed cultivation and formulation through mixed farming.

The case study analysis of the research is concerned with the identification of process bottlenecks within the value stream of an on-going low-cost microalgae farm in India, as well as process predictability and repeatability in terms of transferability to Nigerian farmers. Consequently, cost of failure and defects rates *vis-à-vis* microalgae contamination were used in the analysis process. It was found that open-air microalgae cultivation systems used to grow algae for human food could be adopted with minor modifications to grow biomass for animal feed. Specific causes of failure originate in the sun drying process and scaling-up of the mother-culture process. A typical Nigerian solar dryer model is suggested to improve the drying process while maintaining a high pH of above 10.5 in the culture medium may help sustain a monoculture free from biological contaminants. It was also found that a further 19% of the initial investment cost of setting up microalgae *cum* livestock production system could be saved by eliminating the cost of those equipment needed for human food processing such as hot air oven, electric sealing machine and so forth.

1.3 Statement of the Problem

Competition for the use of conventional feedstuff in Nigeria for human and livestock consumption coupled with low domestic productivity in agriculture have led to significant escalations in feed prices (Esiobu, *et al.*, 2014). These together with general shortage of high-quality protein source ingredients such as fishmeal and soybeans warrant the need for research on alternative feedstuff, preferably on those feed materials that are not in demand by humans for food. Moreover, there is need to develop affordable and accessible technologies for producing non-conventional feedstuff such as single cell protein (SCP) like microalgae and yeast as well as earthworm meal and tadpole meal. Several studies have been done in Nigeria to replace fishmeal with animal sources such as blood meal, tadpole meal and terrestrial or aquatic worms, and plant sources such as SCPs, and *bambara* meal (Abowei & Ekubo, 2011; Selvakumar, *et al*., 2013; Sogbesan & Ugwumba, 2008). Different results have been obtained ranging from poor to very good animal response in terms of growth and feed conversion ratio. While microalgae could be used in animal production, it appears that fishmeal is indispensable in livestock production. This can be attributed to the fact that the cost of microalgae feedstock per kilogram of dry matter is approximately twice the price of fishmeal (Rana, *et al*., 2009; Tantikitti, 2014). However, microalgae can be cultivated in low cost open pond systems, which could be integrated with traditional animal production systems. Moreover, the cost of on-farm cultivated microalgae feedstock could be significantly reduced by using a modified Zarrouk's medium or even animal waste effluents as fertilizer (although this requires further studies) for the culture medium of the algae (Ramírez, *et al*., 2018).

1.4 Research Question(s)

The research questions for this study were:

1. What are the current constraints militating against animal production in Nigeria?
2. Can microalgae be used to supplement animals or partially replace high-cost animal feed ingredients like fishmeal in Nigeria?
3. Which animal feed market segment presents the largest market development opportunity for microalgae-based feedstuff?
4. Can existing open-pond microalgae cultivation system for food be adopted and/or modified for on-farm feed production in Nigeria?

1.5 Research Aim and Objectives

1.5.1 Aim

The aim of this research is to investigate the market growth opportunities for cultivating microalgae biomass as feedstock for animal feed application in Nigeria.

1.5.2 Objectives

1. To segment the livestock and aquaculture subsectors in Nigeria in order to determine which market segment is best suited to adopt microalgae production for feed or feed supplement[1].
2. To evaluate the competitive potential of using microalgae in livestock and aquaculture feed in comparison to traditional feedstuff[2].
3. To examine the Nigerian livestock and aquaculture subsectors in order to obtain farmers feed needs and requirements i.e. the "voice of the customer" (VoC)[3].
4. To develop a conceptual framework for measuring process variation in open pond microalgae farm(s) based on lean 6-sigma (LSS) DMAIC model[4].
5. To apply the developed conceptual LSS's DMAIC framework in an open-pond microalgae case study farm to identify non-value adding activities based on animal farmer's feed requirements[5].

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[1] Achieved in Chapter 4
[2] Achieved in Chapter 5
[3] Achieved in Chapter 6
[4] Achieved in Chapter 7
[5] Achieved in Chapter 7

6. To offer a set of recommendations by which animal farmers in Nigeria can adopt open-pond microalgae production systems.

1.6 Thesis structure/Road Map

Figure 1 below summarises the road map of the present research, showing the interplay between the research objectives and approach adopted across the chapters to achieve them.

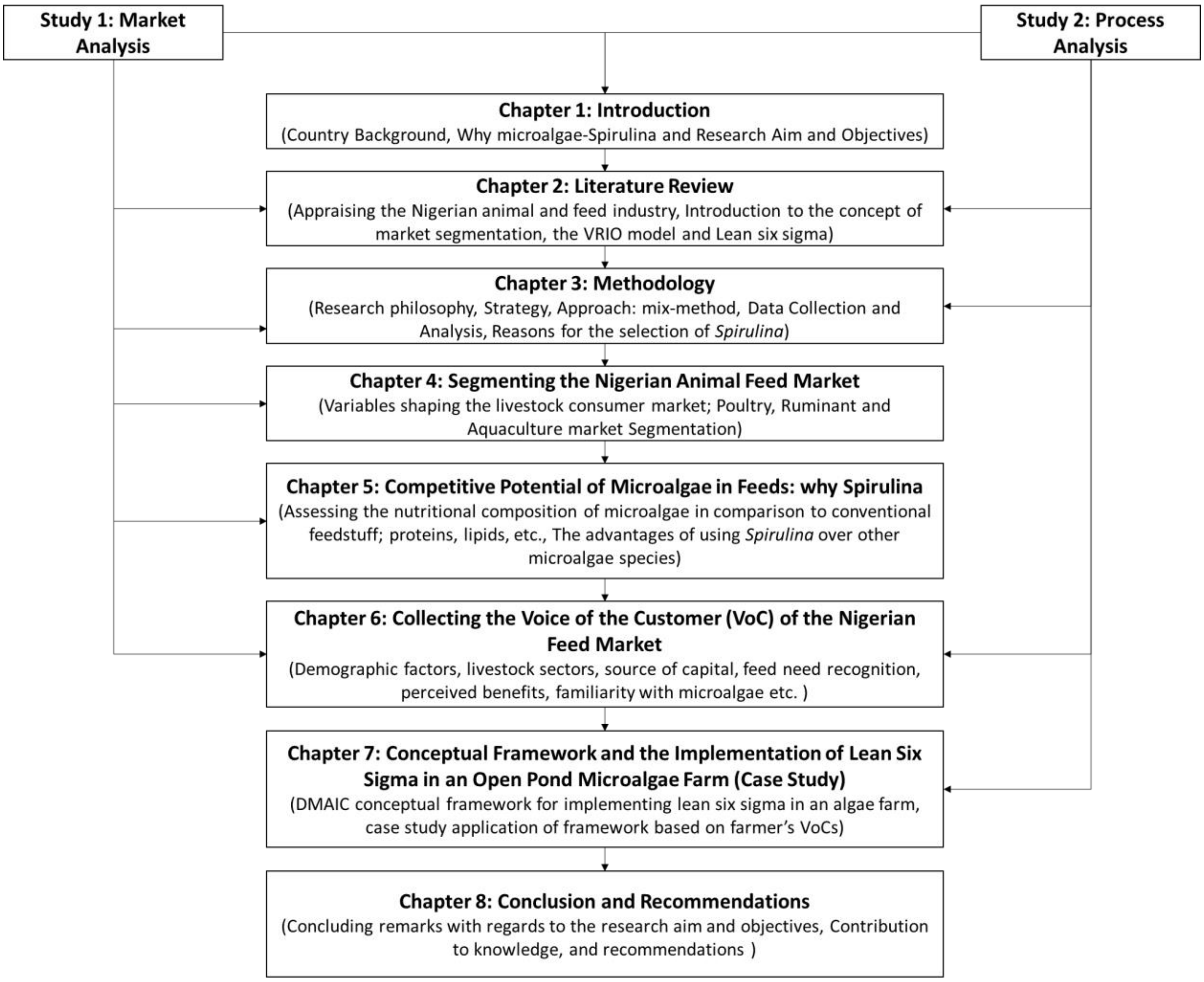

Figure 1: Thesis Structure

1.7 Thesis Outline

The goal of this research is twofold. Firstly, to investigate the feed market in Nigeria to obtain livestock farmer's feed needs and requirements in form of voice of the customer for potential microalgae-based feedstuff. Secondly, to analyse an existing small-scale microalgae farm in India using the voice of the customer's feed requirements derived from Nigerian farmers as the critical to quality criteria for process assessment and/or design efforts. The report begins with an appraisal of the livestock and aquaculture industry in Nigeria by conducting a detailed literature review on the animal feed industry, constraints militating against animal production, prospects for sustainable livestock and aquaculture production in Nigeria. The animal feed market in Nigeria was divided into potential feed user groups or segments who share similar needs based on the literature. A detailed market analysis was also carried out to obtain information with regards to the potential feed customers in Nigeria using primary data collected by means of a survey (questionnaires). A literature review on the evolution of LSS was also conducted and a conceptual framework for analysing a microalgae production farm is developed based on the DMAIC cycle. DMAIC model was extensively utilised in the case study to identify potential areas of improvement and stabilization (based on reproducibility and repeatability) within the case study processes of production. The outcome of the analysis was used to investigate available options in the literature for potential improvement and/or modification for the processes identified as "out of control". The overall contents of the chapters in this report are summarised as follows.

1.7.1 Chapter One

In this chapter, an introduction to the Federal Republic of Nigeria is presented. It contains brief high-level discussion about the factors impacting animal production in Nigeria. It also contains introduction to what microalgae are. Additionally, the statement of problem, research question(s), as well as aim and objectives are also presented in this chapter.

1.7.2 Chapter Two[6]

This chapter reviews the literature on the Nigerian animal industry. Specific attention was given to the livestock and aquaculture feeds and feed Ingredients, constraints militating against animal production including the present macro-environmental factors that have impact on the industry, and finally the prospects for sustainable livestock and aquaculture production in Nigeria. This Chapter also provide background information of the frameworks and models used throughout the research such as LSS, VRIO framework and market segmentation.

1.7.3 Chapter Three

Here the underlying methodology (both epistemology and ontology), the methods adopted for collecting data (i.e. qualitative-interviews and quantitative-questionnaires), and the research strategy(s) (i.e. case study and survey) used throughout this research to achieve the research objectives are presented. It also discussed measures taken by the researcher to adhere to ethical principles in order to protect the rights of the participants of the research.

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[6] The goal of this chapter is to answer the first research question by providing the reader with a background information on the challenges affecting animal production in Nigeria and whether the introduction of a potential high-quality feed material like *Spirulina* is warranted.

1.7.4 Chapter Four

Presents the theoretical background for the market segmentation undertaken to explore what and how many prospective animal market segments should be explored based on livestock species, population size and production system(s) in Nigeria. This chapter further investigates microalgae feeding trials in the literature involving different animal species, to highlight the benefits and shortcomings of using microalgae in animal diets. This chapter also provides the researcher attempt to answer the third research question – Which animal feed market segment presents the largest market development opportunity for microalgae-based feedstuff? And the second research objective.

1.7.5 Chapter Five

This chapter introduce the reader to the VRIO framework that is employed to evaluate how microalgae feedstock compare in terms of nutritional profile to traditional feed materials readily available to farmers in Nigeria. Finally, the chapter presents the findings in a summarised VRIO model to show where microalgae's fits compare to traditional feedstuff including its potential to offer competitive parity and advantage to early adopters. This chapter presents the researchers attempt to answer the second research question of the study - *can microalgae be used to supplement animals or partially replace high-cost animal feed ingredients like fishmeal in Nigeria*? And the third research objective of the research.

1.7.6 Chapter Six

In this chapter, the results from the data analysis conducted on the Nigerian animal feed market are presented. The chapter provide insights into the consumption patterns, needs and requirements for feed by small-scale farmers in Nigeria. It demonstrates where the highest opportunities for introducing an integrated animal *cum* microalgae culture system is. The chapter also cover farmers literacy level, which is vital for the transferability of the skills required to run a small-scale open pond microalgae farm. The findings of the analysis conducted in this chapter provide the major farmer's requirements and needs by which the production processes of microalgae must met in order to meet the customer's needs[7].

1.7.7 Chapter Seven

Firstly, this chapter presents the conceptualisation of a theoretical framework by reviewing the literature on LSS's DMAIC model as well as the process map of a small-scale microalgae production farm in India. The chapter further discuss the interrelationship between lean manufacturing and six sigma and demonstrates how the methodology's DMAIC approach relates to the process map of a

[7] Mostly the cost of failure, non-value adding activities and repeatability of the processes with regards to operator's capabilities.

microalgae farm. Secondly, it presents the researcher's attempts to answer the fourth research question[8] via a case study analysis of a small-scale open pond microalgae farm. The chapter also offers an introduction to the case organization and defines its production processes. A capability six-pack analysis was undertaken on the harvesting processes (i.e. filtration to drying) to evaluate the major indices and to determine the stability of the activities undertaken, whether they are "in control" and if the data follow a normal distribution or not. FMEA (Failure Mode and Effects Analysis) was also perfumed in the define phase to investigates potential failures withing the cultivation process. The chapter also discuss the potential improvement and/or design modification methods (from the literature) to key processes like sun drying and scaling-up of the mother culture. Both of which were "out of control" or "unstable" according to the results.

1.7.8 Chapter Eight

Firstly, this chapter summarise and discuss the overall findings of the two studies undertaken to achieve the aim of this research. The chapter starts with the findings on the Nigerian livestock and aquaculture market analysis (study 1), which covers research objectives one to three. This is followed by the findings related to the microalgae production process analysis (study 2) that focus on achieving the research objectives four and five. Secondly, it described the conclusions drawn by the researcher from the study, research contribution and the limitations and recommendation for future research.

[8] Can existing open-pond microalgae cultivation system for food be adopted and/or modified for on-farm feed production in Nigeria?

Chapter Two: Literature Review

2 Introduction

The purpose of this chapter was to explore the current literature that has been published on the Nigerian livestock and aqua-feed industry. Firstly, the Nigerian livestock and aquaculture literature were appraised to investigate the status of the animal industry. Secondly, the animal feeds industry in Nigeria is examined focusing on both conventional and unconventional feed materials available in the country. Thirdly, the bottlenecks holding back the expansion of livestock and aquaculture production in Nigeria are also reviewed. Fourthly, the prospects for attaining sustainability in livestock and aquaculture production and the potential role that microalgae could play in these are investigated. This Chapter also provide background information of the frameworks and models used throughout the research such as LSS, VRIO framework and market segmentation.

2.1 An Appraisal of the Nigerian Animal and Feed Industry

The development of the livestock sub-sector is an important component of agriculture in Nigeria with abundant socio-economic potentials. The literature is rich with research studies that investigate the role of the Nigerian agriculture sector to the country's economy. According to Lawal-Adebowale (2012), animals play significant role in the economic wellbeing of Nigerians, serving as a source of income to farmers and dealers/sellers of live animals and/or butchers. The sub-sector also generates employment for the larger population who explore animal-based product and by-products for economic benefits. In the same vein, according to the Nigerian National Bureau of Statistic (NBS), agriculture in the second quarter of 2018 contributed 22.86% to overall GDP in real terms. Although this figure was lower than the contribution in the second quarter of 2017 (i.e. 22.93%), it was higher than the first quarter of 2018 (i.e. 21.65%) (Kale, 2018). However, it is interesting to note that the crop production subsector is the key source of agriculture growth in the country, contributing 83.5% to 92.06% of overall growth in the sector between 2011 and 2018 respectively (Odetola & Etumnu, 2013; Kale, 2018). Livestock and fishing subsectors in particular represent ₦283,559.35m (7.35%) and ₦80,979.01m (2.10%) respectively of the ₦3,857,705.59m (22.82%) GDP contribution from agriculture in the second quarter of 2019 (CBN, 2019). Figure 2 shows the GDP of all the agriculture subsectors in Nigeria as of the second quarter of 2019.

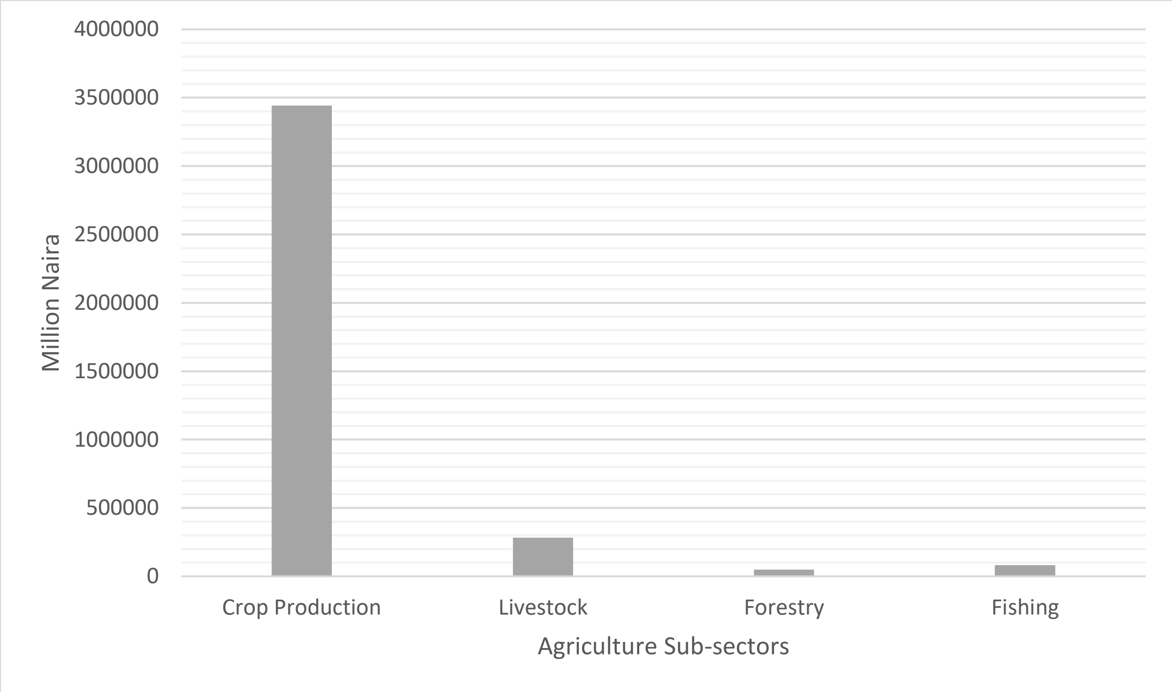


Figure 2: 2nd Quarter of 2019 Real GDP of Agriculture Subsectors in Nigeria[9] (CBN, 2019).

Notwithstanding the economic significance of both livestock and fishery subsectors to the Nigerian economy, the animal industry is still unable to supply the minimal recommended animal protein requirement of 0.75g per kg body weight per day of the average citizen (Campbell, *et al*., 2008). The livestock subsector is the largest source of animal protein including milk and eggs products, evidence through income creation as well as food supplies and hide as raw material (Odetola & Etumnu, 2013). In spite of this, the subsector is declining in its contribution to the country's economy. For example, between 1981 and 2019 the share of livestock farming in agricultural GDP dropped from 14.43% to as low as 7.35% respectively (CBN, 2019). Similarly, the fishery subsector which consist of both fish landings from industrial and artisanal fisheries as well as aquaculture fail to reach its target for domestic demand and consumption. According to Essien & Effiong (2010), "Nigeria's total domestic fish production stands at 640,000MT from both marine and freshwater bodies with a current national fish demand of about 1.6 million MT/year". The authors further assert that "this quantity is grossly inadequate for domestic consumption; thus Nigeria imports 700,000MT of fish per year [despite the 80,000MT from aquaculture] to cushion the supply - demand gap and provides at least a 50% animal protein intake for the millions of Nigeria's population". These studies highlight a serious gap between the demand and supply of both livestock and fish in Nigeria.

[9] Latest available data

2.1.1 Feed and Feed Ingredients in Nigeria

According to Fagbenro & Adebayo (2005), Nigeria has the highest number of feed manufacturers in Sub-Saharan Africa, dominated by small-scale operators producing between 0.5 – 5.0 tonnes per hour. Moreover, the demand for animal feed in Nigeria is an endeavour that increases on a daily basis (EDR, 2014). Yet, gross underutilisation of the feed milling capacity has been reported over the years. For instance, Moehl & Halwart (2005) reported that only 10,760 tonnes of fish feed are produced in the country prior to the year 2000 while the demand rate was an estimated 35,570 tonnes of feed. In 2015, the fish feed production capacity stood at 647,750 metric tonnes out of the total 5,300,000 metric tonnes produced in Nigeria: second to only poultry feed (Udo & Dickson, 2017). In the same year, Nigeria's global ranking in "the leading animal feed producing countries" in the world moved from number 51 to 40. Yet, there are few sources of specialised commercial feed in the country engaged in livestock feed especially poultry and fish feed. Consequently, the majority of the feeds produced in Nigeria are made locally on farm sites (70% for aquafeed) (Fagbenro, *et al.*, 2003). Subsequently, the government has been encouraging indigenous feed millers that utilises local ingredients to formulate feed especially for the poultry and fish industry through input subsidies, pricing policies and production credits (Ekpo, *et al.*, 2016). However, the country's efforts to meet the needs of the animal industry has been constrained by the devaluation of the Nigerian Naira as well as feed-food competition issues, which has led to higher prices of feeds and feed materials (such as fishmeal and cereal grains). In connection with the issue of farm made low quality feed, Udo and Dickson (2017) suggest that commercial feed mills could serve as "the catalyst in rebuilding and developing efficient aquaculture, [which can also] serve as a centre for animal husbandry training while simultaneously supporting commercial poultry and dairy production, sheep and beef fattening feedlots and meat processing units". Unfortunately, although commercial feed milling has been in existence in Nigeria since the 1960s (Chete, *et al*., 2014), it still fails to meet the increasing local demand, despite modernisation efforts in terms of structural reforms and equipment. Perhaps, finding ways to improve the quality of on farm locally formulated feeds through better quality ingredients and self-cultivated feed materials could succeed where unspecialised commercial feed mills continue to fail.

2.1.2 Conventional and Unconventional Feedstuff in Nigeria

The goal of formulating feed is to grow animals quickly and economically. To achieve these, a number of researchers have suggested that animals should be fed with compounded diets for optimum production and return on investment within a short time (Ogunji & Wirth, 2001; Ahmad & Ibrahim, 2016). These diets must provide the following dietary components:

- **Protein:** Is a feedstuff component that makes animal grow well and ensures repairs of damaged tissues (Joshi, 2015). Fishmeal, legumes and soybean meal are good sources of protein. In the literature, health concerns are raised concerning the utilization of raw fish as a main ingredient in aqua-feeds due to the presence of thiamine, which is an anti-nutrient that destroys vitamin B1. Amino acids, which are the building blocks of proteins such as *methionine* and *lysine*, can be supplemented by microalgae in animal diets (Habib, *et al*., 2008).
- **Energy**: Is supplied by adding lipids (fat and oil) and carbohydrates sources like maize, sorghum, wheat or rice meal in the feed. This feedstuff provides the animal (usually non-ruminants) with energy for their daily activities (Ahmad & Ibrahim, 2016).
- **Lipids**: Sources of lipids include vegetable oils from sunflower, rapeseed (*Brassica napus*) and canola as well from marine fish such as menhaden are traditional sources of lipids in non-ruminants' diet (Abowei & Ekubo, 2011).
- **Vitamins and Minerals**: Vitamins that help animal to remain healthy include vitamins A, B, C, D, E and K, while minerals help in building animal teeth, bones and scales in fish. Common sources of minerals in animal diet are calcium, phosphate, bone meal, oyster, shell and so forth. According to Abowei & Ekuto (2011), the variety and complexity of vitamins and minerals allows them to be "prepared synthetically and are available commercially as a balanced and premeasured mixture known as a vitamin or mineral premix". Subsequently, researchers such as Venkataraman, *et al*. (1994) asserts that the nutrient rich composition of microalgae such as *Spirulina* when used in animal diets provides all the necessary vitamins and minerals, and thus can help increase net revenue.
- **Roughages**: These include ingredients with high fibre contents such as wheat bran, corn/maize bran, which aid animal digestion by "forming bulky materials that move the waste out of the digestive system of the [animal]" (Ahmad & Ibrahim, 2016; Ogunji & Wirth, 2001).

Some of the conventional and unconventional sources of the aforementioned dietary components are summarised in Table 1 below.

Table 1: Conventional and Unconventional Feedstuff

Conventional feedstuff	**Description**	**Sources**
Fishmeal	Commercial animal feeds are rarely formulated without fishmeal, because of its exceptional protein content and attractant properties. Fishmeal can be produced from fish waste from the canning industry or trawling trash. The crude protein in fishmeal is contingent on the source of the fish product as well as the way the fishmeal is produced.	(Huntington & Hasan, 2009) (Abowei & Ekubo, 2011)
Groundnut cake	Up to 45% protein can be derived from groundnut cake, however, little or no lysine and essential amino acid can be obtained. Moreover, groundnut cake can be poisonous due to the presence of aflatoxin when mouldy.	(Davies & Ezenwa, 2010)
Soybean meal	With its balanced amino acid profile and the potential to replace certain part of fishmeal constituents, soybean meal is fast becoming an acceptable feedstuff in the feed industry. It contains about 38% crude protein	(Ruan, *et al.*, 2019) (Abowei & Ekubo, 2011)
Palm kernel meal	Although contains relatively small crude protein content (16 - 18%) compared to fishmeal, palm kernel meal contains high level of crude fibre, an important constituent in animal feed composition.	(Alimon, 2004)
Maize	In addition to been free from anti-nutritional factors, maize and/or corn are palatable. It is also a good source of energy and commonly used in livestock and poultry feeds than in aqua-feed. It contains approximately 9-10% protein the whole grain and can easily be substituted by sorghum (also 10% protein).	(Prasanna, *et al.*, 2001)
Unconventional feedstuff		
Tadpole meal	Frogs and toads laid their eggs in stagnant water bodies at the beginning of the rainy season and later hatch into tadpoles. These tadpoles metamorphosised into toads and frogs in about 12 months. Similar to fish farming, these tadpoles can be cultivated, harvested and processed by drying for immediate use in poultry and fish diets. Tadpole meal contains about 50% crude protein and can be used to replace fishmeal in a more cost-effective way.	(Sogbesan & Ugwumba, 2008) (Abowei & Ekubo, 2011)

House fly larvae	Houseflies thrive on damp decaying matter, which serve as a breeding ground for the adult housefly and their larvae. This damp decaying condition can be "simulated" by mixing decaying organic matter with an attractant e.g. shrimp waste with ground soybeans, maize, palm kernel cake or groundnut cake into a slummy watery waste with water. The maggots begin to form from the third day and when the wriggling maggots is satisfactory high, the mixture is diluted and the larvae is harvested using a fine mesh sieve, rinsed to get rid of the substrate and drip-dry prior to oven drying. The processed larvae contain about 45% protein, 15% fat, 8% ash and 8% moisture.	(Hussein, *et al.*, 2017) (Abowei & Ekubo, 2011)
Earthworm meal	Earthworms are detriticolous terrestrial oligochaete worms that feed on decaying plant waste and other organic matter, which they pass out as worm caste. They can be produced commercially by heaping organic matter from animal waste or refuge in a land with high moisture or swamps. This is followed by introducing pairs of earthworms and harvesting can begin shortly, usually after six months. The harvested worms are rinsed in water and kept in a container for 30 minutes to evacuate the residual undigested materials in their guts. The harvest can then be processed either by smoking over a kiln or oven dried at 80^{o}C for three hours. The worms are then weighted, then milled into powdered form. Earthworm meal contains about 56.1% crude protein.	(Akpodiete & Okagbere, 1999) (Sogbesan & Ugwumba, 2008) (Abowei & Ekubo, 2011)
Blood meal	Blood meal is the richest source of protein (85%). Animal blood is readily available in slaughterhouses or abattoirs and can be obtained freely. Blood meal is processed by boiling the blood and then dried in the oven or even sun dry during the dry *harmattan* season in Nigeria. This dried blood is added straight into the mixture feed ingredients.	(Abowei & Ekubo, 2011) (Fisher, 1968) (Memon, *et al.*, 2002)
Aquatic macrophytes	Common aquatic plants that grow on water surface such as rooted flowering plants e.g. sedges, grasses, water lilies, *ceratophyllum* etc. as well as free floating plants like water lettuce, duckweed, water fern, *salvinia* and water hyacinth.	(Abowei & Ekubo, 2011)
Leaf Protein	Leaves abandoned in the tropics contain diverse amount of proteins that can be used as an "inexhaustible and inexpensive" source of protein in animal feeds. Leaf protein sources include nutritional valued leaves from pawpaw, groundnut, cassava, soybean and plantain. The protein from the leaves can be extracted by crushing the leaves into a *trichloroacetic* acid solution, which is then allowed to settle. The settled slurry on the bottom of the separating flax is rich in protein and can be obtained by decanting and drying. Leave protein concentrate can range from 13.7 to 88.9% depending on the source.	(Rathore, 2010) (Abowei & Ekubo, 2011)

Single cell proteins (SCP)	Single cell protein includes bacteria, yeast, and microalgae. Bacteria and yeast contain high level of nucleic acid in the form of RNA, which promote protein synthesis. Single cell protein sources are promising substitute for fishmeal in non-ruminants' diets and can replace up to 25 - 50% fishmeal. Studies have also shown that they can be use as sources of Highly Unsaturated Fatty Acids (HUFA). Moreover, high nucleotide levels in aquafeed improves hepatic function and lipid metabolism in non-ruminants' diets e.g. fish. The SCP are far becoming acceptable as the strategic replacement to fishmeal.	(Selvakumar, *et al*., 2013) (Adedayo, *et al*., 2011)

2.1.3 Constraints Militating against Animal Production in Nigeria

One of the major bottlenecks holding back the expansion of animal production in Nigeria is the persistent lack of high-quality feed (Fagbenro & Adebayo, 2011; Becker, 2008). According to Becker (2008), livestock feed cost accounts for "60 – 70% of total livestock production cost in any given year". This is in agreement with Fagbenro *et al*., (2003) and Fagbenro and Adebayo (2011) who found that in Nigeria 40 – 60% of the operational cost in aquaculture and an approximate 60-80% of the total production cost in intensive and semi-intensive poultry farming are spent on purchasing feed "particularly the protein source". Adebisi & Bunmi (2017) finds similar results for mono-gastric animals in their inventory survey of small-scale animal feed production in central Nigeria. As a result, farmers made use of available feed materials like garbage heaps and kitchen waste, or alternative feedstuff like crop residues and roadside grasses to supplement commercial feeds. Nigeria has a well-developed animal production industry, which is made up of livestock (such as goats, cattle, sheep, pigs, donkeys, horses, giant rats, rabbits and guinea pigs), poultry (such as chickens, turkeys, geese, ducks, and guinea fowls), and aquaculture (such as catfish and Tilapia fish) resources (Fagbenro & Adebayo, 2011). However, only aquaculture and poultry farming subsectors presently adopt extensive commercial production techniques and are supported by government initiatives such as the Agriculture Promotion Policy (APP) created to help improve these sub-sectors value chain activities in the country (USDA, 2016). Other factors that influence livestock production in the country include inadequate finance, transportation, lack of government incentives, lack of feed ingredients, poor infrastructure, high cost of veterinary treatment, manure disposal, high cost of labour, access to technical services, climatic and environmental factors, and poor extension services (Bamaiyi, 2013).

2.1.4 Availability of Feed Materials and Prices

Studies have shown that the cost of feed constitutes substantial input cost in animal production process in Nigeria (Esiobu, *et al*., 2014; Ohajianya, *et al*., 2013; Mukhtar, 2012; Adebayo & Adeola, 2005). In poultry production process for instance, feed cost constitutes the highest variable cost (Nmadu, *et al*., 2014). According to Adebayo & Adeola (2005), in the past decade, large-scale operators in the livestock industry in Nigeria have been forced out of business due to feed shortage and high price. Consequently, farmers find it difficult to purchase the required quantity (let alone quality) of feeds for efficient production. Moreover, market price fluctuations for animal feed does not vary in proportion with variation in meat and other livestock source products prices, generating uncertainty for smallholders (Hamra, 2010). As of the present research, no solution has been found for this problem, which continues to hinder livestock productivity in Nigeria.

Several ruminants and non-ruminant farmers in Nigeria compound their own feeds for their livestock, however, they face the challenge of raw materials, which may be highly priced or unavailable (Bamaiyi, 2013). The key ingredients in feeds according to the literature are fishmeal, soybeans and maize while main diets constituents include fat, carbohydrates and proteins, which function as sources of energy and building blocks of body tissue in animals (Udo & Umanah, 2017). The lack of feed ingredients in Nigeria could be attributed to suboptimal production of raw materials as well as animal and human competition for conventional feed materials (Babatunde & Ajayi, 2010). For example, corn and sorghum are popular food ingredient for local dishes like "*tuwo*, and *akamu*" consumed by the poor while soybeans and groundnuts are used to make soymilk, soy-*iru*, soy-*garri*, *kuli kuli* and so forth. Moreover, fishmeal is one of the key raw material, is estimated at about 75% of the total feedstuff in animal diets especially in aquaculture (Shepherd & Jackson, 2013). Yet, the present production of fishmeal in Nigeria does not meet the demand and needs of the livestock industry (Ahmad & Ibrahim, 2016). The nation's reliance on imported feedstuff like fishmeal has also stimulated wide fluctuations in price of feeds. According to Fagbenro & Adebayo (2011), feedstuff prices in Nigeria are also consistent with product quality, which is attached to crude protein levels and moisture level for grains. While larger feed producers maintain routine laboratory checks on the quality of ingredients, they import large quantities of raw materials [mostly fishmeal] raising the retail prices for feeds to the point where 50% of all the feeds produced are fan made [to reduce cost] (Fagbenro, *et al.*, 2003).

Unconventional feedstuff (e.g. algae, yeast, phytoplankton and so forth) that could be used as substitutes for conventional feed materials are constraint by seasonality, localised availability, inconclusive toxicology results, and lack of effective research study on how to produce them locally with the intention of commercialisation (Abowei & Ekubo, 2011). High prices of feed ingredients have led to numerous researches into other means of providing animal feeds to enhance the effects of high cost of feed such as the use of roots, tubers, bananas and plantains (FAO, 1992). Unconventional animal and aquafeeds are potential feedstuff that have hitherto not been utilised in feed production for the abovementioned reasons although they may contain high quality feed ingredients, which can compete favourably with traditional or conventional feed materials. By virtue of the fact that they do not compete directly with materials for human consumption, they are expected anecdotally to cost less. Table 1 above describes some of the unconventional feedstuff that could be used to replace expensive and unsustainable feed ingredients in Nigeria and other sub-Saharan countries in Africa. According to Roberts (1989), they can be sourced from animals or plants. The former includes feed derived from any animal other than humans such as earthworm meal, fly larvae, crab meal, toad meal, shrimp waste, and animal waste such as blood meal and poultry droppings. The latter is comprised of non-motile multicellular organisms with cellulose cell walls and chloroplasts containing chlorophyll for synthesising food (i.e. photosynthesis), for example *Bryophyta*, *Thallophyta* and *Tracheophyta*. The plant sources of non-ruminant animal diets include "leaf protein, leaf meal, aquatic *macrophytes*, cultivable pulses such as *mucuna* bean, yam beans, broad beans, winged beans or any legume ornamental that can yield pods with seeds" (Abowei & Ekubo, 2011). Additionally, breweries, canneries and distilleries are potentially important sources of inexpensive assortments of protein-rich waste that could be used as animal feeds especially for ruminant diets (Fagbenro & Adebayo, 2011).

2.1.5 Animal Diseases and Access to Veterinary Treatment

Livestock products are constantly threatened by diseases, which affect the animal production industry and reduce overall productivity (MacRae, *et al*., 2005). According to Aromolaran *et al*. (2013), diseases remain a major constraint faced by livestock in Nigeria especially poultry, which is devastated by viral infections like infectious bursal disease (*Gumboru*) and Newcastle disease despite several vaccination attempts. According to Olugasa *et al.* (2013), these vaccine attempts continue to fail in Nigeria because of the involvement of too many "quacks" in the fight against these endemic animal diseases throughout the country. Widespread livestock diseases like Contagious Bovine Pleuropneumonia (CBPP), *peste des petits* ruminants (PPR), Helminthosis, and mastitis, brucellosis, have overwhelming effects on animal production leading to economic losses in hundreds of millions of dollars annually in Nigeria and other developing countries (Bamaiyi, 2012). For instance, brucellosis in goats and sheep in Yobe and Borno states is estimated to cost the Nigerian economy $3.2 million annually (Bamaiyi, 2013). Similarly, since most animal production is based in rural or remote areas, access to proper and affordable veterinary services can be difficult. This has led rural farmers to "quacks" veterinarians known for administering unapproved or low-quality drugs, expired vaccines and wrong prescriptions for treating diseases (Bamaiyi, 2013). According to Babalobi (2005), low quality animal medications and vaccines are readily available for purchase in the market and can be used by just about anybody.

2.1.6 Lack of Capital and Inadequate Labour Force

The importance of capital in setting-up, processing and sustaining animal production cannot be overstated in the literature. According to Haruna *et al*. (2007), small-scale farmers do not have adequate capital to scale-up their farming operations in Nigeria. Financial inadequacies among small-scale livestock farmers is also a key contributor to the slow growth rate of the animal production industry in Nigeria, because low income earners who form the majority of the industry are unable to cope with the increasing demand (Bamaiyi, 2013). Moreover, with the exception of aquaculture and poultry, most of the livestock production in the country is concentrated in the Northern zones, which have lower financial power compared to the South (McKay, 2012). These suggest that small-scale farmers in Nigeria do not have enough disposable income to afford the necessary facilities and infrastructures needed for maintaining optimum level of productivity. Disposable income is the "balance of income and all distributive transactions emanating from a household" (Reich, 1991). The disposable personal income in Nigeria as of the second quarter of 2016 was ₦17,054,468 Million

(TRADING ECONOMICS, 2017). Ucha (2010) multidimensional study on poverty in Nigeria (*vis-à-vis* income inequality) also found that, income inequality between rural [mostly farmers] and urban dwellers is remarkably high (Ucha, 2010). This is due to dependency on oil exportation which led to lack of diversification in the economy, having practically ignored other labour-intensive sectors such as agriculture and services that provide income to rural household (USAID, 2008; Ucha, 2010). Yet, Izuchukwu (2011) maintains that despite poor output of livestock and crops, the agriculture sector has continued to be a major contributor to the economy of Nigeria, accounting for 20.9% of GDP in 2015 (The World Bank, 2015), the sector can play a key role in eradicating extreme poverty and hunger as well as unleashing "all-encompassing" economic growth. Subsequently, contributing to the United Nation's Sustainable Development Goals (SDGs).

According to Ohajianya *et al* (2013), livestock production in Nigeria is heavily dependent on the cost and availability of skilled labour and yet, due to low level of education, skilled labour is rare. Moreover, as far back as the 1980's and despite the gratifying efforts by women and men alike, inadequate man-power remains a major bottleneck for the subsector (Ude & Salau, 1987). Besides, labour cost in the country is one of the major cost factors of livestock production (Emaikwu, *et al*., 2011). Consequently, smallholders depend on family members to meet the labour requirements, which lessens the hiring cost, and exert considerable influence on the overall profitability of livestock production (Esiobu, *et al*., 2014; Emaikwu, *et al*., 2011). Unfortunately, very often this practice has been known to lead to child labour (Ukoha, *et al*., 2007). Family dependent livestock farming practices also influence the level of technological innovation adoption in Nigeria, in the sense that; family members unlike extension agents could not provide access to technological information and/or provide efficient use of improved technology (Sokoya, *et al*., 2014). According to Bamaiyi (2013), just like China, adequate labour can be achieved in Nigeria if more people are encouraged to go into livestock rearing.

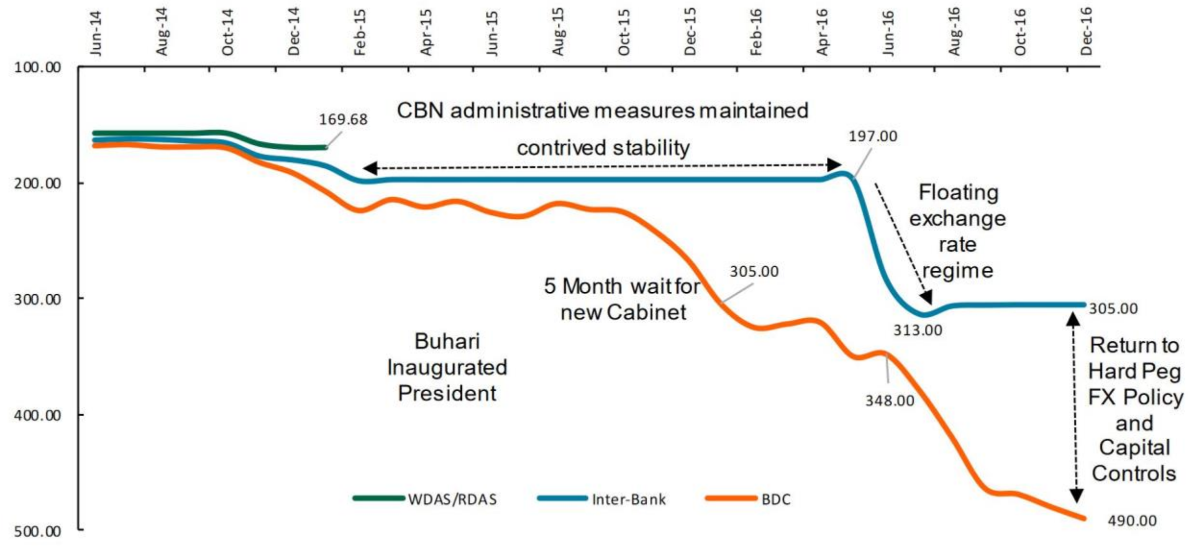


Figure 3: Exchange Rate in Interbank and Parallel Market[10] (Naira/USD) (AFRINVEST, 2017).

Loan facilities are also hardly available and where they are available, the cost of borrowing or interest rates constraints their accessibility to farmers (Bamaiyi, 2013). Interest rates in Nigeria are quite high, pegged at about 14%, and it is the 15th highest interest rate in the world (TRADING ECONOMICS, 2017; iECONOMICS, 2017a). This makes it had for companies to act in accordance with credit policies and raise stakeholder's uncertainty. Moreover, in 2016 the inflation rate increased to an average of 15.7% from 9.1% in the previous year (Barungi, *et al*., 2017). This increase in inflation rate is attributed to the rises in consumer goods prices due to high exchange rate (see Figure 3 above). Olu & Idih (2015) investigated the nature of the relationship between the economic growth and inflation rate in Nigeria. The author's found that inflation rate rises as the GDP rises and the federal government's efforts thus far to curb inflation have not yielded the desired results as there is still set-back in living standard of most Nigerians due to high price level of consumer goods. Fortunately, the present administration of President Muhammadu Buhari [and in some part the previous administration of President Goodluck Jonathan] is taken steps to diversify the economy by building strong public-private partnerships for agriculture (TWFB, 2017). For instance, in 2012 the federal government approved a fiscal policy measure to encourage investment from within and outside Nigeria: 0% duty for all agricultural and power sector machinery and equipment (CBN, 2012). In the same vein, the Agricultural Transformation Agenda (ATA) now Agricultural Promotion Policy (APP) agenda have set up reform of the Agricultural Research Network (ARCN), the Nigeria Incentive-Based Risk Sharing System for Agricultural Lending (NIRSAL) credit guarantees, and the Growth Enhancement Scheme (GES) to enrol smallholder farmers and offer targeted input subsidies (FMARD, 2016). Furthermore, the agro-processing industry enjoys 5 years tax holidays (initially 3 years) called "pioneer status" incentives

[10] Wholesale Dutch Auction System (WDAS); Retail Dutch Auction System (RDAS); Bureau de Change BDC

(NIPC, 2016). Similarly, in an effort to increase the production of food, farmer's income and improve standard of living of smallholders, the government sought technical support from the International Fund for Agricultural Development (IFAD) for a programme to increase cassava production (Adofu, *et al*., 2013).

2.1.7 Low Literacy rates among Farmers

In 2005, Adebayo & Adeola carried out a study in Osun state in Nigeria on the impact of education level on farmer's productivity. The authors found that literacy or education level of farmers has major and positive relationship with livestock production. Similarly, according to Bamaiyi (2013), low levels of education or even illiteracy among rural livestock farmers in Nigeria makes it extremely difficult for them to adopt modern animal production technologies or techniques where traditional methods have failed to yield profit. This *ipso facto* means that higher farm productivity is directly correlated to farmer's ability to adopt new technology, which depends on the level of education. Historically, empirical studies into the factors influencing the adoption of innovative technology by farmers in Nigeria have shown that farmer's education, along with type of farming system (i.e. subsistence or commercial), and characteristics of the new technology itself directly influence technology adoption among farmers (Onyenwaku, 1988; Iwueke,, 1989; Mijinadadi & Njoku, 1985). More recently, literature has emerged that contradicts these findings. For example, Kolade & Harpham (2014) comparative study into the relative impact of farmer's cooperative membership with other socio-economic factors such as education, gender and access to land on the adoption of technological innovation, argues that cooperative membership has a higher impact on farmers' adoption of technologies than say farmers education level. However, according to Ibrahim (2013), education and land holdings are key in defining the ability to adopt improved technologies in developing countries (Ibrahim, 2013). Furthermore, Olaniyi *et al* (2008) reported that, the major factors influencing the utilization of technology by livestock farmers are lack of extension contact and access to capital. These findings mirror those of recent study by Sokoya *et al*. (2014), who demonstrated the importance of agricultural extension officers in disseminating relevant information to farmers in order to increase the level of innovation literacy in rural remote areas of Nigeria. Likewise, Esiobu *et al* (2014) holds the view that lack of funding holds back farmers from acquiring the necessary resources and technologies they need to produce effectively. Other researchers, who have looked at the adoption of improved technologies by Nigerian farmers found that non-availability and inadequate knowledge of technologies affects the technology adoption behaviour of farmers (Adeniji, *et al*., 2007). Although the latter findings by Adeniji *et al.* (2007) (i.e. inadequate knowledge of technologies) corroborates previous research by the United Nations Office for South-South Cooperation into the adoption of improved production technologies by farmers in Nigeria. The former (i.e. non-availability) however, contradicts the finding by the UNDP that innovative technology are very much available, but most of the farmers still use traditional methods (UNDP, 2004). A possible explanation for these might be that, although improved technology may be available, they are not readily accessible to farmers at an affordable price (Adofu, *et al*., 2013; Adeoti & Sinh, 2009).

Despite the government effort to implement education reforms and raise the literacy rate, the quality of education among Nigerian farmers is generally low with some 25% of the population only completed elementary schooling. The United State Agency International Development (USAID) attributed this high illiteracy rate to the fact that; nearly half of the population of Nigeria fall under the age of 15, which puts pressure on the country's health and education systems (USAID, 2008). This has a negative impact on animal management practices. Livestock farmers in developing countries are generally ignorant about disease prevention, modern feeding, stocking and housing practices, biosecurity, proper waste management techniques and disinfection (Jordan, 1990). According to Aboki *et al*. (2013), increasing the overall level of education could boost farmer's ability to adopt new technology and acquire relevant information in relation to the aforementioned livestock management practices and thus stimulate productivity (Aboki, *et al*., 2013). Studies have also shown that, experienced farmers have better insights into the market situation, climate conditions and are more efficient in running a profitable enterprise (Esiobu, *et al*., 2014; Onyebinama, 2004; Bassey, *et al*., 2014).

2.1.8 Climatic and Environmental Issues

In addition to the general environmental concerns such as climate change and its impacts, deterioration of terrestrial ecosystems, forests and marine resources, their effects on the contribution margin (CM) of agricultural production are detectable in developing countries (Enete & Amusa, 2010; Ziervogel, *et al*., 2006). For instance, the agricultural industry in most emerging economies faces increasing shortages of raw materials (USDA, 2002), which can be attributed to climate change affecting rainfall and crop cultivation and as a result, local livestock feed millers in these countries are turning to imported wheat (a food crop) for their feed rations requirement. According to Ladan (2014), climate change is said to occur when, weather phenomenon become hysterical, creating negative impacts on agriculture, human life, water and land resources, ozone layer, and increasing the carbon dioxide content in the ecosphere. This is triggered either directly or indirectly by human activity, which alters the overall composition of the atmosphere (Amanchukwu, *et a*l., 2015). Climate change is an important component in the environmental threats facing humanity and plays a key role in agricultural production in developing countries (Ziervogel, *et al*., 2006). Floods, draughts and shifts in rainfall patterns as the earth warms up is leading to soil depletion, food shortage, weight reduction and increased deaths of farm animals (Abaje, *et al*., 2013). In northern Nigeria for instance where rainfall is seasonal, the occurrences of drought has led to the construction of dams such as the *Tiga, Zobe* and *Goronyo* in Kano, Katsina and Sokoto state respectively for irrigation (Ladan, 2014).

According to Manyong *et al*. (2005), the agro-ecological condition in Nigeria is highly diversified making it possible for the production of a wide variety agricultural products. It has approximately 79 million hectares of arable land, creating major agricultural opportunities, and yet less than 50% is utilised for agriculture. Agriculture (both crop and livestock subsectors) in Nigeria is dependent on climatic conditions (90% agricultural production is rain-fed) and as a result faces risk of changing rainfall patterns, rising temperatures, and desertification (Nwajiuba, 2012; Ladan, 2014). Moreover, with subsistence farming accounting for 80% of the farm holdings in the country (Mgbenka, *et al*., 2015), traditional agricultural practices such as bush burning, free grazing and poor manure handling practices are very common and can contribute to global warming (Jamala, *et al*., 2012; Enete & Amusa, 2010). In their study on agricultural adaptation to climate change in Southern Nigeria Ozor *et al.* (2012) found that, although most farmers are aware of changes in the intensity and distribution of rainfall, increasing drought, floods and temperature, they have limited understanding of the implication of such environmental changes in the long term (Ozor, *et al*., 2012). It seems possible that their limited understanding to the consequences of climate change might be due to socio-cultural factors like lack of requisite education, training and information, as such terminologies lack standard translation into local dialects (Enete & Amusa, 2010).

2.1.9 Other Macro-environmental Constraints Affecting Livestock Development

In addition to the abovementioned constraints facing animal farming in Nigeria, the external environmental forces such as political, economic, socio-cultural, technological, environmental and legal matters abbreviated as PESTLE stimulate thoughts when investigating the overall condition of the country concerning livestock and aquaculture production. The PESTLE framework is a type of *aides-mémoires* that help strategists to group the macro-environment factors in order to identify sources of general uncertainties and opportunities (Witcher & Chau, 2010). At first sight, these factors appear rather general and change at a slow speed relative to the dynamicity of the prospective market (Jabnoun, *et al*., 2003). However, they provide information about the degree of uncertainty and the indicators of long-term opportunities and threats (Issa, *et al*., 2010). Table 2 below summarises these external constraints and their implication on market development of agricultural products (microalgae biomass for livestock supplementation and/or partial replacement feed ingredient like fishmeal) in Nigeria. The political factors explore any type of government intervention that attempts to improve the livestock subsector "or to alter the structure of economic activity towards sectors, technologies or tasks that are expected to offer better prospects for economic growth or societal welfare that would occur in the absence of such intervention" (Warwick, 2013). The economic factors look at the current rate of economic growth in Nigeria in connection to Gross National Product (GNP) of the livestock market while the socio-cultural factors look at local farmers believe values and norms that shapes their feed buying patterns. The technological factors help to uncover changes in technology, which creates new opportunities and highlights the obsolescence of others. An important element of the technological factors is the type of animal production methods in Nigeria. The legal factors focused on any laws or regulatory constraints imposed on production to prevent “too high market prices”, fraud, smallholders’ exploitation and consumer long-term health and safety. Finally, the environmental factors are concerned with how climatic changes and general environmental awareness could affect market development opportunities [for algae biotechnology] (Sorensen, 2012).

Table 2: PESTLE Analysis of the External Factors Influencing the Nigerian Livestock Subsectors

External influences	Key Findings
Political Factors	• In Nigeria, the president precedence as head of state and of the central government give him legislative power, which is safe guarded by ways of "checks and balances". However, social and economic forces coupled with the country's poor political sophistication influence the way the president exercise these powers (Igbuan, 2011). • Corruption and abuse of office has infiltrated Nigeria's political and economic landscape, leaving large part of the population extremely poor despite income generation opportunities offered by large oil reserves, biodiversity and landscape variety (Falola & Heaton, 2008). • The political environment of Nigeria is uncertain despite the implementation of economic and political reforms (Ugwu & Kanu, 2012). • The anti-corruption platform ran by the present administration of President Muhammadu Buhari has made some progress in the alleviation of corruption through the implementation of a Treasury Single Account (TSA) for better resource management. Moreover, the administration is also working towards building strong public-private partnerships for agriculture, power, and roads (TWFB, 2017).
Economic Factors	• The World Bank characterised the Nigerian economy as one of the fasted growing in the world, concentrated on agriculture and trade, carrying the largest weight of Africa's GDP (The World Bank, 2014; AEO, 2017). • In 2016 against all expectations, investor's sentiment was impaired due to oil production capacity shocks, weak financial response, incoherent economic policies, and security issues in the Delta and North-eastern regions, slipping the economy into a recession (AFRINVEST, 2017; Barungi, *et al.*, 2017; AEO, 2017). • Approximately two thirds of the population are living in absolute poverty (i.e. less than US $1 a day) despite the country's natural resources and GDP growth (UNICEF, 2007; BBC, 2012). These shows that there is disparity between growth in the country's GDP and increasing poverty, which is indicative of a skewed economy. • Nigeria is an exemplar of the "Dutch Disease", were rise in the Naira due to boom in oil exports leads to decline in other sectors such as agriculture, export activities and competitiveness (Collier, 2007). • The foreign exchange rate in Nigeria is very high in relation to other major currencies like the USD and GBP. • Foreign exchange is also unavailable to individuals, thus business owners whose transaction is in foreign currencies such as importers of goods most rely on parallel market rates, which are higher than the already inflated interbank rates (Oladele, 2015). • Uncertainties in government policies to tackle inflation has led to low foreign currency reserve and weakened the Naira, resulting in the parallel market rate of almost double the official exchange rates (AEO, 2017).

Socio-cultural Factors	• Nigeria is the most populous country in Africa with about 190 million people according to the National Population Commission of Nigeria (NPC, 2017), and It is ranked seventh in the world (The World Bank, 2017). • Nigeria's population is projected to reach half a billion to a billion by the year 2100 (Marais, *et al*., 2014), providing major invested opportunities for both product and market-focused stakeholders in livestock production. • Unfortunately, widespread poverty is a reality and unemployment rates continue to increase in the country (UNICEF, 2007; BBC, 2012; Ucha, 2010). • Nigeria is arguably one of the most ethnically diverse nation in the world (Ukiwo, 2005), which can be linguistically and territorially divided into more than 250 ethnic groups (Okoro & Day, 2013). • These ethnic groups can be further divided politically and numerically into three hegemonic groups, the Yoruba of the southwest, the Hausa-Fulani of the north, and the Igbo of the southeast collectively refer to by the generic term '*wa-zo-bia*' (Mustapha, 2005). • Been one of the few countries divided almost evenly between Muslims and Christians, religion can be a very sensitive subject in Nigeria and has led to both conflicts and terrorism (Green, 2011). • Extremist religious groups have transformed the northern region of the country from a fertile ground for religious activism into a terror ground, threatening the security and economy of the country (Ajayi, 2012). • On the other hand, despite the political instability, high poverty and unemployment rates in Nigeria, foreign direct investment has increased, which can be attributed to the population size.
Technological Factors	• Livestock are kept in two conventional systems in Nigeria. Namely rural (or subsistence) and commercial farming (Nwajiuba, 2012; Alufohai & Oyoboh , 2013), and accounts for 80% and 20% of the nation's farm holdings respectively (Mgbenka, *et al*., 2015). • Rural livestock farming is generally small scale and household based, with limited marketing of produce (Tegebu, *et al*., 2012; Mohammed & Ortmann , 2005). While commercial livestock farming system is based on large scale stock of modern hybrids livestock, demanding more technology, capital and is the target market for commercial investors (Alufohai & Oyoboh , 2013). • Over 80% of the rural dwellers in Nigeria are directly or indirectly dependent on agriculture - "the artificial cultivation and processing of animals, plants, fungi and other life forms of food, fibre and other by products" (Adofu, *et al*., 2013) for their livelihood. • However, in order to boost agricultural productivity to meet the increasing food demand as well as sustain rural farmers, the adoption of improved technologies is pivotal (Maertens & Barrett, 2012).

Legal factors	• **Individual income**: 24% Imposed on the income of all citizens or residents in Nigeria: a flat rate charge imposed on every taxable individual. • **Companies' income tax**: 30% imposed on profits of registered corporate entities except the petroleum sector. • **Petroleum Profit Tax**: 50-85% imposed on profits of registered entities in the oil and gas sector. • **Education tax**: 2% imposed on registered corporate entities. • **Technology Levy**: imposed on selected entities in Nigeria to support the development of technological infrastructure and capacity. • **Capital gain tax**: 10% imposed on any gain of capital from sales of chargeable assets. • **Value added tax**: 5% of the value on the net sales value of qualifying products. • **Stamp duties**: variable rates imposed on corporate or individually executed instruments. • **Import & export duty**: 0-35% imposed on imported or exported goods into or outside the Government territory respectively. • **Exercise duty**: imposed on goods manufacturing within Government territory (Dike & PRESIDENT , 2014; iECONOMICS, 2017b). • Fortunately, the Nigerian government is promoting investment in agriculture by legalizing zero minimum tax for agriculture related businesses and tax-free dividend for all establishments entering the agricultural market from income tax for five years (Oghoghomeh, 2014).
Environmental factors	• Floods, draught and shift in rainfall pattern as the earth warms up are leading to soil depletion, food shortage, weight reduction and increased deaths of farm animals (Abaje, *et al*., 2013). • The occurrence of drought has led to the construction of dams such as the *Tiga, Zobe* and *Goronyo* in Kano, Katsina and Sokoto state respectively for irrigation (Ladan, 2014). • Diversification in agro-ecological condition in Nigeria makes it possible for the production of wide variety agricultural products (Manyong , *et al*., 2005). • Out-dated agricultural practices such as bush burning, over-grazing and so forth are very common in Nigeria and contributes to global warming (Jamala, *et al*., 2012; Enete & Amusa, 2010).

The implications of the PESTLE analysis (Table 2) findings on potential microalgae production in Nigeria are fourfold.

- Firstly, changing government's agendas and political unrest in Nigeria (as in most developing countries) present uncertainties that could impede investments on the introduction of algae farming and the speed of market development, as opposed to countries with a relatively more stable government. However, there are relieves and exemptions provided by the new tax laws implemented by the current government in favour of agriculture related entities. Thus, microalgae culture for feed production in Nigeria could potentially enjoy backing of the federal government.
- Secondly, in an effort to eradicate poverty and unemployment among rural farmers, agendas such as ATA now APP have set up reforms to support agricultural research, incentive-based risk sharing for agriculture by lending credit guarantees, and the enrolment of local farmers for input subsidies. This gives local farmers opportunity to adopt innovative farming methods such as/potentially microalgae culture. Similarly, investors in algae biotechnology are likely to invest in Nigeria given the zero tax rates and input subsidies. However, due to current security issues from extremist religious groups in the northern part of the country, investments in algae production should be concentrated in the central and/or southern states.
- Thirdly, low literacy rate among local farmers indicative of poor technology and/or innovative farming techniques adoption, which suggests the need for the development of a cost effective, simple and easy to adopt microalgae farming methods such as open-air microalgae production.
- Finally, feed shortages among livestock farmers during the dry seasons in Nigeria coupled with high cost of (mostly imported) fishmeal also provides opportunity for year-round microalgae farming.

2.1.10 Prospects for Sustainable Livestock and Aquaculture Production in Nigeria

The Northern states of Nigeria are the nerve-centre of the country's ruminant's production while non-ruminants especially aquaculture production are concentrated in the South. The semi-arid nature of Northern Nigeria is recognised "by average rainfall of 500 – 1000mm, prolonged dry season and sparsely distributed vegetation, [and] is known to have greatly favoured livestock management in the country over the years". Moreover, the sub-humid region (mostly Southern Nigeria) has a "rainfall distribution range of 1000 - 1500mm, vegetative cover and moderately dry periods" (Lawal-Adebowale, 2012). These indicate that Nigeria has the potential to support both ruminant and non-ruminant production, as long as the nation's agro-ecologies consciously harness the environment through the following:

- Efficient livestock and aquaculture feeding
- Improving animal health and veterinary services
- Proper livestock and aquaculture waste management and disposal
- Government support to farmers

2.1.11 Efficient livestock and aquaculture Feeding

Ruminants have the larger proportion of the animal market in Nigeria (FAO, 2004). However, ruminant farming "lies in the hands of herders who keep them under extensive and semi-intensive management systems, whereby the animals only rely on natural pasture and crop residue for survival" (Lawal-Adebowale, 2012). Consequently, whilst the ruminant's farmers may have access to abundant feedstuff during the wet seasons, they are unable to efficiently feed their animals during the dry seasons. On the other hand, the poultry and aquaculture industries are mostly intensive in nature requiring continuous supply of feedstuff year-round for maximum productivity (Bamaiyi, 2013). Thus, year-round feedstuff supply is one of the key factors for efficient animal and aquaculture production in Nigeria. Moreover, the quality of the feedstuff (traditionally define by the protein content) in conjunction with their market price also limits feeding efficiency of livestock since majority of the farmers cannot afford them (Ahmad & Ibrahim, 2016). According to Orheruata & Omoyakhi (2008), farmers in Nigeria should adopt close grazing system (under extensive ruminant farming) where animal waste are utilised within the farm as organic fertilizer for feedstuff cultivation. This farming system has been found to be more efficient in crop *cum* ruminant systems than in crop *cum* aquaculture farming systems (Ezeaku, *et al.*, 2015). For example, Lungu (1999) found that, "in the densely populated areas of Nigeria, between 77 and 100% of the animals [cattle, sheep, and goats] were fed farm-grown cassava". Other benefits of crop *cum* animal systems (apart from improving on-farm feeding efficiency) include waste recycling to prevent nutrient losses in soil; CO_2 sequestration; adding value to crop products by providing income to farmers for purchasing feedstuff unavailable on-farm. However, crop *cum* livestock farming continues to fail in Nigeria because rural farmers cannot support the intensive nature of such systems of agriculture especially outside of cereal-based mixed farming (Lungu, 1999). Moreover, livestock kept in traditional crop *cum* livestock systems relies on the cultivated fibrous crop residues for their feed requirements, which are limited in quantity, low in important nutrients like proteins and lipids (giving in the Nigerian Industrial Standard – NIS265: 2003 shown in Table 3 below) as well as possess low digestibility when dried. According to Owen & Jayasuriya (1989), one of the ways to improve on-farm crop residue as feedstuff for livestock is by supplementation; yet farmer's uptake of supplementation is low. Introduction of microalgae like *Spirulina* into the livestock farming systems to form a microalga *cum* livestock system could function as a key factor for providing high quality protein in fodder for animal consumption as well as biomass for poultry and aqua-feed formulation (Ezeaku, *et al.*, 2015). Moreover, the integration of microalgae with animal farming has the potential to contribute to the sustainability of livestock production in developing countries like Nigeria (Bature, *et al*., 2017). However, it is important to segment the different livestock subsectors in the country, recognising their market size, accessibility, profitability and animal responsiveness to dietary algae.

Single cell proteins (SCP) other than algae such as yeast and bacteria that possess fast protein synthesis and shorter multiplication period have also been suggested in the literature as potential fishmeal replacement and/or protein supplements in feeds (Udo & Dickson, 2017; Orheruata & Omoyakhi, 2008; Selvakumar, et al., 2013). According to Orheruata & Omoyakhi (2008), microbial proteins from cheap agricultural by-products can be cultivated "for cheap" using simple technologies. Bacteria and yeast proteins contains relatively high nucleic acid level in the form of RNA, which promote their rapid protein synthesis (Adedayo, *et al*., 2011). Single cell protein sources are playing a greater role in the evolution of non-ruminant's diets than in ruminant, which could be attributed to the fact that high nucleotide content in these types of protein sources can improve hepatic function and lipid metabolism in non-ruminants especially in fish. The chemical composition of SCP such as lipids (1.1 – 30.8%), protein (23 – 65%), ash (4.2 – 9.0%), carbohydrate (4 – 33%) and fibre (2.2 – 3.4%) makes them attractive for livestock feed formulation. See Table 3 for the requirements for fishmeal feedstuff in Nigeria. Consequently, approximately 30% of algae produced in the world are used for feed production especially in aquaculture (Udo & Dickson, 2017).

Table 3: Requirements for Fishmeal as Livestock Feedstuff (NIS, 2003).

Characteristics	Grade 1	Grade 2
Moisture % by mass (max)	10.00	10.00
Crude protein % (N X 5.27) (min)	68.00	60.00
Crude fat % (max)	10.00	10.00
Total ash % (max)	10.00	19.00
Crude fibre % (max)	1.00	4.00
Calcium % (CaO) (max)	2.00	6.00
Lysine % (min)	5.00	4.00
Phosphorous % (P_2O_5) (max)	1.70	3.50
Methionine % (min)	2.00	1.30
Ammonia Cal nitrogen % (max)	0.50	0.50
Acid insoluble ash % (max)	3.00	3.00
Chlorine (as NaCl) % (max)	4.00	5.00
Energy (ME)	2800 kcal/kg	2650 kcal/kg

2.1.12 Improving Animal Health & Veterinary Services

It is challenging to prevent livestock from pests and diseases entirely especially in developing countries where these issues are common (Lawal-Adebowale, 2012). In Nigeria, present veterinary services are limited by both the high cost and scarcity of drugs as mentioned earlier, thereby making it more difficult to effectively protect the livestock subsector as it were. These have led ruminant herders in the country to take to ethno-veterinary treatment for their livestock (Alhaji & Babalobi, 2015). However, such treatments cannot ensure proper clinical remedy and are only possible when the livestock begin to manifest symptoms, which might already impair the animal's health or cause internal damage. In the literature, the establishment of affordable and accessible veterinary services by both the government and non-governmental organisations to take care of infected livestock is suggested (Lawal-Adebowale, 2012; Kingsley, 2015), while acknowledging the value of traditional medicine in livestock health care, subject to further clinical investigation for safety and efficacy (Patwardhan & Partwardhan, 2005). However, prevention is known to be better than cure and thus it becomes important to have immune boosting components in the animal diets. Clinical studies on microalgae have found that immune system in animals can be improved together with beneficial bacteria in guts, toxins protection, anti-inflammatory and anti-viral properties by supplementing microalgae like *Spirulina* in their diets (Gershwin & Belay, 2007). Moreover, according to Blinkova *et al*. (2001), algae have the ability to augment disease resistance and stimulate livestock immune system (especially non-ruminants) by stimulating antibodies and *cytokines* production. In addition, algae can also preserve intestinal flora and reduce yeast infection in ruminants (Blinkova, *et al.*, 2001). Mcrolalgae have aslo shown positive results in antibody production in mice, also suggesting that the immune system in animals could be boosted using microalgae (Hayashi , *et al*., 1994). Moreover, enzymes such as *superoxide dismutase* or SOD in algae could be used as an anti-oxidant by improving animal models against oxidant (Kinnula , 2005; Moorhead , *et al*., 2011). However, as pointed out earlier, farmers uptake on supplementation to date has been low and production responses to using affordable and locally farmed supplements also lacks convincing evidence. In the light of these, it becomes important to investigate the Nigerian livestock market response to feeds, feed supplements and on-farm compounded feeds prior to the conceptualization of a mixed farming system that could improve animal immunity like algae *cum* animal production system.

2.1.13 Improved livestock and Aquaculture Waste Management

As noted by the Food and Agricultural Organization (FAO), the right amount of protein in animals is essential not only for animal performance, but also to decrease nitrogen emission in excreta and reduce pollution (FAO, 2002). Moreover, animal feed manufacturing and processing as well as ruminant's enteric fermentation constitute two of the main sources of emissions, representing 45% and 39% of the earth's livestock and agriculture emissions, respectively. 10% of emissions is represented by the storage and processing of manure, the rest being attributable to processing and transportation of livestock products (FAO, 2013). The introduction of microalgae *cum* livestock production system could provide farmers with a sustainable means of managing waste by recycling nutrients. According to Schneider (2006), microalgae require copious amount of inorganic nutrients commonly present in animal waste to grow. This microscopic alga possesses the ability to efficiently utilise phosphorus, inorganic nitrogen (Benemann & Oswald, 1996; Abdel-Raouf, *et al*., 2012) and CO_2 (a potent greenhouse gas) ten times greater compared to terrestrial plants (Miao & Wu , 2006). Moreover, wastewater treatment and recycling concepts using microalgae in aquaculture has also received a lot of attention over the past three decades (Hammouda, *et al*., 1995; Muller-Feuga, 2000; Guedes & Malcata, 2012). According to Zhu and Hiltunen (2016), microalgae cultivation in animal waste (water) has the potential to reduce the environmental hazards and substantial operational costs of livestock agriculture and microalgae biotechnology respectively. Furthermore, Gendy & El-Temtamy (2013) commenting on capital rationing of microalgae multiple co-products to develop pathways for technological maturity for algae also uphold this view. There is a unique opportunity here to both reduce the impact of (animal) waste in Nigeria and provide nutrients for large-scale microalgae production (Abdel-Raouf, *et al*., 2012) by integrating and modifying livestock systems to manage reactive Nitrogen (N) more efficiently (Janzen, 2011). Consequently, microalgae cultivation by farmers could contribute to the effort against climate change of which animal waste is a major contributor. However, a successful integration of the farming systems should be waste-free (or at least close to) with minimum undesired by-products; as by-products of one sub-system (animal waste) is recycled by the second sub-system (microalga-culture) and *vice versa*, producing useful biomass and gases (Phang, 1991).

2.1.14 Government Support to Farmers

There are numerous ways by which the Nigerian government can help in the development of sustainable livestock and aquaculture. For instance, Udo & Dickson (2017) suggest the need for better legislation and taxation policies towards agriculture as well as development of a youth empowerment programme. Fakoya *et al*. (2005) proposed demonstration of government's commitment to prioritise the livestock subsector, creation of a holistic consultation and participatory forum to include all stakeholders, providing tax free incentives similar to the telecommunication industry, research into the challenges facing the livestock sector should be initially funded by the government, professionalism of the extension service system, enhancing flow of credit by improving financial institution participation in funding livestock farmers, formation of a producers association among local small-scale commercial farmers, and establishment of a livestock information network centre. Fortunately for the last ten years the Nigerian government has pursued pro-livestock programmes at the local, state and federal government levels in an effort to diversify the economy (Olaniyi, *et al.*, 2008; Bamiro, *et al*., 2012). According to Olaniyi *et al*. (2008) and Bamiro *et al*. (2012), establishments such as the Microcredit Scheme for Livestock Production, Agricultural Development Project (ADP), Farm Settlement Scheme, and the United Nation Development Programme (UNDP) have been playing a significant role in boosting investments and mass production of animal sourced products. In addition, there are relief and exemptions provided by the government on agriculture related activities (Oghoghomeh, 2014), zero import duties for all types of agricultural technology as part of the measures to diversify from oil and gas to agriculture as mentioned earlier (Udo & Dickson, 2017). The Central Bank of Nigeria (CBN) has also made efforts to support farmers. For instance, in addition to funding the Agricultural Credit Guarantee Scheme (ACGS), in 2015, CBN further approved the disbursement of approximately ₦75 billion (£161 million equivalent) as loan to farmers under the Nigerian Incentive-Based Risk Sharing in Agriculture Lending (NIRSAL) (CBN, 2016). Suggesting that any effort to explore the integration of microalgae culture with livestock farming in Nigeria could enjoy federal government backing. Moreover, insecurity due to terrorism and farmer-herder clashes in the country is costing livestock producer large sums of money due to inability to sell their products. Insecurity in Nigeria is having a negative influence on the animal subsector and most not be taken lightly as it continues to threaten the economy. It is thus important for the government to provide farmers with alternative market outlets around areas not affected by terrorist attacks and threats (Bamaiyi, 2013).

2.1.15 Remarks

Agriculture is an important industry for Nigeria to invest in, and to diversify its economy away from been oil and gas focused. Nigeria has a heterogeneous agriculture sector that is made up of small to large farms with varying levels of efficiency. However, small-scale farmers control the crop and livestock production landscape. These farmers primarily grow crops and keep ruminants and poultry. The development of the livestock and aquaculture production in Nigeria is of grave importance to both the country's socioeconomic postion and environmental health. Although the the subsector has always been a vital component of the country's economy, providing both income and employment opportunities for the rural population, growth in animal output has been slow. In the face of constraints posed by lack of feed ingredients, poor waste management and infrastructure, high cost of veterinary treatment, and access to technical services, the government policies have not been successful in introducing the necessary changes needed to exploit the potential that exist for efficient growth of the livestock subsector. Thus, it is important for animal farmers to explore other on-farm solutions such as microalgae culture, whereby they could contribute to the resolution of some of these challenges like lack of feed materials and poor waste management. However, the diversity of animal species within the Nigerian livestock industry makes it necessary to segment the sector into homogenous subsets based on their ability to embrace microalgae-based feedstuff as well as their capability to adopt low cost microalgae farming.

2.2 Theoretical Background of Market Segmentation

The aim of the market segmentation is to divide the Nigerian livestock market into homogenous subsets of feed consumers where any subset may conceivably be chosen as a target market to be reached with a distinct marketing mix. A marketing mix (and its four Ps – **product**, place, price, and promotion) is a set of parameters that could be controlled, depending on the internal and external limitations of the marketing environment. Market segmentation is one of the bases for strategic marketing (Matzler, *et al*., 2004), and can be traced back in business literature since the 1930s (Goller, *et al*., 2002). Unlike mass marketing where one product is produced in the same way and sold to all possible customers, market segmentation allows companies to divide potential customers into homogenous groups that differ from one another in behaviour, geography, demography (e.g. species), life style, and psychography. It is a powerful driver for improving the profitability and productivity of a market as well as the cornerstone of any market-based strategy. Armstrong *et al*. (2012) viewed segmentation as "the process of dividing a market up into distinct groups of buyers who have different needs, characteristics or behaviours, and who might require separate products or marketing programs". For McDonald & Dunbar (1998), market segmentation refers to "the process of splitting customers, or potential customers, within a market into different groups, or segments, within which customers have the same, or similar requirements satisfied by a distinct marketing mix". A segment as part of a whole refers to a distinct group of customers in a broad market. Taken together, market segmentation is primarily concerned with the identification of customer groups that react differently to different configurations of product, price, place, and promotion from other groups. In Nigeria, agriculture (both animal and crop sub-sectors) remains the largest contributor to the GDP (Gross Domestic Product) of the economy (Afolabi, *et al*., 2013). Moreover, the various animal-farming sub-sectors such as aquaculture, poultry, pigs, and ruminants farming make Nigeria a very diverse market with different needs. Consequently, the success of introducing microalgae-based feedstuff into the feed market of Nigeria is contingent on both the ability to discover the animal feed consumers' needs and the level of management controls and organization structure (i.e. firm's configuration) of the algae producers.

There are six criteria for determining the effectiveness of a market segmentation process. They are "*identify-ability, substantiality, accessibility, stability, responsiveness, and action-ability*" (Wedel & Kamakura, 2000). However, these six criteria can be clustered further into four main groups. The first criterion is *measurability*, which is concerned with determining whether the *identified* market size is profitable and quantifiable within a segment. The second criterion is *accessibility* that measures the degree by which the segment can be reached and served through promotional and distributional efforts. The third criterion is *action-ability*, which is concerned with what meaningful and effective marketing mix configuration can be designed to better attract and serve the market segment. The final criterion is *profitability*, which includes both substantiality and stability of the prospective target market segment(s). Therefore, the market must be sufficiently large and stable to ensure profitability (Kotler, 1997).

In the literature, market segmentation has not escaped criticism from both industry experts and academics alike. For example, Hoek *et al*. (1996) assert that the concept is only usable if it provides marketing managers with different options to define what marketing actions would best fit different consumers. Moreover, the segmentation process needs to provide enough information to satisfy the marketing mix elements for the target market. In the same vein, the narrow target-based communication approach of market segmentation ignores other potential segments (Cahill, 1997). Nonetheless, segmentation is still considered to be one of the most important and practical concepts to gain competitive advantage or at least competitive parity.

2.2.1 Segmenting the Nigerian Livestock and Aqua-feed market

Segmentation is becoming indispensable to a company's success and a vital part of business strategy. The first step of a successful market segmentation is identifying the customer needs, because the features of the customer(s) provide bases for dividing the overall market into segments (Sun, 2009). Accordingly, it is important to identify livestock species indigenous to Nigeria, the type of animal production system(s) as well as their dietary needs, prior to developing a market penetration strategy for introducing microalgae into the country's feed market. Since prospective feed consumers will rarely have similar needs and preferences, a strong market-oriented approach such as this one will divide the market into segments depending on the species of the livestock and the marketing mix - product. In this study, 'segment marketing' by which microalgae nutritional composition satisfy any one or more of poultry, ruminants, and aquaculture feed needs in Nigeria is developed. Moreover, the segmentation levels, variables, and dimensions for dividing the market are also discussed. The most common segmentation variables and dimensions in a B2C (business to consumer) markets are: demography (e.g. age, type or species, occupation, education, and gender); behaviour (e.g. volume of use, purchase occasion, brand loyalty, buyer readiness stage); geography (e.g. region, country size, and climate); and psychography (or lifestyle) (e.g. benefit sought/problem solved, values and category beliefs or perception) (Haley, 1993).

The abovementioned variables along with their various dimensions are meticulously discussed below together with the "need-based segmentation" approach based on livestock response to dietary algae to identify a realistic target segment for microalgae-based feed material. To a certain extent, every livestock farmer purchase feed, however the preferences and motivations for buying a specific type of feed differs. Identifying and recognising the common traits between farmers that supplement their animals or formulate their own feeds could help the microalgae biotechnology industry to develop products and formulates marketing strategies to penetrate the feed market in Nigeria. In addition, because each segment will have fewer competitors in comparison to all companies operating in the animal feed market, there will be less pressure to initiate price competition (Cahill, 1997), which is important since present commercial prices of microalgae cannot compete against the most expensive feed materials like fishmeal. Moreover, when focusing on a narrow target market, there will be fewer substitutes' products and thus, less competitive intensity in the microenvironment (Porter, 1979).

2.2.2 Forces and Variables that Shape the Livestock Feed Consumer Market Need

Animal feed consumer needs and requirements (and the resultant customer preferences) often shift as one moves demographically from one specie to another. Moreover, inconsistent trend of dietary microalgae in poultry, fish, pig, and ruminant feed trials also contribute to changing set of animal requirements and what feedstuff to replace (Holman & Malau-Aduli, 2013). Demographic segmentation uses demographic forces such as age, income, education, religion, occupation, race, gender, marital status, nationality, type (or in this case animal species) to divide customers and/or consumers into different market segments (Armstrong , *et al*., 2012). Demographic differences among the variety of animals in Nigeria suggest a large array of differences in dietary needs, as well as what farmer(s) can afford, and buy. The extent to which dietary needs and requirements are reflected in animal species, clearly indicates that demographic factors could be used to divide the feed market in Nigeria into segments (Quester, *et al*., 2007). Another important element to consider while segmenting a market is the fact that customer's purchasing behaviour is highly influenced by the geographical area in which they live (Gunter & Furnham, 1992). Geographic segmentation therefore divides customers into segments based on their region, countries, states and so forth. In this study, the researcher focusses on the nation of Nigeria by targeting the country's geographical zones of – north central, north east, and north west. This approach is particularly useful in this country due to differences in tradition, culture, and politics across geographical zones. The combination of demographic and geographic characteristics usually attributed to increasing globalisation is referred to as "geodemographic" (Nelson & Wake, 2003). This describes the segmentation strategy of dividing customers based on where they live. However, geodemographic segmentation cannot provide potential customer lifestyle, identify relevant feedstuff characteristics and/or explore consumption models. Therefore, complete marketing segmentation information for increasing target market share and deciding product positioning involves both geodemographic segmentation and psychographic elements (Lin, 2002).

Psychographic (or lifestyle) forces concerned with differences in values, interest, attitudes and benefit sought, can be used to complement geodemographic factors, as well as contributes to shaping customer needs and market demand. Demographically related livestock may differ significantly in their response to different percentage of dietary microalgae (Ghazali & Othman, 2004). For example, in ruminants, sheep fed microalgae (*Spirulina*) levels of "10% had greater body weights than those given 20%" (Holman & Malau-Aduli, 2013). Similarly, cattle fed 200g of the same microalga daily produced more milk than the control groups and are about 8.5-11% fatter (Kulpys, *et al*., 2009). Moreover, feed customers may also express their lifestyle through their purchasing behaviour as well as their personality with regards to the type of products they buy (Lin, 2002; Plummer, 2000). In the same vein, Dolnicar's historical review on market segmentation found that three out of every four studies involving market segmentation employs psychographic constructs such as customer motivation, preference and benefit sought as grouping criterion (Dolnicar, 2006). Likewise, in this study emphasis is made on potential nutritional benefits to consumers and the motivation behind customer purchase behaviour and preference.

Finally, customers' attitude in connection with the way they respond or use a product is the basis for segmenting a market by behaviour. According to Kotler & Keller (2011), behavioural variables such as benefits derived (according to the benefits a customer seek for), occasions (according to the time they make their purchase), user status (according to potential and non-users), rate of usage (according to how much of the product they use), "buyer-readiness stage" (according to customer interest and awareness), attitude (according to enthusiasm and lack thereof towards the product) and loyalty status (according to customer loyalty towards the same product) are crucial for conducting a market segmentation. Some of these variables are described further in chapter 6 of this report: Market data collection and analysis. Overall, defining the target audience for microalgae-based feedstuff requires the consideration of all the aforementioned variables due to differences in animal and farmer's needs and purchasing behaviours respectively. Considering these variables, the researcher attempts to identify which animal segment(s) is best suited when developing market strategies for the introduction of microalgae feedstock into the livestock and aqua-feed market in Nigeria.

2.2.3 Remarks

Based on the above discussion, it can be argued that the geographic and demographic segmentation can be achieved using secondary data available from the literature. While psychographic and behavioural segmentation is best conducted empirically through primary data collection and analysis. This is because geodemographic information such as the different conventional farming methods and types of livestock in Nigeria can easily be found in the literature. The theoretical concept(s) of market segmentation discussed above are used as the basis for segmenting the Nigerian animal feed market in Chapter 4. In addition to segmenting the livestock and aquaculture market, it is important to compare the nutritional composition of microalgae with the readily available conventional feed materials in Nigeria. This will provide validation for exploring the potential use of microalgae in animal diet by livestock farmers rather than the conventional feedstuff. To achieve this, the resource-based view's VRIO model (valuable, rare, imperfectly imitable, and organisational support) is adopted as the decision-making mechanism for comparing microalgae with conventional feed material as well as for deciding whether the addition of microalgae feedstock into the heterogeneous resources of the livestock feed industry could help achieve potential sustained competitive advantage (SCA) for livestock smallholders.

2.3 Theoretical Background of the VRIO framework: A Resource-Based View

The resource-based view (RBV) and the resultant resource-based theory (RBT) is fast becoming a key instrument in explaining and predicting performance outcomes and competitive advantages (Slotegraaf, *et al*., 2003; Bridoux, 2004; Kozlenkova, *et al*., 2014; Barney, 1991; Andjelkovic Pesic, *et al*., 2013), making it one of strategic management's most influential paradigm (Akio, 2005). RBV initiated as the logical development in opposition to traditional industry-level sources of competitive advantage. It is concerned with firm-level resources and the systematic reasons for profit differentials in the nature and characteristics of an industry. The theory encompasses several principles from strategy research (Grant, 1991), paradigm of organizational economics (Conner, 1991), and industrial organizational thought (Das & Teng, 2000). A firm's resources and capabilities that allow performance differences among competitors are the focus of the RBT (Peteraf & Barney, 2003). According to Lin *et al*. (2014), the theory attributes "superior financial performance" to resources and capabilities that are "firm specific, rare, and difficult to imitate or substitute". Therefore, conferring to the RBV, gaining sustained competitive advantage[11] (SCA) depends on the development of intangible or implicitly distinctive and unique resources or capabilities (Teece , 2011). Accordingly, if the entire animal feed products in the Nigerian market have very similar "stock of resources" (i.e. feed materials with similar nutritive values), then the same strategic options are available for all to exploit (Pettigrew , *et al*., 2006). In 2012, Barney & Hesterly demonstrated that achieving SCA is possible when resources are simultaneously valuable, rare, inimitable, and supported by the organization. The value, rarity, inimitability and organizational support (henceforth referred to as VRIO) framework (Barney, 1997), formerly VRIN (valuable, rare, imperfectly imitable, and not have substitutes) framework (Barney, 1991) is an excellent decision-making mechanism that integrates both the positioning perspective and the resource-based view theoretical frameworks. It is a tool for internal analyses of a firm's resources and capabilities and their potential to generate competitive advantages (Barney & Hesterly, 2012).

2.3.1 Conceptualizing Microalgae as a "Resource" within the RBT and VRIO Paradigm

The resource and capability of a firm contributes to its survival and competitive advantage (Barney, 1991; Johnson, *et al*., 2017). In reviewing the literature on firm's resource and capability, numerous definitions emerged stressing different dimensions of the terms. Whereas resources refer to organizational assets (i.e. what the organization have (noun)), capabilities refer to the ways the organizational assets are utilized or deployed (i.e. what the organization do well (verb) (Johnson, *et al.*, 2017). Sahlman & Haapasalo (2009) viewed resources as the basic unit of analysis that work together to create capabilities or competences rooted in business routines and processes. The term resources embody both "tangible and intangible assets firms use to conceive of and implement its strategies" (Barney & Arikan, 2001). In the same vein, Barney (1991) asserts that a firm's resources include "all assets, capabilities, organizational processes, firm attributes, information, knowledge, *et cetra* controlled by a firm that enable the firm to conceive of and implement strategies that improve its efficiency and effectiveness". While a variety of definitions of the terms, resource and capabilities have been suggested in the literature. This research adopts the definition first suggested by Kozlenkova *et al*. (2014) who defined resource as "something an organization can draw on to

[11] Referred to "when it [a company's resource] is creating more economic value than the marginal firm in its industry and when other firms are unable to duplicate the benefits of this strategy" (Barney & Clark, 2007).

accomplish its goals", and capabilities as "information-based, tangible or intangible processes that enable a firm to deploy its other resources more efficiently and therefore enhance the productivity of those resources". Thus, microalgae as feed material and/or supplement may be considered a "strategic resource" for feed producers and on-farm formulation, with the potential to enable farmers in the livestock industry to deploy and enhance their livestock productivity. Unlike the industry-level analyses, RBV rest on resource heterogeneity and immobility. This means that for microalgae biomass to be a source of competitive advantage they must be different (i.e. better nutritional quality) across conventional feed materials. Peteraf (1993) added to these conditions "*ex-ante* limitation" and "*ex-post* limitations" to resource competing power, which includes customer understanding to the competitive dimension of resources. *Ex-ante* limitation to competition is the idea that a resource (microalgae) can be acquired at a price below its true economic value. While *ex-post* limitations to competition refers to the idea that economic value of microalgae cannot be competed away by readily available conventional feed materials. Chapter 5 of this report investigates how microalgae could perform with regards to the aforementioned conditions.

2.3.2 Remarks

Supposing that microalgae could meet the criteria of having superior nutritional composition compared with conventional feed materials in Nigeria (see Chapter 5). It is imperative to understand whether the feedstuff could be produced locally by smallholders in the country. According to the literature, algae culture is constraint by/or limited to bottlenecks associated with "cultivation, harvesting and genetic engineering of microalgae as well as the conversion of algal biomass into methane by anaerobic digestion" (Rösch, *et al*., 2009). Chapter 7 of this report employed the Lean Six Sigma's data-driven improvement model called the DMAIC cycle to measure and analyse process repeatability and reproducibility in a case study open pond algae farm in India. Bottlenecks were found in the harvesting stage particularly the sun drying process. The biomass/slurry was also found to be more prone to contamination in the cultivation stage particularly during the scaling up process of the mother culture. The section below discussed the theoretical background of LSS through a literature review.

2.4 Lean Six Sigma: Theoretical Background

2.4.1 The Lean Concept

John F. Krafcik first used the term "lean" in 1988 in the article "*Triumph of the lean production system*" to describe the Toyota Production System (TPS) led by Taiichi Ohno (Krafcik, 1988). In 1990, Womack *et al*. popularised the concept of lean through their book "*The Machine That Changed the World*" (Womack, *et al*., 1990). The TPS was built on two pillars (namely Just-in-Time (JIT) and *Jidoka*) and focuses on the elimination of '*muda'* Japanese word for waste, to increase production efficiency (Ohno, 1988). While JIT is characterised by the production of the requisite product on time and in the right amount (Golhar & Stamm, 1991), *Jidoka* is targeted at improving the quality of the product through "auto*no*mation" and 'stop at every abnormality' (Jasti & Kodali, 2015). In the literature, lean concept is often referred to as LP (Lean Production) or LM (Lean Manufacturing) to distinguish TPS (one-piece flow) from mass production systems (economies of flow). According to Russell & Taylor (2000), the main aim of the LP system is to eliminate all waste, so that only the value-added minimum amount of materials, equipment, space, time, and parts are utilised. The term "waste" has been widely used by researchers in the literature relating to LP when referring to all non-value creating activities to final products or services and are not needed for the system or process under inspection (Nave, 2002). The term non-value adding activity(s) refers to those activities that produce direct or indirect cost, and take time and resources, but "do not add value or progress" to the product, service or customer satisfaction (Alwi, *et al*., 2002). Non-value adding activities differs from waste in that they are needed by the processes and systems in use and should be reduced not eliminated. However, value-adding activities (sometimes referred to as value-creating activities) takes resources and convert them in a way that meets the needs of the customer. Waring & Bishop (2010) suggest seven areas based on the TPS by which waste is elaborated in a manufacturing environment, including inventory, transportation, waiting time, motion, over processing, defects and overproduction. In 2004, Liker added "unused employee creativity" as the eight waste, since lack of employee engagement could result in the loss of improvement opportunities (Liker, 2004).

Table 4: TPS's seven commonly accepted wastes (Hines & Rich, 1997).

TPS's Wastes	Remarks	TPS's Solution
Overproduction or Faster - than - necessary - pace	This is the most serious type of waste that could lead to excessive lead and storage times; work-in-progress stocks; and encourages the push system to get rid of unwanted goods.	*Kanban* or the pull system is a way of overcoming such waste.
Waiting	This occurs whenever time is not been used effectively. It affects both workers and goods that are waiting to be worked on.	Waiting time should be used for *Kaizen* or maintenance and training activities and not result in overproduction
Transport or Conveyance	This is the movement of resources in the manufacturing plant or store floor. "Double handling and excessive movements are likely to cause damage and deterioration with the distance of communication between processes" proportional to the time it takes to feedback reports of poor quality and to take corrective action.	Transport minimization rather than removal is the goal here. Consequently, layout planning plays an important role in product quality and quantity by reducing this type of waste.
Inappropriate Processing	This occurs whenever an overly complex solution is used to simple procedures. It encourages overproduction in order to recover the cost of expensive complex machineries. It also encourages poor layout and therefore could lead to excessive movement and poor communication	"The ideal, therefore, is to have the smallest possible machine, capable of producing the required quality, located next to preceding and subsequent operations. Inappropriate processing occurs also when machines are used without sufficient safeguards, such as poke-*yoke* or *jidoka* devices, so that poor quality goods are able to be made".
Unnecessary Inventory or Excess Stock	This interrupts problem identification as well as increases lead-time and space. Thus, discourages communication. Moreover, excess stocks increase storage cost and consequently lower organizational competitiveness.	Reducing inventory.
Unnecessary Motion	"This involve the ergonomics of production where operators have to stretch, bend and pick up when these actions could be avoided". This is very tiring on workers and may affect their productivity.	-
Defects or Correction of Mistakes	According to the TPS philosophy, defects present opportunities for improvement and should not be traded off as poor management.	Defects are taken on for immediate *Kaizen* activities.

According to the literature, there are five key principles imperative to the lean thinking, which may reduce the abovementioned wastes (see Table 4). The first is to specify the value created by the operational process. The second is to pinpoint those value stream activities that will ultimately add value to the operational process. The third is to create flow between boundaries. The fourth is to create a (customer) pull supply system rather than (supplier) push. Finally, the fifth is to strive for perfection through continuous quality improvement activity(s) (*Kaizen*) (Nave, 2002; Waring & Bishop, 2010).

Specifying microalgae's dietary benefits in livestock and aquaculture requires the determination of the biochemical composition that add value to the product from the standpoints of the internal and external customers or subsequent process (Nave, 2002). Therefore, in this study, value is expressed in terms of how microalgae-based feedstock meets livestock and aquaculture needs for quality feeds, at a given price and time. Once value is specified and the entire sequence of activities (or value streams) that add value are identified, then an examination as to the necessity of each process activity(s) to the product is made. This is followed by improvement efforts to make the activities flow. Some of the common inhibitors that slows process flow and tie-up funds include transportation, work in queue and batch processing. After the process flow is improved by reducing non-value-adding activities and eliminating the wastes, effort should then be made to make the process responsive to providing the product only when the customer needs (pull) it. Lastly, attempts should be made to continuously maintain the aforementioned practices (Hines & Taylor, 2000).

2.4.2 Lean Manufacturing (LM) & Lean Product Development (LPD)

Although the literature is rich with studies involving lean concept, there is no agreed-upon definition of *lean* among academics and practitioners. One comprehensive definition of lean that is in-line with this study is provided by Womack & Jones (1996) who defined lean as "a way to specify value, line up value-creating actions in the best sequence, conduct those activities without interruption whenever someone requests them, and perform them more and more effectively. In short, lean thinking is lean because it provides a way to do more and more with less and less – less human effort, less human equipment, less time, and less space – while coming closer and closer to providing customers with exactly what they want". In the same vein, the resultant LM according to the Environmental Protection Agency (EPA) of the United States of America is "a business model and collection of tactical methods that emphasize eliminating non-value-added activities (waste) while delivering quality products on time, at least cost, with greater efficiency" (EPA, 2016). Moreover, LM has been referred to as "a multi-dimensional approach that encompasses a wide variety of management practices, including just-in-time, quality systems, work teams, cellular manufacturing, supplier management, etc. in an integrated system" (Shah & Ward , 2003). De Treville *et al*. (2005) argued that LM is an integrated manufacturing system that maximizes capacity utilization and minimizes inventories by reducing system variability. The research of "vague and imprecise concepts that examine slightly different perspectives of the same underlying constructs, but that are masked by different terminology" together with the evolutionary nature of the lean concept as a function of the context it is in, makes it hard to find an agreed upon definition of LPD (León & Calvo-Amodio, 2017). Nonetheless, there is a high level of overlap between the aforementioned definitions, such as the reducing non-value-added activities, waste elimination, and optimisation of value-adding activities.

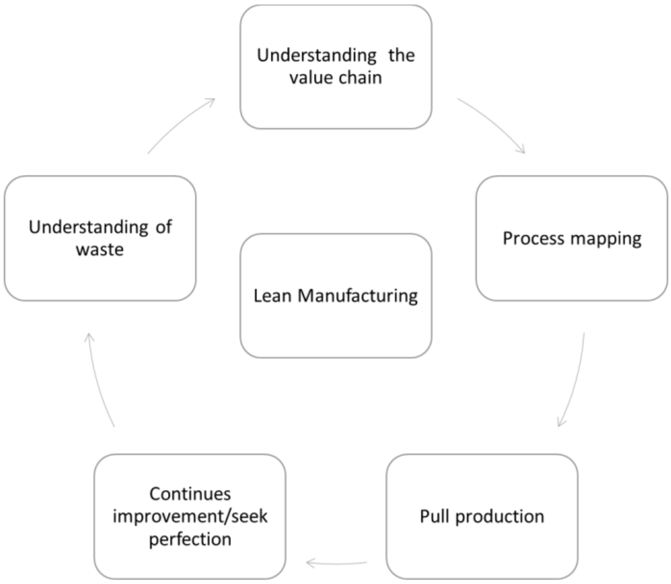


Figure 4: Features of Lean Manufacturing (Drohomeretski, et al., 2014).

One of the main goals of implementing lean concept in a manufacturing shop floor is to improve; effectiveness by increasing product value and quality from the customer's perspective and efficiency by reducing common and special variations along with minimizing waste in production and information flows (Marodina, *et al*., 2018). Selecting appropriate practices to modify and/or improve open pond microalgae production processes (for human food to feed) is one of the major targets of this study. Previous studies on LM construct have found that limited implementation of the method typically lead to neither significant nor sustainable improvements. Thus, this research attempts to simultaneously apply the relevant bundles of LM practices concurrently in the production processes of a microalgae (*Spirulina*) farm in a developing country (India). According to Shah & Ward (2003), lean practices can be covered in four bundles, namely: Total Quality Management (TQM), Just-in-Time (JIT), Total Productive Maintenance (TPM), and Human Resource Management (HRM). The authors further proposed ten lean operational constructs out of which one was customer-related (such as customer involvement), three were supplier-related (such as supplier JIT delivery, feedback, and development), and six were internal practices related (such as controlled process, employee involvement, pull, flow, productive maintenance, and short setup times) (Shah & Ward, 2007). Whereas some studies focus on the supplier perspective of lean, this study is limited to "customer involvement" and internal lean operational constructs. The former construct focuses on having the right skilled people in place at the right time to work in or around the manufacturing operations to reduce non-value adding activities (Chavez, *et al*., 2015). The latter is similar to lean principle in that they both consider "customer's perception of value to create new and profitable value streams within the different organizational area" (Kumar, *et al*., 2015).

Similar to LM, the definition of LPD in the literature is even less clear. On the surface, LPD focuses on the application of lean concepts to product development in order to produce improved and successful products in the market. However, according to Liker & Morgan (2006), it is "a knowledge work job shop, which a company can continuously improve by adapted tools used in repetitive manufacturing processes to eliminate waste and synchronized cross-functional activities". According to Rauch *et al*. (2016), LPD is "a cross-functional activity that seeks to uncover product knowledge hidden within the end-to-end production flow, typically in the hand-over points between functional units". Despite disagreement among authors on a conclusive definition of LPD, Letens *et al*. (2011) ventured that LPD appears to use engineering system and organizational principles and techniques most of which popularized by Toyota to achieved higher quality, shorter lead times, and reduced cost compared to traditional product development. The authors also state that the exact systems, principles and techniques along with the extent to which LPD can be customised by project type and industry has not yet received consensus. For example, Womack *et al*. (2007) identified; dedicated cross-functional teams; heavy weight project managers; joint decision-making; and CE (concurrent engineering) to be the core LPD techniques. However, Dombrowski, *et al*. (2014) identified; continuous improvement; standardisation; visual management; flow and pull principles; zero-failure principle; leadership and people; and frontloading as the principles and methods of LPD, arguing that LPD should follows the same principles as traditional lean principles. Matt *et al*. (2014) and Rauch *et al*. (2016) support the latter view asserting that LPD follows the same lean constructs as conventional lean to obtain product and services at an increased speed and reduced costs for the customer.

2.4.3 Six Sigma (SS): Theoretical Background

Unlike lean manufacturing method, which aims at identifying and reducing waste (Russell & Taylor, 2000), six sigma is targeted at improving processes by eliminating root causes of variance for product (or service) outputs, which are considered to influence customer's quality perceptions through different types of tools and techniques (Swink & Jacobs, 2012). Six sigma is developed by Motorola under the leadership of Bill Smith in 1987 to reduce the amount of defective parts and errors to 3.4 defects per million opportunities (DPMO) (Schroeder, *et al*., 2008). The methodology focuses on product quality and inefficiencies in operations using the Define, Measure, Analyse, Improve, and

Control (DMAIC) cycle to measure and statistically control process and product variability. According to Snee (1999) SS is a "business strategy that seeks to identify and eliminate causes of errors or defects or failures in business processes by focusing on outputs that are critical to customers". Schroeder *et al*. (2008), adopted John G. Wacker's theory for constructing conceptual definition to define SS as "an organized, parallel-*meso* structure to reduce variation in organizational processes by using improvement specialists, a structured method, and performance metrics with the aim of achieving strategic objectives". By parallel-*meso* structure the authors refer to a centralized office that overseas project execution hierarchy and trainings. For Stanton *et al*. (2014), SS refers to "a quality improvement methodology that focuses on reducing variation in product quality using tools such as process mapping and root cause analysis derived from the Japanese concept of Kaizen (continuous improvement) adopted by Toyota". According to Kumi & Morrow (2006), SS is a statistical method of measuring product and process performance. While a variety of definitions of the term SS have been suggested in the literature, a conceptual definition should show evidence of clarity, consistency, communicability, differentiability, parsimony, inclusivity, and exclusivity (Wacker, 2004). Thus, this study will use the definition first suggested by Linderman & Schroeder (2003) who saw SS as "an organized and systematic method for strategic process improvement and new product and service development that relies on statistical methods and the scientific method to make dramatic reductions in customer defined defect rates".

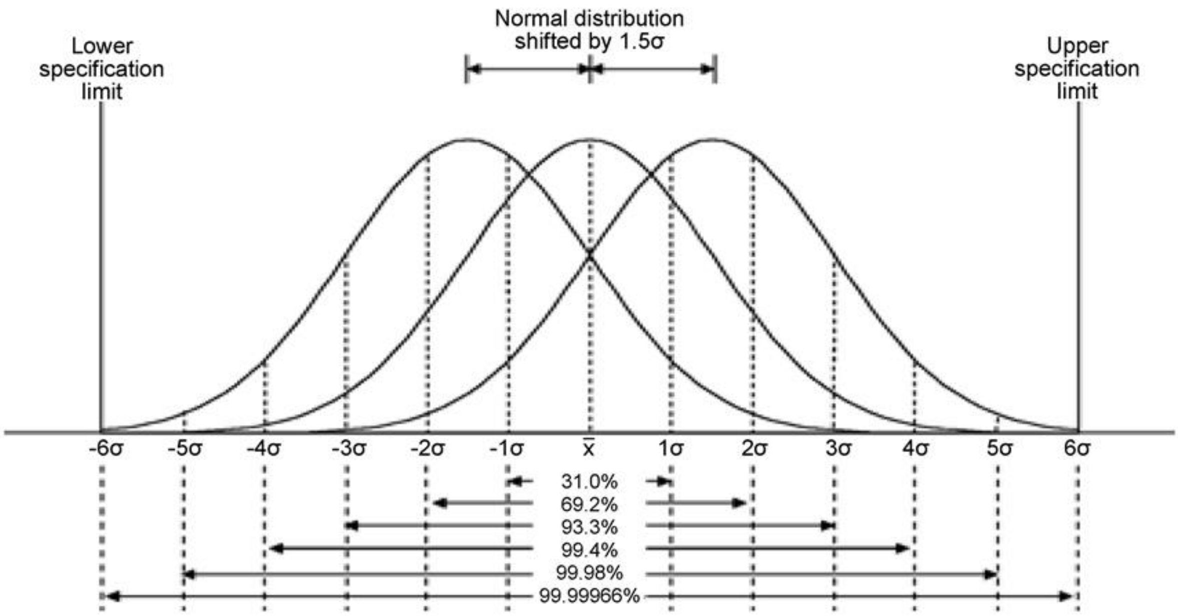


Figure 5: Shifted Normal Distribution & Corresponding Quality Levels (Heckl, et al., 2010).

Figure 5 above "illustrates how Six Sigma measures quality. […] for example, when 30.9% of products are without defects, the Sigma level is 1; and when 99.9997% of products are without defects, the Sigma level is 6. Fewer defects correspond to higher level of Sigma, and thus higher level of customer satisfaction: each additional Sigma level corresponds to an exponential reduction in defects" (Almakadmeh & Abran, 2017). Commenting on the sigma level in Figure 5 above, Nanda & Robinson (2011) added that they (the sigma levels) correspond to "where a process or product performance falls when compared to customer specifications. In other words, the difference between the upper and lower bounds of the customer specification (denoted by the Lower Specification Limit, or LSL, and Upper Specification Limit, or USL) represents the range within which the process, product or service must fall in order to meet customer specifications […]" (Nanda & Robinson, 2011).

According to the literature, reduction in variability in production processes to minimize defects/errors could also reduce "cost of failure" (Teli, *et al*., 2018), which contributes more than 70% of overall quality cost (Zimwara, *et al*., 2013). Moreover, in practice, substantial savings in cost have been documented as one of the benefits of adopting six-sigma. However, this is contingent on the cost of adoption, since large-scale enterprises require considerable investments in initial training, consulting support, organizational restructurings and information technology (Swink & Jacobs, 2012). Similar to other improvement constructs, SS initiated from the manufacturing industries where process repeatability and "setting of asset-intensive" are the norm. Thus, limiting the methodology to specific production context. Small to medium size open pond microalgae production system is similar to conventional manufacturing shop floors in that it is asset-intensive and depends on labour-intensive repeatable processes such as culture agitation and periodic harvesting of biomass, making it suitable to adopt SS. Tjahjono *et al*. (2010), suggest four main streams of research for understanding SS. They are:

- As a set of statistical tools for improving process quality.
- As an operational management philosophy, which can benefit organizational stakeholders
- As a top-down implemented business culture.
- As an analysis methodology, that employs scientific methods for CIP (Continuous Process Improvement).

Although in a company-wide adaptation of the framework, all the aforementioned streams have to be covered, continuous process improvement study such as this one will find its core in the first and final research streams. According to Breyfogle (2003), SS differs from other process improvement methods because of its exclusivity in data-defined system and customer-driven approach. It provides structure and encourages a culture that foster identification of opportunity(s) or problem(s), the creation of sustained improvement and process analysis (Swink & Jacobs, 2012). Studies have also shown that the structured approach of SS can contributes to dynamic capabilities of an organization and the VRIN (value, rareness, inimitability and non-substitutability) characteristics that provide competitive advantage (Gowen & Tallon, 2005; Zollo & Winter, 2002). Dynamic capability is a "leaned and stable pattern" of joint tasks for systematic generation and modification of an organization's routine operations in order to achieve improved effectiveness (Zollo & Winter, 2002). Thus, SS adaptation has the potential to enable open pond microalgae production business to efficiently "adapt, integrate and reconfigure" (Teece, *et al*., 1997) their resources to suit the animal feed industry. Moreover, although SS is primarily designed for continuous improvement of "existing processes" rather than the development of new products needed to drive growth in sales or radical changes (Morris, 2006), it produces other effects such as signalling customer markets of improved product quality.

Swink & Jacobs (2012) found three mechanisms by which the adoption of SS might foster greater return on sales and asset turnover both of which could presumably lead to customer satisfaction improvement. First is through supporting product innovation, second is through improving product and brand image (reputational enhancement), and third is through process improvements that reduces number of defect and create better quality products. The effects of these mechanisms however depend on the type of firm (i.e., whether asset-intensive or labour-intensive). According to Hendricks & Singhal (2001), the number of processes and reliance on trainings and skills in labour-intensive firms makes them more environmentally fertile for SS quality process improvements. The processes of cultivating microalgae in open pond systems are inherently more variable than in "heavy and automated" photo-bioreactor systems and therefore more likely to present higher range for variance reduction opportunities. Moreover, although Braunscheidel *et al.* (2011) argues that SS leads to "documented savings" and innovation benefits, other authors felt that when a firm as a matter of strategy positioned itself as a leading innovator in technology, it employees may regard SS structured approach to continuous process improvement as something negative, potentially leading to implementation hampering (Hoerl & Gardner, 2010; Parast, 2011).

2.5 Concluding Remarks

This chapter set out to review the available information on the Nigerian livestock and aquafeed industry as well as the theoretical background of methods used to achieve the research objectives and the overall aim. This literature review as shown that, despite being the largest source of animal protein and a major contributor to the nation's economy, the Nigerian animal subsector continue to fail to meet the demand for animal source food and raw materials. There are several issues responsible for this failure. Such as, persistent lack of high-quality feed and/or feed materials, high cost of feeds, inadequate financing, lack of government incentives, high cost of veterinary services, poor waste management practices etc. Key ingredients in feeds were found to be fishmeal, soybeans and maize while main diets constituents include fat, carbohydrates and proteins, which function as the sources of energy and the building blocks of body tissue in animals. The lack of locally produced high-quality feeds in Nigeria has been attributed to suboptimal production of raw materials as well as animal and human competition for conventional feed materials like cereal grains. The nation's reliance on imported feedstuff like fishmeal has also stimulated wide fluctuations in price of feeds. Moreover, according to the literature, unconventional feedstuff like microalgae and yeast etc., which could be used as substitutes for conventional feed materials are also constraint by seasonality, localised availability, inconclusive toxicology results, and lack of effective research study on how to produce them locally with the intention of commercialisation.

Having discussed the factors challenging the livestock industry in Nigeria, the chapter addresses ways by which microalgae culture could help mitigate some of the constraints above. For example, it was found that immune system in livestock could be improved together with beneficial bacteria in guts, toxins protection, anti-inflammatory and anti-viral properties by supplementing microalgae like *Spirulina* in their diets. Similarly, the high-level of proteins, lipids, carbohydrates and fibre in microalgae feedstock makes them attractive for feed use. Studies have also shown that, microalgae require copious amount of inorganic nutrients commonly present in animal waste to grow. Thus, algae could provide farmers the means by which they could improve their animal waste management practice through recycling of nutrients.

In reviewing the literature on the Nigerian animal subsector, it was found that the industry is made up of a variety of livestock (such as goats, cattle, sheep, pigs, donkeys, horses, giant rats, rabbits and guinea pigs), poultry (such as chickens, turkeys, geese, ducks, and guinea fowls), and aquaculture (such as catfish and Tilapia fish). This finding suggests that the Nigerian livestock industry has a very diverse potential target market with different needs. A literature review on the theory behind the market segmentation methods indicates that geographic and demographic segmentation of the Nigerian livestock sector could be achieved by using secondary data available in the literature. See chapter 4. While psychographic and behavioural segmentation are best conducted empirically through primary data collection and analysis. See chapter 6. In addition to segmenting the livestock and aquaculture market, it is important to investigate the nutritional composition of microalgae and how livestock response to them in comparison to conventional feed materials in Nigeria. To achieve this, the theoretical background of the resource-based view's VRIO model (valuable, rare, imperfectly imitable, and organisational support) was reviewed. It was found that microalgae as feed additive or supplement may be considered a "strategic resource" for feed producers and/or local farmers, with the potential to enhance livestock productivity. Subsequently, the VRIO framework was adopted as the decision-making mechanism for assessing the biochemical composition of microalgae against conventional feed material. The Framework also help in deciding whether the addition of microalgae feedstock into the heterogeneous resources of the livestock feed industry in Nigeria could help achieve potential sustained competitive advantage (SCA). See chapter 5.

Finally, the theoretical background of lean 6 sigma indicates that this process improvements framework could help reduce the number of defects and create better quality products. Moreover, the number of processes and reliance on trainings and skills in labour-intensive open pond manually operated microalgae farms makes them more environmentally fertile for lean 6 sigma quality process improvements application. It was also found that the processes involved in the cultivation of microalgae in open pond systems are inherently more variable than in the "heavy and automated" photo-bioreactor systems and therefore more likely to present higher range for variance reduction opportunities using lean 6 sigma. Chapter 7 of this report present the conceptual framework for implementing lean 6 sigma's DMAIC model in an open pond case study microalgae farm.

Chapter Three: Research Methodology

3 Introduction

Research theses should contain enough methodological details to allow reproduction and/or comparison with similar studies, which can only be achieved by disclosing basic criteria in the report. Thus, this chapter describes and discusses the methodology used in this research to achieve the research aim and objectives. It consists of five sections. The first section explains the research methodology by discussing the rationale and underlying philosophical assumptions. The second section describes the strategy, approach and method used. The third section describes the data gathering and analysis techniques. The fourth and final section addresses ethical and confidentiality considerations for the research. There are two studies carried out within this piece of research. The first study explores farmers' experience and expectations from feeds within the livestock and aquaculture industry in Nigeria through primary data using preliminary interviews and surveys, as well as secondary data through literature reviews to investigate the market potential, the size of consuming units and the untapped market opportunities for potential microalgae feedstock production. The second study translate the farmers' experience and expectations from the first study into Voice of the Customer[12] (VoC) to develop Critical to Quality[13] (CtQ) factors, which then serve as bases of the process improvement/modification measurement set. This is followed by an assessment of the value stream of a small-scale open pond microalgae production case study company in India using a tailored conceptualised Lean Six Sigma's (LSS) DMAIC (Define, Measure, Analyse, Improve and Control) framework to identify process flaws that could result in output variation based on the predefined CTQs. Moreover, the method used by the researcher to mobilise this data-driven framework in a real-world case study environment is also discussed in this chapter. Figure 6 below shows the outline of the different aspects of this research concerning strategies, methods and methodologies used, respectively.

[12] "The Voice of the Customer (VOC) is a term used in business to describe the process of capturing customers' requirements. The Voice of the Customer is a product development technique that produces a detailed set of customer wants and needs which are organized into a hierarchical structure, and then prioritized in terms of relative importance and satisfaction with current alternatives" (Gaskin, *et al*., 2005).

[13] "The activities that cause the customer's critical to quality issues and create the longest time delay in any process, offers the greatest opportunity for improvement in cost, quality capital and lead time" (George, 2003).

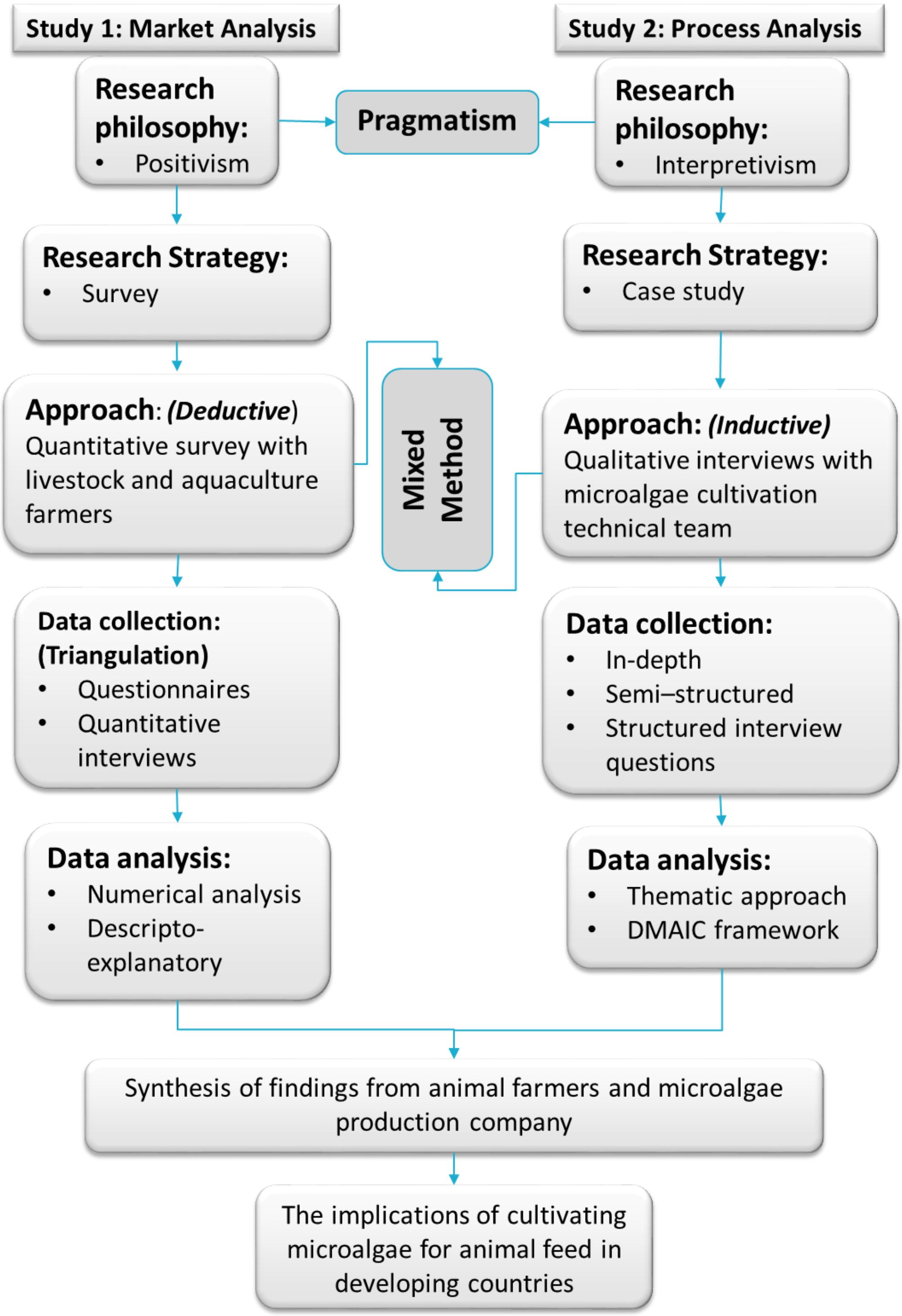


Figure 6: Underlining Research Methodology and Philosophy

3.1 Research Methodology & Philosophy

By way of preamble, it is important to discuss the theoretical perspective as well as the philosophical assumptions and worldview that the researcher brings to the research. Methodology is the theory of how a research study should be conducted and shows the logical development of the process and the procedural framework used to generate knowledge (Saunders, *et al*., 2009; Remenyi, *et al*., 2010). It is the “explanation of the approaches, methods and procedures with some justification for their selection" (Smith, 2002). According to Sayer (2003), the research paradigm defines the methodological decisions, which then guides the selection of data collection and analysis. However, Hammersley (2018) has challenged Sayer's assertion, arguing that the research goals and circumstances are the bases for selecting the method of data collection, rather than methodological and philosophical commitments. Unlike research method, methodology is not about providing solutions to the research questions but offers the theoretical underpinning for choosing the appropriate research approach, strategy, and method(s) used for data collection (Saunders, *et al.*, 2009). Moreover, Integral to methodology are the ontological and epistemological assumptions. Taken together, the term research methodology in this research is primarily concerned with the logic of justification and ensuring rigorous arguments such as reasonable inferences and internal coherent of method(s).

3.2 Underlying Ontological & Epistemological Assumptions

Ontology is concerned with the assumptions a researcher makes about how the world operates and thus focuses on the "philosophy of reality" (Smith , 2003; Saunders, *et al*., 2009). According to a definition provided by Blaikie (2010), ontology is the "claims and assumptions that are made about the nature of social reality, claims about what exists, what it looks like, what units make it up and how these units interact with each other. Thus, ontological assumptions are concerned with what we believe constitutes social reality". The two aspect of ontology generally accepted among researchers for producing valid knowledge are *objectivism* and *subjectivism*. While the former stresses the reality of social entities and empirical facts external to the consciousness of the social actors (i.e. the researcher) concerned with them, the latter adopts a constructivist position, which argues that social phenomena or what is "real" depends on the "perception and consequent actions" of the social actors. Ontology is important because a researcher's understanding about the nature of social phenomena will have significant impact on the way he/she chose to analyse social reality (Grix, 2002). Moreover, the ontological position that there is no one force that limit market demand for a product like animal feed clearly suggests that this study cannot be approach purely from an objectivist or naïve realist ontological position. Thus, some of the methods used come from what might be considered a subjectivist or social constructivist position. Moreover, the very notion of collecting VoC from animal farmers and developing measurement set for the DMAIC framework indicates the needs for both objectivist and subjectivist ontology in this research.

Epistemology on the other hand determines what is or is not considered acceptable knowledge in a particular field of study (Saunders, *et al*., 2009). It is the ways of attaining knowledge of social reality, "whatever it is understood to be" (Blaikie, 2010). An epistemological position of *positivism* is related with logical empiricism (Uebel, 2013) and is underpinned by the objectivist postulate that empirical facts exist independent of consciousness. Subsequently, to the positivist only observable phenomena can lead to the generation of credible data. Often regarded as the scientific method, positivism also involves the gathering of knowledge in ways that are not subjective but are replicable and requires logically deduced objectives and/or hypotheses (Charmaz , 2006). Thus, the deductive approach of positivism was utilised during the proposal and conceptual stages of this research for identifying existing theory(s) in research strategy to develop data collection methods that could yield quantifiable statistics such as surveys to answer the research questions. The reason for collecting data using this approach is to maintain the researcher's objectivity from the subjects under study. Conversely, the *interpretivist* argues that social phenomena are far too complex to be reduced entirely into "a series of law-like generalisation" (Saunders, *et al*., 2009). It advocates that, only in the interpretation of the meanings and constructions of social actors that knowledge can be found. This epistemological position recognises that interpretation of data is a subjective endeavour and cannot be wholly objective. In other words, the interpretation of social roles of the research subject(s) under scrutiny should be done in accordance with the researcher's set of meanings. Therefore, the interpretivist begins by attempting to understand the contextual reality of the research subject and then used the experience gained to interpret information. Researchers have argued that this strand of epistemology is highly appropriate in the field of marketing where little or no information is available about the research subject and therefore utilises qualitative means like interviews and focus groups (Patton, 2002; Corbin & Strauss, 2015). In this study, the researcher seeks to gather information from an open pond microalgae production case study company by qualitative means through interviews. This suggests that the researcher uses qualitative approach associated with subjectivism and interpretivism to interpret responses recorded from participants.

Between the 1970s and early 1990s, debates on which one of these opposing views of epistemology is the better choice in terms of research philosophy heighten and many researchers held the notion that a researcher must select one position or another (Gage, 1989). However, in 1990 Guba asserts that the competition for superiority of positivism over interpretivism or *vice versa* is irrelevant because each paradigm is an alternate offering with its own advantages (Guba, 1990). In the same vein, Tashakkori & Teddlie (1998) suggest that research philosophy should be viewed as "a continuum rather than opposite positions", since "at some points, one may be more 'subjective', while at others more 'objective'". That is, "at some points the knower and the known must be interactive, while at others, one may more easily stand apart from what one is studying". These views form the foundation of the *pragmatist* position, which "argues that the most important determinant of the epistemology, ontology and axiology you adopt is the research question [or objective] – one may be more appropriate than the other for answering particular questions" (Saunders, *et al*., 2009). However, it is not an “anything goes” approach, but one that offers some flexibility in data collection (Denscombe, 2008). This study was based on a set of objectives that drove the researcher to particular methodological choices about how best to undertake the study as well as specific choice of methods and design of instruments. Thus, this study is founded on a pragmatic approach to the epistemological and ontological decisions in the research design and the believes that intuitively multi-paradigm inquiry is necessary to offer insights into the animal feed customer characteristics and motivations, as well as production practices with regards to feeding regimens for the continuous improvement in the quality/sustainability of feed through the use of microalgae. In view of all that have been mentioned so far, the choice between mainly positivist and mainly interpretivist paradigms of evaluation in this research rest on the degree of knowledge of the phenomenon under study. The more secondary theoretical data is available about a research objective, the more possible and logical it becomes to adopt quantitative data collection methods. On the other hand, the less that is known, the more it makes sense to adopt qualitative methods.

3.3 Study 1: Market Analysis

3.3.1 Research Strategy: Quantitative Research Method

Quantitative research systematically deals with numerical data to investigate measurable phenomena with the intention of explaining, predicting and controlling the relationship between them (Leedy & Ormrod , 2012). Aliaga & Gunderson (2002) defined quantitative research as the explanation of phenomena by gathering numerical data, which are analysed using mathematical methods such as statistics. Therefore, since quantitative research is fundamentally concern with the collection of numerical data, the researcher asked specific questions that are suited for been answered and analysed quantitatively. Quantitative method is used in this research to measure the amount of feed materials used by farmer, mode and frequency of purchase; ingredients trade-off etc. to investigate the market size. This method normally begins with data gathering based on the literature, which is then analysed by applying inferential or descriptive statistics to either identify the characteristics of what is observed (in this research; farmers feed needs and requirements) or explore the correlation between the observed phenomena (Saunders, *et al*., 2009).

3.3.2 Sampling Procedures

First, rural areas around north central Nigeria (reachable by the researcher based on distance, safety and affordability to travel) were selected[14] and interviewed using semi-structured interview questions

[14] The researcher conduct field works around local farming communities talking to farmers that are willing to share their experience. These farmers where initially randomly selected/contacted by the researcher; however, this effort provide opportunity(s) to identify and contact corporative farming societies in Nigeria.

based on animal feed challenges themes identified in the literature (see Table 50 in the Appendix). Thus, 4 geographical zones out of 6 were selected based on livestock and aquaculture population, membership to cooperative society and online presence (i.e. reachable via e-messages and/or mobile etc.). Respondent selection was based on those involved in animal farming for at least 1 year or above.

3.3.3 Survey Strategy

Usually associated with deductive research approach, surveys are one of the most popular strategies of quantitative research design in the field of management and social sciences (Saunders, *et al*., 2009). They are typically characterised by their use of standardised questionnaires that can be self or researcher-administered through telephone, email, web-based or postal pen and paper forms to collect data, and recruit participants (Muijs, 2004). Apart from using numerically rated items from questionnaires, survey research can also apply qualitative methods through open-ended questions or *mixed methods* (Ponto, 2015). According to Check & Schutt (2011), surveys are "the collection of information from a sample of individuals through their responses to questions". They are frequently used in descriptive and exploratory studies to answer the "who, what, where, how much and how many questions" (Saunders, *et al*., 2009). Survey is a popular strategy among researchers trying to study a large population by focusing on a sample of the population (Ponto, 2015). This 'sampling' feature of surveys allows the researcher to generate results, which are representative of the entire population at a lesser cost. In this research the researcher presents a series of questions using questionnaires (See Table 51 in the Appendix) to livestock and aquaculture farmers in Nigeria and then summarises their responses in frequency distribution, percentages, as well as other statistical methods. The data collected by survey strategy (via quaetionnaires), however, is limited by the number of questions that the respondents is willing to answer. Ponto (2015) identified four sources of error that may be asssociated with survey research such as coverage, sampling, measurement and noneresponse error. To reduce the chances of these errors, the researcher ensures that the respondents included in the sample represent the major geographical zones in Nigeria and thus characteristics of the population. The researcher also makes sure that the questions asked where pre-tested to reflect the research objective and that the survey are designed and presented in a user-friendly way (for example the researcher translates questions to local dialect (Hausa) and/or pidgin english, provides multiple choice questions and open-comment sections in the questionnaire. In the same vein, other data collection methods like semi-structured interviews are also considered by the researcher to reduce survey errors. The interview questions are devised from the challenges/gaps facing Nigerian animal production in the literature (see Chapter 2).

Initially the researcher contacted and conversed with local livestock farmers (n=31) around the North [c]entral region of Nigeria about their animal production challenges, needs and requirements. While majority of the respondents belong to the following cooperative society: Nigeria Farmers Group and Cooperative Society (NFG & CS), International Institute of Tropical Agriculture (IITA), Fishfeed and Fisheries Traders Association (FITA) and/or Fisheries Cooperative Fedeartion of Nigeria Ltd (FCFNL), other respondents belong to local farming communities acessible to the researcher around Northern Nigeria, where the researcher is based. During these meetings the researcher presents a number of semi-structured interview questions to the farmers highlighting the main areas under investigation. Following these conversations a structured questionnaire is designed (based on the challenges/gaps in the literature and information collected) and administered to a larger population of smallholders (n=104) via electronic messengers (for literate respondents with access to messengers like whatsapp and facebook) and telephone calls (for illiterate respondents). Overall, the survey strategy used in this research is 'cross-sectional' in design to obtained a *snapshot* of what is happening in the animal industry of Nigeria. Cross-sectional surveys are traditionally used in descriptive or exploratory research similar to this one to provide behavioural description. Therefore, the researcher employs this approach to measure some aspects of the animal feed consumer satisfaction.

3.3.4 Primary Data Collection: Questionnaires

Questionnaires are well-recognised tools for acquiring data on participant's present behaviour, social characteristics, attitudes, standards, and "their beliefs and reasons for action" concerning the topic of interest (Bird, 2009). They do not work well with studies that necessitate "large numbers of open-ended questions" such as exploratory research. However, they are usually particularly good in explanatory or analytical research with standardised questions (Saunders, *et al*., 2009). Moreover, when executed correctly, they require little skill set and sensitivity to manage than interviews (Jankowicz, 2005). Although questionnaires can be use as the main method of collecting data in a research, it is recommended to link them with other data gathering methods in a triangulation or mixed method. In this study for example, the researcher conducted interviews using semi-structured questions to explore livestock farmer's attitudes towards their animal feeds and feed ingredients and to pilot-test the questionnaire questions making minor adjustments to clarify semantics and/or wordings within the final questionnaire. The semi-structured interviews questions are designed based on the challenges and gaps in the literature in connection with animal husbandry such as availability and price of feed and feed materials, literacy, farm size, financial supports, cooperative membership and so forth (See Chapter 2). In line with both Jenkins & Dillman (1995) and Ponto (2015), the methods of administration and amount of contact between the researcher and respondents are used to categorise questionnaires into 'self-administered' or 'interviewer administered'.

In self-administered questionnaires, the respondents are being asked to undertake on a task, which from their point of view may differ from what the researcher expect them to do. They can be administered electronically via the intranet (intranet-mediated questionnaires) or internet (internet-mediated questionnaires), hand delivered to respondents and collected on completion (delivery and collection questionnaires) or posted to participants (mail or postal questionnaires) (Saunders, *et al*., 2009). In contrast, in interviewer-administered questionnaires the interviewer manages the perceptual process (Jenkins & Dillman, 1995) and record responses based on the respondent's answers. Both methods of questionnaire administration are used in this study to improve the sample coverage and to ensure that farmers understand what the researcher is asking them, as respondents with insufficient knowledge or experience may give 'uninformed response' or may require translation into local dialect to make sense of the questionnaire. The researcher delivered the self-administered questionnaire in an electronic format via email (to the literate respondents), and the interviewer-administered questionnaire is delivered (to respondents without access to the internet or a computer and to those that are unable to read or write) via telephone questionnaires. The researcher adapted Patton (1990) five types of questions to design the questionnaire questions for this study. According to Patton (1990) there are five basic types of questions that can be asked of respondents. The first are *classification questions*, which are concerned with the characteristics of the respondents and serve as the basis for the socio-demographic questions in the questionnaire. The second are *behavioural questions*, which are concerned with discovering what a respondent does. The third are *knowledge questions*, which are concerned with determining what 'factual information' a respondent has regarding the area of interest. For example, "have you heard of algae or microalgae?" The fourth set of questions are *perception questions*, which are concerned with understanding the "cognitive and interpretive processes" of respondent. Finally, the *feeling questions*, which are concerns with exploring the respondents' emotion on their thoughts and experiences. Although the feeling questions suggested by Patton (1990) are acknowledged, they were not used in this study. The complete questionnaire used in this section of the study can be found in Table 50 and 51 in the Appendix.

To obtain *reliable* and *valid* responses, the researcher endeavour to use unambiguous and precise wording for each question to ensure that farmers can interpret the meaning accurately and easily. For instant "do you supplement you animals, Yes or No?" Moreover, simple and short questions (with clear role and purpose) that are in line with the targeted market segment's vernacular are used to further achieve reliability and validity. For example, fishmeal to local farmers involved in aquaculture is considered to mean aquafeed rather than the high protein source feed ingredients "fishmeal". Other examples involve the meaning of words when spoken in "pidgin English" compare to its "standard English" meaning. The researcher also ensure that the questionnaire contains "as many questions as necessary and as few as possible" (Bird, 2009).

Table 5 below shows the socio-demographic distribution of livestock and aquaculture farmers by geographical zones in Nigeria. Four out of the six geographic zones in the country with both animal and aquaculture clusters were carefully chosen. Thirty questionnaires are distributed equally across the four-targeted zones. The researcher also administered structured questionnaires to livestock and aquaculture farmers with access to telephone. Overall, 104 questionnaires are completed with 64 being self-administered via email and 40 are administered by the researcher via telephone.

Table 5: Socio-demographic Distribution of Livestock and Aquaculture Farmers

Farmers characteristics	Total Responses	
	n	**%**
Geographical zone		
North central	29	27.9%
North west	36	34.6%
North east	30	28.8%
South East	9	8.7%
South West	0	0.0%
South-South	0	0.0%
Sex		
Male	87	83.7%
Female	17	16.3%
Age group		
18-24	8	7.7%
25-34	38	36.5%
35-44	33	31.7%
45-54	14	13.5%
55 and over	9	8.7%
Prefer not to say	2	1.9%
Farming sector		
Aquaculture	24	23.1%
Poultry	50	48.1%
Ruminants (small & large)	30	28.8%
Number of animals		
1 to 30	14	13.5%
31 to 60	32	30.8%
61 to 90	25	24.0%
91 and above	33	31.7%

3.4 Study 2: Process Analysis

3.4.1 Research Strategy: Qualitative Research

Qualitative research is used to answer questions about meaning, perspective and experience from the participants' point of view (Hammarberg, *et al.*, 2016). In this method, the collected data does not usually agree to counting and/or constructing statistical models but seek to convey insights into participant's thoughts and feelings (Sutton & Austin, 2015) that provide the researcher with the bases for mapping out survey questionnaires for future use in the measurement phase of the DMAIC cycle in Chapter 8. According to Denzin & Lincoln (2000), the "qualitative researcher[s] study things in their natural settings, attempting to make sense of or to interpret phenomena in terms of the meanings people bring to them". It allows the researcher to reflect during (and before) the research process in order to provide contextual information for the reader. The approach also offers a number of different choices for carrying out studies according to certain parameters of the research question, topic, setting and participants. Some of the methods used in a qualitative research include case study, ethnography (Leedy & Ormrod, 2001), focus groups, archival research, narratives, interviews, and participant observation (Saunders, *et al*., 2009; Edwards & Holland, 2013).

Qualitative research is built on inductive reasoning within the poststructuralist paradigm (Wiesenfeld, 2000). Inductive approach is particularly suitable for the LSS's DMAIC method were the researcher collect and analyse data to develop theory. Moreover, considering that there are currently no open pond microalgae culture systems in Nigeria, which practiced process improvement methods like LSS, it would be appropriate to explore real-life cultivation processes first to gain holistic insights on the production practices and their potential causes of failure, prior to generating tentative improvement theory(s) (Weiss , 1994). Thus, the researcher adopted a qualitative data gathering method (interviews) grounded in participants understanding that enables the uncovering of subjective meanings of the processes under investigation. Moreover, developing a detailed picture of open pond alga-culture as well as the interplay between customer (animal farmers) CTQ requirements and working out the value-added steps within the production process would be almost unattainable through quantitative methods due to their closed-ended nature.

3.4.2 Case Study

The qualitative method that primarily underpinned this study is that of case study, which enables the researcher to collect and analyse data within a real-life context. According to a definition provided by Yin (2018), a case study is "an empirical inquiry, which investigates a contemporary phenomenon within its real-life context (e.g. open-pond microalgae farm), especially when the boundaries between phenomenon and context are not clearly evident and in which multiple sources of evidence are used". The researcher collected deep and rich data from the case study microalgae farm by conducting in-depth interviews, elucidating how the processes of production currently gets done, what the company consider good quality algae product, and their most recent wastes and defects reduction methods. According to Miles & Huberman (2009), qualitative data "are a source of well-grounded, rich descriptions and explanations of processes in identifiable local contexts. With qualitative data one can preserve chronological flow [as in value stream mapping], see precisely which events lead to which consequences [as in FMEA and SIPOC analysis], and derive fruitful explanations" (Miles & Huberman, 2009). Accordingly, in the context of animal feed market and microalgae cultivation processes in particular, the researcher explores how livestock and aquaculture farmers feel about their animal feeds and the start to finish chain of events using lean 6 sigma process stapling techniques in the case study respectively. Through a case study strategy, the researcher was able to surpass the quantitative statistical results and appreciate the real-life conditions through the viewpoints of the technical team on the farm. By utilizing primarily qualitative data, the case study method helps the researcher to explain both the values (using a value stream map) and the outcomes of each manufacturing step through primary information and analysis of the case under research.

Like most case study projects the number participant is restricted, the researcher worked with the technical team in charge of production. A detailed longitudinal examination of the case provides a systematic way of defining, measuring, analysing, and reporting the lessons learned over the period of the study. Unlike the market research section of the study where quantitative methods are used to collect data at the macro-level; the case study provides the researcher with the means to investigate the phenomena (i.e. open pond microalgae culture) at the micro-level. The data collection is extensive and draws from various sources including interviews, and archival company records. Moreover, in line with Creswell (2003), research such as the present study that explores "processes, activities, and events" should consider using case study and grounded theory strategies (Creswell, 2003).

In 1984, Yin set forth three categories of case study, namely descriptive, explanatory and exploratory case studies (Yin, 1984). The descriptive case study follows a narrative approach in portraying the phenomena under study by describing the "data as they occur" (Zainal, 2007). This approach may be used as a forerunner to a piece of explanatory and exploratory research (Saunders, *et al.*, 2009). For the reason that it is important to have a clear picture of the process(s) on which the researcher intend to investigate prior to data collection, a *descripto-explanatory*/*exploratory* case study approach is adopted. Yin (1984) corroborates the use of descripto-explanatory or exploratory approach and cautions against seperating these categories or regarding them as a hierarchy. Thus, the researcher begins by describing the theory and developing conceptual framework(s) (where suitable) based on the literature to support the description of the various aspects of the case study. Moreover, general questions such as "what are some of the effects of having sharp angled pond to the microalgae culture?" were designed to serve as precursor for in-depth examination of the process being *explored*. In the same vein, Stake (1995) classified case study into intrinsic, instrumental and collective research. Whereas intrinsic case study is focused on examining the "case for its own sake", instrumental case study examines a small group of the subjects for a particular partern of behaviour and a collective case study is concerned with coordinating data from multiple sources (Stake, 1995). In this study, the intrinsic type of case study in which the researcher set out to solve specifc problems (i.e. how to improve the quality of a process outputs) of a particular case is used, rather than instrumental or collective case studies were generalization of findings is the goal.

3.4.2.1 Case study Selection

This research used a longitudinal case study[15] to evaluate the processes of cultivating microalgae in open pond systems within a single organisation - *Spirulina* Production, Research and Training Centre (SPRTC) - to assess the predictability and repeatability of the production activities. This aids to investigate whether local animal farmers in Nigeria could adopt existing open-air microalage cultivation system based on the findings presented in Chapter 6[16]. Although this organisation is based in India and not Nigeria it was an appropriate case study for this research given that the SPRTC technical department performed microalgae cultivation tasks using locally available materials and operators with little or no education. Thus, can be considered similar to the rural farming communities in Nigeria. In addition, previous contact with other open pond microalgae farms in other countries such as Cyanotech Corporation in Miami, Earthrise Californian *Spirulina*, and Dogondoutchi Farm in Niger were unsuccessful. For example, while both Cyanotech Corporation and Earthrise Californian *Spirulina* do not want to share their company information with the researcher and declined request to partake in this study, Dogondoutchi Farm in Niger (which has similar climatic and socio-cultural characteristics as the northern regions of Nigeria) was unresponsive to all the researcher's efforts to contact them.

3.5 Primary Data Collection: Qualitative Interviews

Interview is an integral part of qualitative research and is used by the researcher for exploring and examining the current situation in the case study as well as for collecting preliminary information from animal farmers, prior to quantifying and prioritising their requirements and needs. Interview and questionnaire are the most common approach used by researchers to collect qualitative data (Dornyei, 2007). However, interviews present the researcher with better options in eliciting narrative information for in-depth investigation (Cohen, *et al*., 2017). An interview is "a two-person conversation initiated by the interviewer for the specific purpose of obtaining research-relevant information and focused by him on content specified by research objectives of systematic description, prediction, or explanation" (Cohen, *et al*., 2017). It allows the researcher to explore concepts used (in

[15] "Longitudinal studies employ continuous or repeated measures to follow particular individuals over prolonged periods of time […]. They are generally observational in nature, with quantitative and/or qualitative data being collected on any combination of exposures and outcomes, without any external influenced being applied" (Caruana, *et al.*, 2015).

[16] Farmers' requirements for feeds, affordability, technology adoption and so forth.

cultivating algae) from the interviewee's (case study technical team) point of views, which cannot be observed directly (Edwards & Holland, 2013). Moreover, without using numerical data this aspect of the study seeks to explore and describe the "quality and nature" of how microalgae are currently being cultivated in the case study farm with emphases on the behaviour, experience and understanding of the technical/production team.

There are different formats for conducting interviews such as structured, unstructured (in-depth) and semi-structured. The type or format of interview is determined by the level of formality and structure used in the conversation (Saunders, *et al.*, 2009). Other researchers have used different typology to categorised interviews. For example, Healey & Rawlinson (1993) uses the terms 'standardised' and 'non-standardised interviews' to refer to structured and un-structured interviews respectively. To Robson (2002) interviews can be directive, which he referred to as 'respondent (or participant) interviews or non-directive informant interviews. This research incorporates all three formats of interviews. For example, as part of the quantitative market survey, the researcher initially uses semi-structured interviews to "help identify the questions that should be asked in a questionnaire administered" as a quantitative study. Likewise, as part of the case study strategy, non-standardised in-depth and semi-structured interviews (via a series video calls) serve as precursors to the interviewer-administered questionnaires as shown in Tables 46 to 48 in the Appendix (page 296 – 306).

3.5.1 In-depth Interviews

This type of interview offers the highest "flexibility and freedom" in planning, executing and organizing the content and questions of the interview to both the researcher and respondents (Gubrium & Holstein, 2001). They are informal and usually used to "explore in depth a general area" of the study. Moreover, no predetermined set of questions are required here, however, the interviewer is expected to have a good idea of the area they want to explore (Saunders, *et al*., 2009). In line with this kind of interview the researcher starts by adopting a non-directive approach or "informant interview" by given members of the technical team member from the case study company "the opportunity to talk freely" about their microalgae cultivation procedures as guide to the conversation (this mostly takes place as part of the end-to-end training sessions by the technical team to the researcher). Then, the researcher begins to direct the interviews by putting forward some questions (Robson, 2011). The used of open-ended questions encourages the participants to respond with "extensive and developmental answers" and may be utilised to obtain facts (Saunders, *et al*., 2009). The preliminary open-ended questions presented to a production in-charge person participant (i.e. technical production team member of the SPRTC - *Spirulina* Production Research and Training Centre) of this study and the investigative goals for asking them are shown in Table 6 below.

Table 6: Preliminary Interview Questions for the Case Study Analysis

Interview questions	Description of investigative goals	Informed gaps in the literature
1. "Could you please describe how you culture microalgae in your farm?"	Aims to understand the fundamental processes necessary for the cultivation of microalgae in an open pond focusing on PEMME (people, equipment, method, materials and environment).	In line with Saunders, *et al*. (2009), the researcher asked these question to explore in depth a general area in which he is interested in with regards to open pond small-scale microalgae farming. There is no predetermined list of sub-questions to work through here, although the researcher has a clear idea about the aspects that he wants to investigate. The interviewees are given the opportunity to talk freely about production processes, activities and beliefs in relation to open pond *Spirulina* farming. This type of interaction is sometimes referred to as "non-directive". Subsequently, the questions that follows below are designed based on both participants response (to this question) and informed gaps in the literature.
2. "What are the steps involved in the construction of your open ponds for alga-culture?	Aims to explore the site selection, tank design/size and construction processes.	One of the most important parameters in cultivating microalgae is the design of ponds used. Microalgae cultured in open ponds (e.g. shallow pond, open raceway pond, circular pond) are comparatively inexpensive, however, they become easily contaminated (Khan, *et al*., 2018). In addition, despite the fact that the majority of commercial microalgae production occurs in unsophisticated, low productive artificial plastic or concrete open ponds, they are influenced by stirring and mixing as well as width and depth of the ponds (Kumar, *et al*., 2015). According to Brennan & Owende (2010), other disadvantages associated with open pond systems involves "environmental variation which imparts a direct effect on culture condition, optimization of pH, temperature, [and] light intensity".
3. "How do you scale-up your microalgae mother culture to meet the number of inoculums needed for the (6X3 metres) open ponds in your farm?"	Aims to examine the morphology, potential risks and growth factors necessary for the cultivation of microalgae both in small scale mother culture and scale-up *inoculum* for large ponds.	Scaling-up microalgae mother cultures to large volumes required for commercial production "is not trivial and is a critical factor to the successful operation of a production facility" (Borowitzka & Vonshak, 2017). However, a small number of papers have been published on the process of scaling of microalgae culture from a small to a large-scale level of production (Shimamatsu, 2004; Belay, 2013; Ben-Amotz, 2004; White & Ryan, 2015). Scaling-up of microalgae cultures is generally done by a factor of 10 per step, that is, from 10 ml to 100 ml and so forth. According to Borowitzka & Vonshak (2017), "for some high-light-sensitive species such as some strains of the cyanobacterium Arthrospira the scale-up factor may need to be reduced to [a factor of] 5 [per step] to minimize photo-inhibition immediately after inoculation". The number of steps required could increase production costs as well as the risk of contamination (Jiménez, *et al*., 2003). According to the literature, the time and cost of inoculum scale-up could be reduced by operating the large-scale cultures as semi-continuous cultures instead of a batch culture. According to Belay (2013) and Jiménez *et al*. (2003), the amount of culture harvested and the time interval between harvests is dependent on the microalgae growth rate and the lowest to highest cell density range of operation to maintain the culture at the optimal biomass concentration. Nutrient replacement to balance the

		nutrients consumed by the harvested microalgae and other losses most also be carefully managed to prevent the depletion of critical nutrient, which could hinder growth. For other algae species like *Chlorella* spp, it is possible to cultivate the inoculum in fermenters (heterotrophically) in the dark on an organic carbon substrate like glucose (Doucha & Lívanský, 2012; Zheng, *et al*., 2012).
4. "What method(s) do you use to harvest microalgae in your farm?"	Aims to determine the method of harvesting, the frequency of harvesting and stages of harvesting.	The separation of microalgae from its growth medium depends on the physiognomies of the algae strain, cell size and density, as well as final product specifications and whether the culture medium is to be recycled or not (Amaro, *et al*., 2011). According to a comprehensive review on dewatering microalga by Singh & Patidar (2018), microalgae harvesting involves chemical, mechanical, biological and/or electrical-based methods (i.e. electrophoresis technique). For example (in no particular order) filtration and centrifugation, coagulation/flocculation, flotation and so forth. To lower cost, it is common to adopt two or more of these methods for greater rate of separation because each method has both avantages and disadvantages. For instance, for large scale microalgae cultures flocculation technique is undesirable as the amount of cationic polymers required is too high (Bharte & Desai, 2018). Although centrifugation is the prime method for harvesting microalgae because it does not require any chemicals, fast and effective in terms of recovering algal cells, it is not economically viable due to high energy consumption (Barros, 2019). Another method of harvesting microalage is sedimentation, which although viewed as a low-cost and simple method, it is restricted to larger algae of more than 70 µm. Inverted sedimentation or flotation (e.g. dissolved air flotation (DAF), electroflotation, dispersed air flotation (Diaf), dispersed ozone flotation (Diof) and/or jet flotation) is another method of harvesting microalgae commonly applied in wastewater treatment processes. Flotation is advantageous in large-scale harvest, however, it generally requires the addition of flucculants (Barros, *et al*., 2015). Another technique for harvesting microalgae is filtration (e.g. dead-end filtration, ultrafiltration, microfiltration, pressure filtration, tangential flow filtration (TFF) and vacuum filtration), were the culture medium is run through a filter to retain microalgae slurry and the remaining water is passed through by a driving force (Harun, *et al.*, 2010; Mathimani & Mallick, 2018). Filtration is sustainable for harvesting *Spirulina* because of its long length corkscrew spiral shape. Nevertheless, the process consumes a considerable amount of energy because of the need to apply high pressure (Zhou, *et al*., 2013), and is susceptible to fouling/clogging, which could lead to increased operational cost. Taken together there is no best method of harvesting microalgae, but rather the strain type and production capacity of the farm determine what technique should be adopted.
5. "What method(s) do you use to dry microalgae in your farm?"	Aims to determine how microalgae is dried after harvesting in the case study farm.	The biochemical composition of microalgae feedstock is typically determined by the growth media, temperature, light intensity and drying methods (Stunda-Zujeva & Veģere, 2008). Similar to banana and pineapples, *Spirulina* powder is hygroscopic and should be dried till the water content is less than 10% (Becker, 2013; Desmorieux & Decaen, 2006). According to Desmorieux *et al*., in order to obtain fine powder and/or thin plates or spaghetti like cylinders of microalgae biomass, spray and

		convective drying remain the most popular methods respectively (Desmorieux, *et al*., 2010). However, few studies are dedicated to drying of *Spirulina*, although this is a vital step in preventing nutritional quality. Traditionally in Africa, algal mash containing *Spirulina* is emptied into sandy hollow digs in the shore to absorb the excess water, which takes 3 to 4 days to dry (Sorto, *et al*., 2015). However, the product obtained contains about 30% sand and require further processing to decant the sand and suspend the algae (Stunda-Zujeva & Veģere, 2008). In the same vein, commercial *Spirulina* producing companies used spray and/or convective drying of extruded noodle-like filaments from concentrated filter pressed wet algal biomass (Habib, *et al*., 2008). A comparative analysis of infrared drying, convective drying, freeze drying and spray drying shows that "protein losses using hot air drying between 40 and 70°C is proportional to the temperature of drying air but loss of total sugar remained constant (30%) from 40°C to 70°C" (Stunda-Zujeva & Veģere, 2008). The authors further observed that "drying above 40 °C damaged border of [the] filaments". However, infrared thin layer drying at 60°C and freeze-drying have the highest repeatability and less losses of total sugars and proteins (less than 10%). Overall, 40°C is considered optimal for drying *Spirulina* including vacuum drying methods in the literature (Larrosa, *et al.*, 2017).
6. "Is there any quality standard that your microalgae product has to comply with?"	Aims to determine whether the case study company follow any quality standard such as ISO 9001:2015.	The quality of microalgae biomass could be asses based on colour (e.g. 4.20/5.0), B-carotene content (e.g. 149.03 mg/100 g) and texture (e.g. 2.68/6.0). According to Prasetyaningrum & Djaeni (2012), the colour test could be "divided into 5-digit levels and preference for the texture of *Spirulina* products with six levels of assessment. The higher and greater level is good quality product".
7. "What are some of the contaminations likely to occur in your microalgae farm?"	Aims to identify what kind of contaminations microalgae cultivation in open ponds is prone to.	Biological contamination by other algal species, fungi, predatory protozoa and bacteria in mass cultivation of microalgae is inevitable (Wang, *et al*., 2013; Flynn, *et al*., 2017). While protozoan and invertebrate predators such as ciliates, amoebae and rotifers and crustaceans can be managed in most cases by different strain selection and/or culture systems (Carney & Lane, 2014). Fungal infections, such as the parasitic chytrid fungi, present a more complicated management problem in both open ponds and photobioreactor systems (Gutman, *et al*., 2009). According to Borowitzka & Vonshak (2017), "growing species with highly selective environmental requirements, such as D. salina (high salinity), Arthrospira (high alkalinity) or Chlorella (high nutrients), is one option to reduce the risk of contamination, but most algal species of interest are not extremophiles". The key factor for minimizing the effects of these contaminants is to maintain optimum conditions in the variable culture environment they are open to (Flynn, *et al*., 2017).
8. "How do you trouble-shoot contaminations and what control measures do you have in place to prevent and/or reduce them?"	Aims to examine how microalgae culture is troubleshot for contaminants and the current control measures used.	Open-air microalgae culture is threatened by various issues, including changeable weather and pest pollution, which could lead to culture contamination and difficulty in maintaining monoculture (Wang, *et al.*, 2013; Flynn, *et al.*, 2017; Gutman, *et al*., 2009).

9. "What is the overall cost for establishing a small/medium algae farm like yours"	Aims to determine the overall cost of production of a small to medium scale microalgae culture in a developing country setting.	The abstract and often incomplete nature of microalgae cultivation systems researched in the literature, coupled with limited sources of empirical data for process and scale-up assumptions, highlights future uncertainties around microalgae production (Slade & Bauen, 2012). Although operation cost such as utilities, labour and raw materials remains the most important production cost in open pond systems, capital cost dominates the cost of production in photobioreactors systems (Fasaei, *et al*., 2018). The authors further concluded that "harvesting and dewatering [processes] contribute 3–15% of the production costs of algae biomass [in both open and closed pond systems]".

The researcher explores the responses for these questions further by seeking for more explanations where the participant response fails to reveal the reasoning in the direction intended. The responses collected from these questions can be found in Chapter 8 (Case study analysis) and Table 49 of the Appendix (transcription) as part of the define phase of the DMAIC methodology.

3.5.1.1 Transcription and Theming of Interviews

Prior to analysing recorded interview responses, it is common practice to transcribe the data. According to Davidson (2009), transcription can be viewed as an "act whereby the recording of speech 'reflects transcribers' analytic or political bias and shapes the interpretation and evaluation of speakers, relationships and contexts depicted in the transcript". Researchers have related different approaches to transcription with the various research paradigms and epistemological assumptions available. For example, the positivist assumes that conversation (or talk) can be presented objectively, and transcription is a manual undertaking that produces accurate interpretation of recordings (Lapadat, 2000). However, to the interpretivist researchers, transcripts are theoretical constructions, and transcription is a process that represents and interprets researcher's choices about how, and what to record in the transcripts (Davidson, 2009). Whilst the positivist views asserted by Lapadat (2000) are acknowledged, the interpretivist viewpoint is taken within this study. The researcher transcribed the interview data himself in line with Oliver *et al*. (2005) continuum of *de-naturalism* where pauses, stutters, and involuntary vocalisations are removed from the script, nevertheless, ensuring that the transcript reflect participants views. The themes investigated for this research are two folds. The first set of themes are derived from the literature review (see Chapter 2) on the challenges and prospects of the Nigerian livestock and aquaculture industries. The second set of themes are derived from informed gaps in the microalgae biotechnology literature and the case organisation shared documentations.

3.5.2 Semi-structured Interviews

This type of interview provides the interviewer with opportunities "to probe and expand the interviewee's responses" (Partington, 2001) through a series of open-ended questions based on the research question(s). In this study, the semi-structured interview format is used, which allows flexibility in creating rich and revealing data that is suitable to the investigation of new ideas such as analysing alga-culture processes to meet animal feed consumer requirements. During this interview sections, the researcher (guided by the literature) is free to modify the order of the questions, rephrase the way a question is expressed, add or leave out some questions depending on the need for further exploration or lack thereof. Opdenakker (2006) argued that the advantage of this method can be further strengthened by conducting the interviews in a face-to-face manner where the participants' cues or other responses can be realised by the interviewer, given him the opportunity to modify the question(s) appropriately. The interviews enable the researcher to obtain descriptive explanations and information to explore the open pond microalgae cultivation processes in the case study farm, which are not available to the public and cannot be acquired by other methods (Partington, 2001). The researcher used the following semi-structured questions to explore the case study company's potential causes of failure and the current control measures used in the production processes. The responses for the potential causes of failure form the bases for the Ishikawa diagram or cause and effect analysis in Chapter 7 - case study analysis. The responses from this interview provide the list of themes and bases for designing the survey for ranking potential failure modes.

Table 50 in the Appendix shows a set of semi-structured interview questions used by the researcher and the exemplary quotes gathered from the technical team responses in the case study company. Given the nature of the questions, interviews are recorded using audio recording [for transcribing, theming, and interpretation] and notes were taken where/when needed [to reflect upon how the interview is conducted] (Snow, *et al*., 2005).

3.5.3 Structured Interviews or Quantitative Research Interview

According to Saunders *et al*. (2009), this type of interview uses interviewer-administered (or at least self-administered interviewer-supervised) questionnaires based on standardised and/or predetermined set of questions. Occasionally referred to as 'quantitative research interview', it enables the researcher to ask participants the same closed questions in similar manner, very much like a questionnaire. For this particular study, both in-depth and semi-structured interviews are conducted in advance as exploratory data gathering methods to develop and refine the closed-ended questions used in the interview surveys. The researcher phrased the interview questions for the questionnaire to elicit only relevant answers from the participants. A self-administered questionnaire was sent to the technical team of the case study farm prior to the interview, followed by a full discussion of the questions (if needed) were the researcher explains and clarifies any queries that the participants have. The participants' work together as a team with minimum interaction to agree on an answer (based on their personal experiences, company culture and method of cultivation). This approach is in line with Tashakkori & Teddlie (2003) 'multi-strand conversation mixed method design' where quantitative data is extracted from data gathered through qualitative means. It is particularly fitting within this research, where qualitative interviews are used to generate data about the process of cultivating microalgae in an open pond farm; however, the data collected is best understood (for the DMAIC framework) by applying quantitative analysis method.

The researcher begins the conversation by proving preliminary explanations of the investigative questions in the interview questionnaire "exactly as written and in the same tone of voice (if/when on a call" to the technical team member[17] of the case study microalgae farm in India (usually via Skype call).

3.6 Data Quality in Qualitative Interviews

Each type of interview outlined above serve a distinct purpose in this study. The in-depth interviews are conducted to gather detailed information, which is then used to "reveal and understand the 'what' and the 'how' but also to place more emphasis on exploring the 'why'" (Saunders, *et al*., 2009). The semi-structured interviews are used to collect data, which were then subjected to qualitative analysis or interpretation. Finally, standardised structured interviews are conducted to collect numerical data, which can then be analysed quantitatively in the FMEA framework during the analysis phase to rank the severity, chances of occurrences and detection of failure in the production cycle of microalgae. A number of shortcomings can be identified in relation to both in-depth and semi-structured interviews. The issues of quality in these forms of qualitative research are very complex and has been criticised by Creswell (2003) for lack of scientific rigour. The issues according to Stenbacka (2001) lies on whether the principles of reliability, bias, validity and generalisability, which are deeply rooted in positivist epistemology and quantitative research can be applied to qualitative interpretivist research such as this one. However, there is an inconsistency with this argument in the literature. For example, Seale (1999) argued that alternative criterions such as transferability, credibility and conformability are better suited to reflect (qualitative research) interpretivist philosophy. However, Mays & Pope (2000) point out that the same set of principles (with some modification) can be applied to both qualitative and quantitative research if the researcher takes account of the conflicting features and the goals of qualitative study. The latter argument is taken within this research. The concepts of reliability, bias, validity and generalisability in relation to the present study are outlined below.

The first issue is *reliability* due to lack of standardisation, which may limit the consistency in results by alternative researchers. According to Joppe (2000) reliability is "the extent to which results are consistent over time and an accurate representation of the total population under study". Moreover, "if the results of a study can be reproduced under a similar methodology, then the research instrument is considered to be reliable". However, a margin of variability for results is tolerated in qualitative study if the research methodology and philosophy (both epistemology and ontology) yield predominantly similar data, which may vary in "richness and ambience" within similar scopes (Leung,

[17] It is worth noting here that the researcher usually converses with the technical team lead who understand both English and Hindi, and who then translates the questions to the team.

2015). In order to overcome the issue of reliability, the researcher provide exhaustive comments relating to the method(s) used and gives reasons underpinning the choice of strategy and the type data gathered, which can help other researchers to understand the processes followed and results obtained.

The second data quality issue that can be recognised in qualitative research is related to "***bias***". Both interviewer and interviewee (or response) related bias also raises concern about the reliability of the non-standardised interviews used in this study. Interviewer's tone, comments and/or non-verbal behaviour may create bias on how participants respond to questions. Moreover, the way the interviewer interprets the responses collected and his ability (or lack thereof) to develop trust with the participants may create bias and increase doubt about the validity of the information given (Easterby-Smith, *et al*., 2008). In the same vein, the way the interviewee perceived the interviewer could also lead to response bias. Saunders *et al*. (2009) assert that participants may be sensitive to unstructured exploration of certain subjects, which could lead to partial answers or bias responses in order to make themselves or their company looks good. There are numerous methods identified in the literature for demonstrating reliability and minimise bias. For instant, Ritchie *et al.* (2013) proposed that researchers could avoid bias; by adopting a systematic way of conducting and reporting their study; and by supporting any interpretation(s) they made with data. In the same vein, Shank (2005) suggests that by requesting participants to clarify any uncertainty, (interviewer) bias can be minimised. Throughout this research misinterpretation of data and bias were addressed in order to ensure that quality is maintained. This involved clarifying that there are no ambiguities in participant's answers, confirming data interpretation with the case study technical team leader/supervisor, comparing the findings with existing literature, and finally reporting the results in a systematic way in line with Ritchie *et al.* (2013).

Finally, data gathered from semi-structured and in-depth interviews may have issues of ***validity and generalisability*** (or external validity). Validity is the "extent to which the researcher gains access to their participants' knowledge and experience and is able to infer a meaning that the participant intended from the language that was used by this person" (Saunders, *et al*., 2009). In order to ensure that this research remains truthful to reality and "measures that which it was intended to measure", the researcher uses *triangulation* (to validate results through data gathering from different methods) and been aware of interviewee's answers that may contradict other responses (Mays & Pope, 2000). In the same vein, external validity or generalisability can be applied in qualitative research. For example, Ritchie & Lewis (2003) suggest that by providing a rich and detail description of the research process and setting, the concepts of generalisability can be applied inferentially to qualitative studies.

Within the context of this study, the researcher ensured appropriate and full use of data to support the interpretation process.

3.7 Ethical Considerations & Consents during Data Collection

Regardless of the method used to collect data, there are ethical issues to consider and principles to abide by while conducting a research study (Saunders, *et al*., 2009). Moreover, since this study deals with human participants and uses interviews as well as researcher-administered questionnaires that may intrude into respondents' lives with regards to the sensitivity of the questions being asked and time allotted, a high level of ethical consideration should be upheld. The researcher considered ethical issues in line with both Fouka and Mantzorou (2011) and Saunders, *et al*. (2009) at all stages of the data collection process. For example, participants are presented with a consent form in relation to their rights to take part or not in the study. The researcher informs participants about what will be required of them with regards to time requirement, any known or predictable risks and so forth. Some important ethical issues considered while carrying out this study are informed consent, beneficence - do not harm (non-maleficence), respect for anonymity and confidentiality, and vulnerability of research subjects (Saunders, *et al.*, 2009; Fouka & Mantzorou, 2011).

Moreover, the Birmingham City University ethical review form by the Computing, Engineering and the Built Environment (CEBE) Faculty Academic Ethics Committee was also completed before this research begins and submitted with a copy of the research proposal. The form covers how the present research relates to "potential physical or psychological harm, discomfort or stress, protection of research subject confidentiality, data protection and consent, moral issues and research/institutional conflicts of interest, vulnerable participants, animals, bringing the university into disrepute, and whether or not the research concern groups that may be construed as terrorist or extremist?". The overall assessment of the aforementioned areas as well as a copy of the university ethics form can be found in Figure 62 in the Appendix, page 317-318 of this report.

Informed consent is one of the main ethical issue in conducting research by which a participant's right to autonomy is protected. It seeks to respect "individual's right to make decisions about themselves and their life (respect for autonomy)", which "requires that research participants are adequately and properly informed regarding the nature of the research project" (Scott, 2017). According to Diener & Crandall (1978), informed consent is "the procedures in which individuals choose whether to participate in an investigation after being informed of facts that would be likely to influence their decisions". The principle involves elements of voluntarism, competence, comprehension and complete information and tresses the researcher's duty to wholly *inform* the potential research participants about their role, the nature of the research, the researcher's identity and organization, the objective(s) of the study, and how the results will be used and published (Orb, *et al*., 2001). However, even where participants grant their consent and agree to participate in the data collection process, it does not automatically imply consent about the way the data provided are used. Hence, consent in a research project is a continuum across *lack of consent* (the use of deception to collect data), ambiguity about the nature of consent (researcher *implies consent* about how data will be used), and *informed consent* that is freely given ("participant's consent […] based on full information about participation rights and use of data") (Saunders, *et al*., 2009). To ensure that consent in this research is both informed and voluntary, the researcher explained the implication of participating in the study to the participants (both verbally over the telephone and in the consent forms) (see Appendix for the consent forms used in this study) and their cognitive ability to exercise consent. The researcher also ensure that participants are free from coercion by informing them that refusal or withdrawal of consent will not affect them in any way.

Beneficence-do good and the mirror principle non-maleficence–do no harm (Ford & Reutter, 1990) are the cornerstone of ethical issue associated with the Hippocratic Oath guided by the principle of *primum non nocere* (i.e. first of all, do no harm) (Fouka & Mantzorou, 2011). To Beauchamp & Childres (2001), it encompasses "the professional mandate to do effective and significant research so as to better serve and promote the welfare of our constituents". According Saunder, *et al*. (2009), the way data is analysed, used and reported all have the capacity to cause harm to research participants. Data collection methods such as interviews and questionnaires used in this study have the potential to be intrusive and can provoke or involve stress in participants. Therefore, researchers most avoid causing unnecessary harm or distress to their research participants. In the same vein, Cohen, *et al*. (2017) citing SSHRC (Social Sciences and Humanities Research Council of Canada) stressed the issue of non-maleficence over beneficence, asserting that risks to psychological, humane, physical, proprietary and cultural values of participants demands greater consideration over potential contribution of the study to knowledge. In line with Ford & Reutter (1990), the results of this research can benefit both animal and aquaculture farmers in Nigeria in growing their own microalgae for feed usage, as well as provide the microalgae industry with primary information on the feed market needs for potential diversification into the animal feed industry.

Anonymity and confidentiality play an important role in gaining access to the case study microalgae farming company. The essence of anonymity asserted Cohen, *et al*. (2017) is that participant information collected during the cause of study should in no way disclose their identity. Thus, the keyway of ensuring anonymity is not using any personal means of identification such as participants' name and address (Saunders, *et al*., 2009). Consequently, the participants' information provided throughout this report are presented in such a way that any identifying characteristics are removed to the point where the researcher or any other person cannot identify individual participants. The quantitative data collected for this study are anonymised by either removing key variables or aggregating where appropriate. However, in qualitative research new points are likely to emerge during the cause of study that may cause the researcher to explore more with other participants, which could affect anonymity. To avoid this the researcher in line with Saunders, *et al*. (2009) attempts to steer the interview conversations towards emergent point(s) without making it clear that other participants have previously brought it up.

The researcher is also responsible for maintaining confidentiality, which means that despite knowing from whom the information is collected, the researcher will in no way make this information public. Confidentiality is therefore concerned with the extent to which the researcher keep faith with his research participants (Fouka & Mantzorou, 2011). To achieve confidentiality, Frankfort-Nachmias, *et al*. (2014) listed four techniques to maitain confidentiality while allowing public access to data. They are:

- removing any kind of identifier by deleting names, addresses or phone number;
- “crude report categories” by releasing age group rather than date of births;
- “micro-aggregation” by using mean and standard deviation from the data on participants;
- “error inoculation” by delibrately introducing errors into individual records while mantaining error-free aggregate data.

In the same vein, Cooper & Schindler (2001) assert that confidentiality can be protected by using non-disclosure agreement, seeking respondent approval prior to any disclosure, and restricting access data containing respondent’s identity. Although this study acknowledged those techniques suggested by Cooper and Schindler, the researcher-maintained confidentiality by employing Frankfort-Nachmias, et al.’s techniques except for “error inoculation”. Moreover, it is worth noting here that all vulnerable groups such as mentally ill individuals, children, and/or captive populations with inability to give informed consent or protect themselves being threatened, deceived or forced to take part in the research are not involved in this research.

The question of **vulnerability of research participants** is at its strongest in research studies where participants’ freedom to choose is limited by dint of their lifestyle, age, social constraints and so forth (Cohen, *et al*., 2017). It is the responsibility of the researcher to protect his participants since the relationship between them is seldom proportional in terms of power; and it is often the case that those with more information, resources and power (i.e. the researchers) study those with less (i.e. the researched).

3.8 Research Rationale: The Thinking and Reasoning behind the Research

The thinking and reasoning behind the present study is influenced by the some of the conditions set out by the sponsors of the research. They include:

- Establishing that the product under study (i.e. microalgae) could be used in animal feeding based on the types of livestock currently found in Nigeria i.e. Nigeria focused.
- Ensuring that the research is focused on solving challenges connected to the Nigerian oil and gas industry (i.e. the need to diversity the nation's economy and encourage smallholder agriculture).
- Establishing that the study contributes to the national growth and development of Nigeria.

3.8.1 Reason for the Selection of Spirulina

The biochemical and nutritional profile of *Spirulina* makes it one of the most richest source of protein, essential amino acids, vitamins and minerals, as well as fatty acids and carotenoids have also been extensively discussed in the literature (Becker, 2007; Phang, 1992; Shields & Lupatsch, 2012; Abd El-Hady & El-Ghalid, 2018). This cyanobacteria also exhibits anti-parasite, anti-bacterial, anti-fungal, and anti-viral properties (Khan, *et al*., 2005). Moreover, when grown in a Zarrouck's medium (Zarrouk, 1966) it can provide an anti-pathogenic function in preserving resident intestinal microbial flora such as *Bifidus* and *Lactobacillus* (Parada, *et al.*, 1998). Although the amount of protein in *Spirulina* varies depending on cultivation methods, it is generally considered to be about three times more than meat meal and 10 time that of soybeans in feeds (Khan, *et al*., 2005). Similarly, it contains superior amounts of *cystine*, *lysine*, *methionine* and *tryptophan* than any order plant, however, not enough to compete with animal sources of amino acids such as fishmeal (Habib, *et al*., 2008; Li, *et al*., 2009). In addition, studies into different microalgae composition have found that *Spirulina* contains considerable level of photosynthetic pigments like chlorophyII (Danesi, *et al*., 2011), beta-carotene (Seshadri, *et al.*, 1991), *xanthophy*II (Anderson, *et al*., 1991), and *canthoxanthin* (Karkos, *et al*., 2011), that could help stimulate immune system and regulation of differentiation of epithelial tissues (Tang, *et al.*, 2012).

Although hundreds of species of microalgae are currently been studied to asses future cultivation scenarios and commercialisation opportunities, *Spirulina* comes highly acclaimed for low cost open-air production because of its unique alkalophilic nature that makes it possible to cultivate in places where only limited sterility can be maintained (Çelekli, *et al.*, 2009; Posten & Walter, 2012; Falquet & Hurni, 1997). It can grow in extremely alkaline medium at a pH value above 10 at which almost all forms of microorganisms die. This helps in maintaining monoculture by reducing the multiplication of contaminating and/or undesired species like *Chlorella.* Consequently, *Spirulina* is referred to as an *alkaliphile* (Ulukanli & DIĞRAK, 2002), which can be found growing naturally in soda lakes (Schagerl, *et al*., 2015). This suggests that, as long as famers maintain a high pH value and provide cover for open-air culture tanks as well as ensure basic hygiene before working with the inoculate, they can generally maintain a pure culture. Moreover, preindustrial communities have extensively demonstrated in the literature the safety of consuming *Spirulina* by both livestock and humans. For Nigerian farmers to feed their livestock with *Spirulina*, they will need to harvest it from the aqueous culture medium and rinse with clean water, as the animals should not drink directly from the fertilizer rich culture medium (Sharma & Singhvi, 2017). However, most harvesting techniques require relatively complex and costly equipment to take the microalgae out of the cultivation medium. Although centrifugation is the most common method of harvesting microalgae, it is not considered cost effective and requires apparatus that may prohibit local farmers in developing countries adopting. The corkscrew spiral shape of *Spirulina* agrees to simple filtration using readily available fabric or cloth. The microalga is caught on the top, as the culture is pass through the fabric. The spiral shape allows the microalgae to accumulate and form a pores-filled matrix for the water to pass through. This is not true of typical algae with small cells that either pass through the finest of fabric filter or form a mass, which slows the process of filtration (Milledge & Heaven, 2013).

Study One: Understanding the Feed Market & Market Analysis

Chapter Four: Segmenting the Nigerian Animal & Feed Market

4 Introduction

A decision was made to divide this chapter into two interrelated parts. First, to explore what and how many prospective animal market segments might be explored based on livestock species, population size and production systems in Nigeria, were the animal feeds market in Nigeria is divided into distinct set of segments based on animal species. The different livestock species dietary needs and farmers preferences provides the variables for determining whether microalgae feedstock can achieve competitive parity in the Nigerian feed market. Numerous sources in the literature points to two main approaches by which market segmentation can be undertaken, namely the post-hoc (Balakrishnan, *et al*., 2011; Tsafarakis, *et al*., 2008) and/or the *priori* approaches (Frank & Strain, 1972). In the post-hoc approaches, segmentation decision is made by analysing the market data through a range of techniques like SOM (self-organizing map), MOEA (multi-objective evolutionary algorithms), CART (classification and regression trees), clustering, and category management (Liu, *et al*., 2018). Alternatively, in the *priori* approach the type and number of segments are determined in advance using prior customer information such as their characteristic, psychographic, demographic (Han, *et al*., 2014) and geographical zones. While the post-hoc segmentation approach is acknowledged, in this chapter, literature from the Nigerian livestock and aquaculture industry is used to investigate potential market segments, complemented by an examination of the empirical data from the market survey (Chapter 6) to identify the most attractive market segment. Thus, this study is primarily adopting the *priori* approach to market segmentation.

Secondly, this chapter also examined how microalgae-*Spirulina* (unless stated otherwise) can best meet potential livestock segments dietary needs based on existing animal feed trials in the literature. Several feeding trials have been conducted in pigs (Grinstead , *et al*., 2000), fish (Ibrahem, *et al*., 2013), chicken (Sujatha & Narahari , 2011), rabbits (Peiretti & Meineri , 2011) and ruminants (Kulpys, *et al*., 2009) to investigate the effects of microalgae - *Spirulina* on health and productivity. Ergo, this microalga is emerging as a potential candidate for supplementing and/or partially replacing traditional sources of proteins, amino acids, fatty acids, vitamins and minerals in feeds (Venkataraman, *et al*., 1994). However, studies on the use of *Spirulina* as a potential additive in animal feed have not all been positive, indicating that, the impact of *Spirulina* in livestock and aquaculture productivity might hinge on which feedstuff ingredient it replaces in the feed and the targeted perfomance parameter(s).

4.1 Poultry Market Segment

Poultry[18] contributes approximately 15% of the total animal sourced protein intake in developing countries (Afolabi, *et al*., 2013). The poultry sub-sector in Nigeria plays a pivotal role of providing egg and meat as well as job opportunities and contributes to the nation's Gross Domestic Product (GDP) (Ohajianya, *et al*., 2013). The "total annual production of poultry meat and eggs is estimated at 300 and 650 thousand tonnes, respectively" (FAO, 2019b). Although there is no current and/or comprehensive data in connection with the size of the Nigerian poultry subsector, it is considered (along with aquaculture) by the FAO to be the most commercialized of all the agricultural subsectors in the country, with a net worth of about USD 1.7 billion per annum (Fagbenro & Adebayo, 2011; FAO, 2019b). It includes both imported and indigenous chickens, turkeys, geese, ducks, and guinea fowls. Poultry has the highest population of all the other species of domestic animals in Nigeria, and chickens are by far the most common and can be found throughout the country more than pigeons, turkeys, guinea fowls or ducks (Bourn, *et al.*, 1994; Pagani, *et al.*, 2008). Prior to the HPAI (Highly Pathogenic Avian Influenza) outbreak of 2006, the estimated poultry population in Nigeria was around 150 million, majority of which are local chicken breeds and others of improved or exotic breeds. In 2017, the Federal Ministry of Agriculture & Rural Development (FMARD) estimated the national herd of poultry to be around 180 million chickens, which represents the largest part of the subsector (FAO, 2019b). According to Salawu *et al.*, (2014), 40 and 60% of poultry in Nigeria are commercially and locally (i.e. in backyards) farmed respectively, accounting for approximately 9-10% of the nation agriculture sector's GDP. It is worth noting here that in Nigeria 'backyard' farming system literally refers to "at the back of the yard", unlike in the FAO scheme were 'backyard' refers to a low-level input and output production system such as "the village or scavenging system" (Pagani, *et al.*, 2008). Recent study by FAO (2019b) observed that "the Nigeria poultry industry comprises about 180 million birds (as mentioned earlier) in three production systems: the extensive or free-range system (46% of the standing population) [flocks of about 50 birds], semi-intensive (33%) [flocks of about 50–2000 bird] and intensive systems (21%) [flocks of about 2000 exotic bird]". Despite being a major drive for the livelihood of over 70% Nigerians (either directly or indirectly) (FAO, 2019b), the poultry sub-sector in Nigeria is neglected by the government, and thus considered to be underdeveloped (Afolabi, *et al*., 2013).

The poultry market segment in Nigeria is comparatively more widespread than ruminants (and/or aquaculture) because of their good feed conversion into protein in eggs as well as meat products, and low production cost per unit as well as high return on investment (Izuchukwu, 2011). In the same vein,

[18] Due to data limitation and to avoid complexity, this and in the chapters to come focus on chicken (unless stated otherwise).

despite being viewed as luxury food by most of the population, poultry products are highly accepted and farmed all over the country, due to shorter production cycle compared to other livestock, which indicates faster returns (Aboki, *et al*., 2013). According to Killebrew, *et al*. (2010), the consumption of poultry eggs and meat from the year 2000 to 2007 increased by 20% per capita in Nigeria. Moreover, domestic poultry production is responsible for about 100% of the nation's poultry products. However, up to 21% of domestic consumption have been attributed to undocumented imports (Killebrew, *et al*., 2010). Traditional poultry production usually consists of indigenous chicken breeds (estimated 51 to 67% of rural smallholder flocks), Guinea fowl, ducks and turkeys. Poultry flock size in Nigeria is also growing, for example, the average flock size increased from five birds on average in 1983 to 49 birds in the North and 181 birds in the East in 2006 (Hassan, *et al*., 2012), indicating a shift from traditional "in backyard" to semi-commercial production system.

According to the USDA (2018), 70% of the cost of poultry production in Nigeria is represented by cost of feeds. This is due to "lack of an integrated and automated industrial poultry sector" in West African countries like Nigeria (Killebrew, *et al*., 2010). The Nigerian poultry feed industry is made up of two sectors, namely commercial and small-scale sectors. The commercial sector produced approximately 65.4% of poultry feed, which is marketed towards chickens, ducks, guinea fowls, turkeys and geese. Although majority of the poultry farming in Nigeria is local and/or "in backyard farming" of all sorts of scavenging birds (Fagbenro & Adebayo, 2017), two-thirds of the country's feed production is accounted for by the broiler and layer chicken subsector (Pagani, *et al*., 2008). According to Bamaiyi (2013), many poultry farmers in Nigeria compound their own feed. However, they are constrained by availability and price of raw materials needed to formulate the feed. Moreover, poultry farmers are unable to transfer the additional cost of raw materials especially corn (which is 60% of poultry feed input) to their customers, leading to operations shutdowns and downsizing by stakeholders. In addition, the government's restrictive import permit and a 5% tariff on imported corn/maize have added to local poultry producers' difficulties to used corn in their poultry formulation (USDA, 2018). Fortunately, the poultry industry is overcoming tannin challenges associated with sorghum and are currently substituting it for corn in their feed ingredients (USDA, 2016; USDA, 2018). The table below shows the breakdown of ingredients used in poultry feed formulation in Nigeria. The price of some of these ingredients like maize and fishmeal is high, which makes it difficult for poultry farmers to produce as well as supply adequate and high-quality feeds to the birds (Akanni, 2007).

Table 7: Raw Materials commonly used in Formulating Poultry Feed in Nigeria (Fagbenro & Adebayo, 2017).

Feedstuff	Quantity - kg per tonne				
	Chicks	Growers	Layers	Broiler	
				Starter	Finisher
Maize	575	510	500	535	545
Groundnut cake	175	100	125	175	100
Palm kernel cake	50	50	70	75	80
Blood meal	30	30	10	30	40
Fishmeal	40	15	30	50	125
Wheat offal	75	200	100	75	50
Brewer's grain	25	60	50	25	20
Bone meal	15	20	10	20	25
Oyster shell	10	10	100	10	10
Salt	2	3	2	3	3
Vitamin/Mineral premix	3	2	3	2	2

As can be seen from Table 7 (above), the most used feedstuff ingredient in poultry feed formulation is maize followed by groundnut cake. It seems possible that these results are due to traditional poultry farmer's practice of only providing a handful of grains (maize, sorghum or millet) once a day to feed the birds, allowing them to roam freely scavenging for insects and plants to make-up the reminder of their dietary needs (Killebrew, *et al*., 2010). These coupled with low veterinary inputs and environmental stresses has contribute to low productivity of smallholder poultry system in the country (Hassan, *et al.*, 2012). Supplementing poultry with dietary *Spirulina* could provide other nutritional benefits like proteins and fatty acids, which a handful of grain cannot provide. Moreover, diseases (especially Newcastle disease) and feed availability are some of the major issues affecting traditional and intensive poultry production in the country respectively. Microalgae has the potential to improve antibody responses in poultry that could eliminate infected cells (Bourn, *et al.*, 1994). In the same vein, in their study on the "biological activity of *Spirulina*", Blinkova *et al*. (2001), found that microalgae could augment resistance and stimulate the immune system in animals such as poultry and fish by stimulating antibodies and *cytokines* production. The authors went on to say that it (i.e. *Spirulina*) can also decreases yeast infections and preserve intestinal flora in animals. Previous research by Hayashi *et al*. (1994), on the enhancement of antibody production in mice corroborate this claims and concludes that *Spirulina* could be used to boost the immune system and response in animals. Furthermore, enzymes such as *superoxide dismutase* or SOD in *Spirulina* could be used as an anti-oxidant by improving animal models against oxidant (Kinnula , 2005; Moorhead , *et al*., 2011).

4.1.1 Feeding Trials of Dietary Spirulina in Poultry Feed

Although partial replacement of soybean meal with dietary microalgae (at either 10 or 20% dry matter) in poultry diet could cause stunted growth in chicks (Ross & Dominy, 1990), no growth variations were found when *Spirulina* is used to partially replace fishmeal (140 and 170 g/kg) (Saxena, *et al*., 1983) and groundnut cake (11.1% and 16.6% of dry weight) in broiler diets (Venkataraman, *et al*., 1994). Moreover, in an experiment to investigate the effects of dietary *Spirulina platensis* on the productive and reproductive performance of poultry, Mariey *et al*. (2012) found that, irrespective of poultry breed, birds fed dietary *Spirulina* achieved significant "means of egg production rate, daily egg mass and feed conversion ratio" in comparison to those fed algae-free diets. The authors also found that egg yolk percentage and colour score increase in poultry fed *Spirulina*. However, no change was found in eggshell and albumen percentages. In addition, as the level of dietary *Spirulina* increased, plasma and yolk cholesterol reduce significantly ($P<0.05$). Sujatha & Narahari (2011) attributed the reduction in cholestrol to high omega-3 polyunsaturated fatty acid (PUFA) and antioxidant content that augments the nutrients in eggs at the expense of the cholestrol level. Moreover, data from Mariey *et al*. (2012) showed that "fertility and hatchability percentages of eggs produced by birds fed *Spirulina*-containing diets were significantly superior compared to those of the control group". In 2001, Toyomizu *et al*. presented the first conclusive evidence that dietary *Spirulina* (at 0, 40, or 80g/kg for 16 days) influences (positively) both redness and yellowness of broiler chicken flesh. The authors also found no significant differences in body weights, nor weights or yields for any of liver, kidney, abdominal fat and *Pectoralis profundus*. Similar results have been found by replacing fishmeal and a vitamin-mineral premix for broiler chicks with *Spirulina* (Venkataraman, *et al*., 1994). However, recent study by Abd El-Hady & El-Ghalid (2018) contracdicts the notion that dietary *Spirulina* have no significant effect on poultry weight. They found that when soybean meal is replaced with 0, 3 and 6% *Spirulina*, "body weight at slaughter age (day 42) and body wight gain (1-6 weeks) were significantly higher" in poultry fed with 6% dietary Spirulina "than the control group". See Figure 7 below.

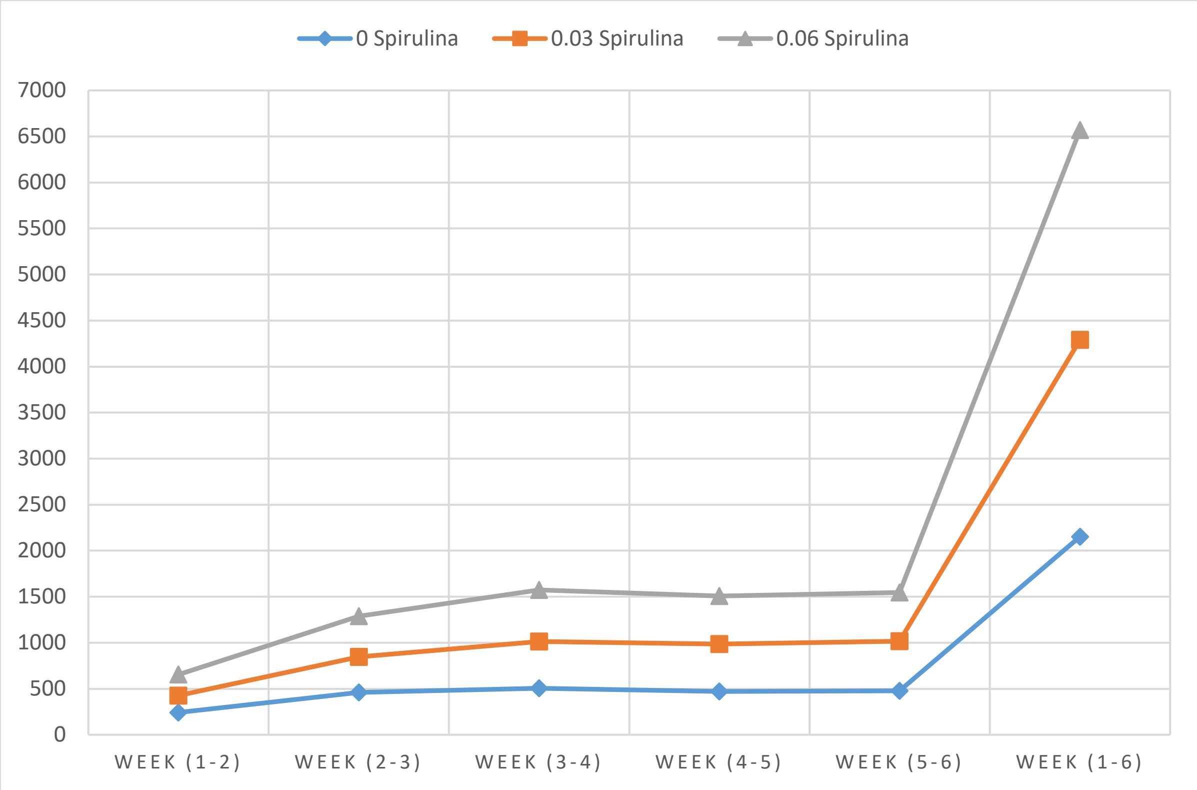


Figure 7: Body Weight Gain at different level of Spirulina platensis microalgae in broiler diet (Abd El-Hady & El-Ghalid, 2018).

Dietary *Spirulina* has also been associated with better health in poultry (Venkataraman, *et al*., 1994). According to Qureshi *et al*. (1996), this is due to increase in functionality of macrophage and mononuclear phagocyte system linked to microalgae supplementation, which is indicative of enhanced resistance to diseases in poultry. The authors also found that economic efficiency of poultry farming could be improved when low dietary *Spirulina* at 10g/kg is included in poultry ration. In the same vein, Venkataraman, *et al*. (1994) found that owing to the nutrient rich composition of *Spirulina*, mineral and vitamin premixes in poultry feed ration can be omitted when the microalga is included, providing higher net revenue.

4.2 Ruminants Market Segment

Despite being as ubiquitous as poultry, ruminants are not as numerous in Nigeria. In 2011, the National Sample Survey reported that the nation's ruminants are made up of around 19.5 million cattle, 72.5 million goats, 41.3 million sheep, and 28000 camels (PT, 2016). They are generally kept under two major production systems, which are rearing of livestock in small numbers by numerous households (i.e. village systems), and large herds of domestic animals reared by nomadic herders (pastoral systems). In Nigeria, the pastoral systems can be characterised by pastoralists' movement from place to place with three animal species such as sheep, cattle and goats to graze on naturally growing vegetation and crop residues along special routes. Some animal farmers practice exclusive pastoralism where they do not grow crops but depends completely on crop residues and/or sell livestock to buy feeds during drought. Other pastoralists have permanent bases and movement is only due to seasonal differences in vegetation quality (FAO, 2004). Overall, the pastoral system accounts for half of the small ruminants and one third of the cattle farming, supplying 40% of small ruminants' meat and 60% of cattle meat in the Sahel and West Africa (Kamuanga, *et al*., 2008).

4.2.1 Cattle

Cattle are by far the most important animal species in Nigeria, surpassing chickens in terms of quality of animal protein (FAO, 2004). However, less than one percent of the cattle population are managed commercially, which suggests that majority of the cattle in the country, are kept under low-input traditional management systems (Tibi & Aphunu, 2010). As of 2017 the population of cattle herd in Nigeria was approximately 18.4 million managed in large herds by transhumant and semi-sedentary pastoralists (FAO, 2019b). According to the FAO, "the aggregate demand for milk and dairy products is estimated at 1.3 million tonnes out of which only 0.5 million tonnes are covered by domestic production. About 1.3 billion USD is spent annually on importation" (FAO, 2019b). There are three main indigenous species of cattle in Nigeria including the West African Dwarf Shorthorn (*Muturu*), *Zebu*, and *Kuri*, which can be categorised further into humped and hump-less cattle (see Table 8 below).

Table 8: Breeds of Cattle Indigenous to Nigeria, Local Names and Population Size (FAO, 2004)[19].

Cattle Breeds	Local Names	Population Size
1. Humped breeds: Zebu	• **Bunaji** (Also called White Fulani White Bororo, White Kano or Yakanaji)	5,118,547
	• **Rahaji** (Also called Red Bororo)	3,029,541
	• **Sokoto Gudali** (Also called Bokoloji)	4,351,528
	• **Adamawa Gudali**	263,019
	• **Azawak** (Also called Tagama)	103,280
	• **Wadara** (Also called Shuwa)	904,731
2. Humpless breeds	• **Muturu**	115,172
	• **Keteku**	180,000
	• **Ndama**	-
	• **Kuri**	-

Bunaji is the most common cattle breed in Nigeria constituting 51% of the nation's herd and can be found across the country. Their mortality rate is around 15.6%, which is less than the other members of the humped or zebu race. The *Muturu* or hump-less breed are found in Southern Nigeria such as

[19] Last available data for individual breeds.

south of the Niger-Benue River and in the northern Savana such as Plateau State. This breed of cattle has a mortality rate of 4.7% for southern savannah (FAO, 2004).

In Nigeria cattle production systems are of three types: the semi-intensive or agro-pastoral system (17%), the extensive or pastoral system (82%) and the intensive or commercial system (1%). In the extensive systems, smallholders move cattle from one place to another in search of water and pasture. Herd size is usually above 100 heads of indigenous breeds characterised by low milk productivity. This system is mostly found in northern part of the country (FAO, 2019b). In the semi-intensive systems farmers are engaged in crop *cum* livestock production. The herd size is made up of between 20 to 100 heads of mainly indigenous breeds. Conversely, in the intensive systems, dairy cattle are kept indoors in sheds and paddocks for milk production. Farmers are engaged in growing mainly exotic breeds ranging from 50 to 1000 heads, which are fed high quality feed from cultivated pasture (FAO, 2019b).

4.2.2 Goats

In Nigeria, goats are the most common small ruminants because they are accepted by all section of the community on social, cultural and religious grounds (FAO, 2004). Therefore, the population of goats is presently higher than all the other ruminants in the country (PT, 2016). Recent estimates indicate that the nation's goat herd is approximately 76 million (FAO, 2019b). Indigenous breeds of goats commonly found in Nigeria include Sokoto Red, Sahel, and West African Dwarf (WAD), which are kept mainly for eating as meat and/or hides for making shoes. According to Oseni *et al*. (2017), WAD goat represents a major livestock resource in the country as it can be raised in low-input production systems. It serves as a major source of income and contributes to the livelihood of smallholders, with women and children playing a major role in the value chain in Nigeria and other countries in sub-Sahara Africa (Ogunlela & Mukhtar, 2009). Their ability to fend for themselves with very little supervision from farmers makes them adaptable to the backyard production systems across millions of households in Nigeria. In connection to feed consumption, goat can thrive on any forage even in extreme weather conditions like rain and drought. Thus, goat is considered to have the toughest mouth compared to other ruminants. In northern Nigeria, it is allowed to forage freely on crop remains throughout the farming season. Despite its susceptibility to parasites like helminths worms, the predominant goat production system in the country is pastoral with minimum management. Overall, in spite of having the largest population of all the ruminants in the country, goat is mostly produced in a village system with low feed input (FAO, 2004). According to Zailani *et al*. (2016) for commercial goat production, feedstuff such as maize and wheat bran, silage, hay and concentrates must be given to the animal *ad libitum*. However only 13-17% of goats are reared commercially in high input production system in the country (FAO, 2004).

4.2.3 Sheep

The population of sheep in Nigeria has increased from 22 million in 2004 to 41 and 43.4 million between 2016 and 2017 respectively (FAO, 2004; PT, 2016; FAO, 2019b). There are four main breeds of sheep indigenous to the country, namely: Uda, West African Dwarf, Balami and Yankasa (Bourn, *et al*., 1994). Second to goats, they are one of the most numerous pastoral ruminants in Nigeria. They are often seen in small flocks accompanied by large number of cattle herds, roaming about surrounding area of villages and towns scavenging for food. They feed on leaves of small trees, scrub bush, maize bran, and fallow grasses. In northern Nigeria, sheep are usually kept for meat and hides production, but rarely for milk (FAO, 2004). The price of sheep fluctuates in the country during religious festivals season and this provides opportunity for feed sellers, since household fattening of sheep for sale requires high quality feeds. Similar to goats, they are broadly managed in pastoral and village-based systems, with pastoral sheep being more productive than any variety of the village-based systems such as reserve production, seasonal confined, fattening, partially confined and free-range (FAO, 2004). These suggest that sheep are "favourites for the poor because they are cheap to manage, and they mature early and breed readily, therefore increase in number quickly" (Hulela, 2010). Moreover, there is a large volume of published studies describing the role of women in sheep management especially in developing countries (Ogunlela & Mukhtar, 2009; Gizaw, *et al.*, 2010). For example, Ogunlela & Mukhtar (2009) noted that in Nigeria, women carry out the bulk labour of sheep management, which is mainly subsistence operation were the animals feed on local grazing. Nonetheless, the rearing of sheep in Sub-Sahara African countries like Nigeria are moving from the aforementioned village-based subsistence farming to commercial production systems (Hulela, 2010). Sheep farming is also getting great support from organizations such as the International Fund for Agricultural Development (IFAD) to fight poverty among developing countries [like Nigeria] (Assan, 2014).

Table 9: A summary of ruminants Production Systems in Nigeria (FAO, 2004)[20].

	Ruminant Species	**Production Systems (%)**		
Operation Type		**Low input**	**Medium input**	**High input**
Subsistence	Cattle	100	0	0
	Goats	100	0	0
	Sheep	100	0	0
Smallholder	Cattle	69	31	0
	Goats	68	32	0
	Sheep	64	36	0
Small-scale commercial	Cattle	48	39	0
	Goats	31	56	13
	Sheep	32	68	0
Large-scale commercial	Cattle	79	7	14
	Goats	61	22	17
	Sheep	70	30	0

The proportion of the population practicing subsistence low-input production system for rearing ruminants in Nigeria appears to be higher than medium or high-input systems, which indicates that the country is an exceptional region for rearing livestock by smallholders. It is apparent from Table 9 above that only 13-17% of cattle, goats and sheep are produced in commercial systems with high inputs in Nigeria. Besides, 64-100% of ruminants kept under subsistence and smallholder farming operation are reared in low-input production systems. According to Kamuanga *et al*. (2008), the productivity and dominance of low-input farming systems can be linked to the high availability of grazing land in the country. Consequently, despite having "a well-articulated agricultural policy document since 1988", the dominance of subsistence farming and its dependence on low technology and rudimentary farm equipment in Nigeria have contributed to the sector's inability to fulfil its role of feeding the population and supplying raw materials for industries (Apata, *et al*., 2011). Statistically, the ruminant's market segment in Nigeria and other Sahel and West African countries presents a 'substantial' opportunity for the feed industry with an annual demand growth of 4% and a supply growth of only 2% as of 2008 (Kamuanga, *et al*., 2008). However, ruminants are fed almost entirely with low nutritious crop residue, hay and/or natural pasture. Suggesting that feed demand in this market segment is 'not stable' as farmers are more likely to feed their animals with natural pasture during the wet season, confining potential feed purchase only to dry seasons. Also, it is becoming increasingly difficult to find herders that do not practise some sort of crop agriculture as a contingency to dry season.

[20] Last available data

4.2.4 Feeding Trials of Microalgae in Ruminant and Pig Diets

In ruminants, several trial studies have investigated the effect of dietary *Spirulina* in both cattle and sheep diets. Some of the positive results of using *Spirulina* have been demonstrated in dairy cows. For instance, Kulpys *et al*. (2009) observed that the use of *Arthrospira platensis* as feed additive in cows could be economically effective as 1 litre cost for *Spirulina* increases milk production by 8.4 litres. This is due to the nutritional properties of the microalga, which prevents the cows from using their body energy reserves to compensate milk production, resulting in increased quality and overall milk production. *Spirulina* can also potentially enhance the quality of cow and goat milk's health by decreasing the level of saturated fatty acid, whilst increasing the level of beneficial PUFAs and monounsaturated fatty acids in milk (Póti, *et al*., 2015; Christaki, *et al*., 2012). According to Póti, *et al.* (2015), the concentration of rumenic acid in cow milk increased from 0.75% to 0.85% with microalgae supplementation. This suggests that milk products from cow and goat fed with *Spirulina* enriched feedstuff could provide health benefits due to a "high level of biologically active promoters" (Luna, *et al*., 2007; Póti, *et al*., 2015). In contrast to pigs, ruminants also display a higher ability to digest *Spirulina* (up to 20% of total feed intake) compared to *chlorella*. Moreover, the alkaline elements of *Spirulina* help to create an effective neutral environment for both microorganisms and the fermentation process that takes place in the forestomach of ruminants (Kulpys, *et al*., 2009). Studies have also shown an increase in ruminant water consumption when *Spirulina* suspension is included, suggesting good palatability (Panjaitan, *et al*., 2010). This is particularly important because of the high sodium content of *Spirulina*, which helps increase urine excretion with more water intake. A study by Granaci (2007) shows that bulls fed with bio-extract from *Spirulina* displayed improved sperm concentration, mobility and post storage viability similar to pigs. Additionally, sheep fed with *Spirulina* exhibits higher ADG (Average Daily Gains), healthier body condition and increased weight in new born lambs than those without dietary *Spirulina*. However, as Holman & Malau-Aduli (2012) pointed out, the age of the sheep and the mode of delivery of the microalga plays a major role on the way the animal response.

In pig diets, *Spirulina* supplementation have shown mixed results. For instance, when 2g of *Spirulina* biomass is added to pig forage, a 9.26 % increase in weight is reached (Šimkus, *et al*., 2013), with better feed efficiency ($p<0.02$) (Grinstead, *et al*., 2000) and improved sperm quality (Granaci, 2007). In a study by Saeid *et al*. (2013) it was found that copper rich *Spirulina* has a positive impact on the liver profile of pigs, meat carcasses grade class and lowers total cholesterol. However, these findings contradict previous results by Grinstead *et al*. (1998) who found no increase in pigs fattening rate or meat quality between the un-supplemented control and supplemented experimental pig group. In the literature, there is no agreed reason for these contradictory effects of dietary *Spirulina* supplementation on pigs. In their two major studies involving dietary *Spirulina* in pig feed, Grinstead *et al*. (1998 & 2000), assert that the form in which the microalga (i.e. pelletized or non-pelletized) is used together with the pig's basal diets affects how they response to growth. Other studies have also point to the genetic make-up of the pigs (e.g. *heterosis* in crossbreds), amount of *Spirulina* used, health of the pigs and the type of feed been replaced with dietary algae may potentially influences the observed growth (Saeid, *et al*., 2013; Šimkus, *et al.*, 2013; Grinstead, *et al*., 2000). Although, the aforementioned studies claim that dietary *Spirulina* has adequate nutrition to supplement pig feeds and support growth performance as long as the amount of *Spirulina* used is limited to 20% or less, other researchers argue that microalgae (*Spirulina*) has no effect on pig meat oxidative stability, pork pH and/or colour (Vossen, *et al.*, 2017; Baňoch, *et al.*, 2013). The limitation in the amount of microalgae (i.e. <20%) suitable for pig supplementation may also be due to decreased dietary protein digestibility caused partly by the complex cell wall structure of some microalgae (such as *Chlorella*), which may be able to resist the digestive enzymes in pigs. Nonetheless, dietary *Spirulina* could positively improve overall sperm quality in boar, with regards to volume (by 11%) as well as motility and post-storage viability (by 5%) (Granaci, 2007).

4.3 Aquaculture Market Segment

In 1951, the construction of the 160 hectares *Panyam* fish farms paved the way to modern aquaculture in Nigeria (Tobor, 1994), and by 2005 the sub-sector is considered the fastest growing food-producing industry in the country (Fakoya, *et al.*, 2005). According to Emmanuel, *et al*. (2014), aquaculture has the potential to improve nutrition in rural areas, diversify revenue, create employments for both women and youths, and curb the importation of fish in the country. It contributes about 3.5 to 4% of the nation's GDP, which translates to approximately 10% of the overall agricultural GDP (Oladimeji, *et al*., 2013). The sub-sector is further divided into small-scale, medium and large practices, with small-scale commercial and subsistence (i.e. non-commercial) farmers accounting for more than 70% of the producers. In general terms, fish farming production can be either fed-dependent (that relies on competing input ingredients like fish meal, soybean, wheat, corn, and fish oil) or non-fed aquaculture systems where fish depends on molluscs and natural aquatic plants for food (Rana, *et al*., 2008). Nigeria's total fish supply in 2004 was approximately 1.16 million metric tonnes of which 56% were from imports, 37.6% from inland fisheries, 2.6% from industrial trawl fishery, and 3.8% from aquaculture. In 2007 the fish demand in Nigeria was around 1.5 million tonnes and the national supply was 0.5 million tonnes (Ayinla, 2007), while 0.7 million metric tonnes were imported, which were valued at about $0.5 billion annually (Nakazawa, *et al*., 2013). This subjects the nation's aquaculture production to global market volatility and shocks. Moreover, in 2016, the Nigerian Fishery Statistics estimated the demand for fish in the country at about 3.32 million metric tonnes while the total domestic aquaculture, industrial and artisanal production was at 1.123 million metric tonnes, some

2.197 million metric tonnes less than the estimated demand (Udo & Umanah, 2017). Figure 8 below provides the domestic aquaculture production in Nigeria from 1995 to 2016.

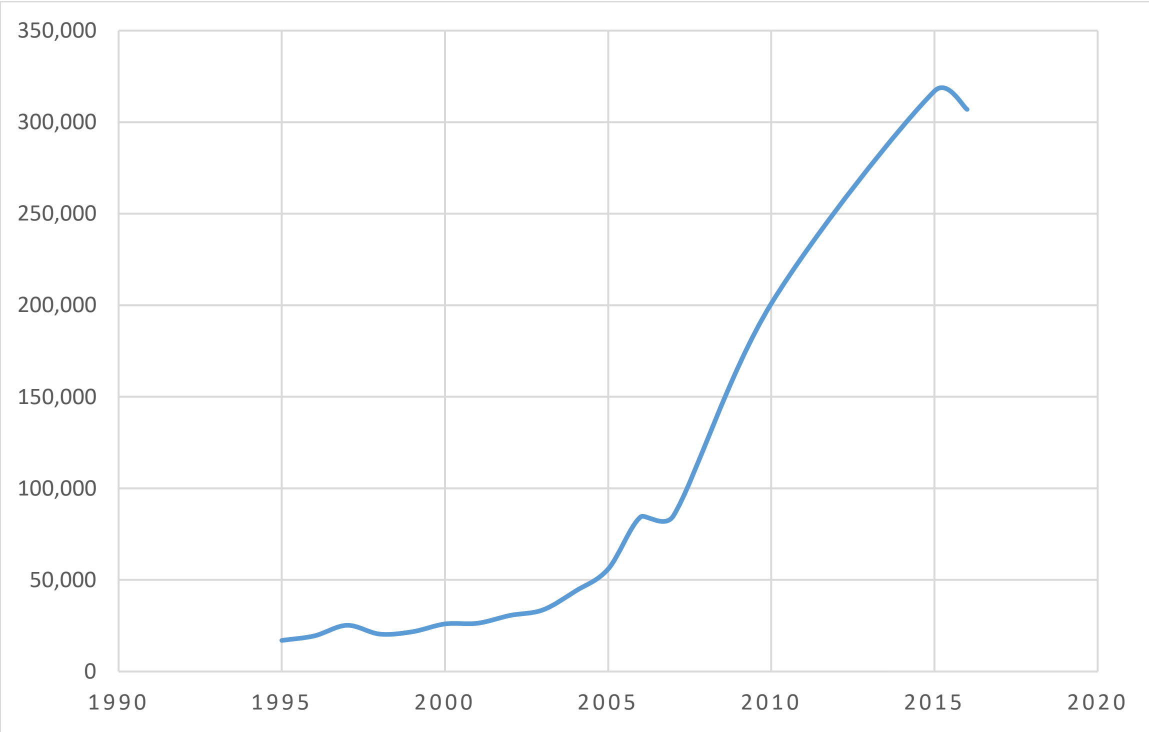


Figure 8: Aquaculture Fish Production in Nigeria (t) (Fakoya, et al.*, 2005; FAO, 2018).*

As of 2013, Nigeria is considered the highest importer of fish and fishery related products (e.g. fishmeal) in Africa, and in the same year, 60% of the total 1.2 million metric tonnes of fish consumed in Nigeria is imported (Nakazawa, *et al*., 2013). The imported fish largely composed of mackerels, cod, sardinella, hakes, croakers, and herrings from countries like Norway, Spain, Senegal, Mauritania, Russia, Denmark, and United States of America. (Nakazawa, *et al*., 2013). According to Oladimeji (2017), the total domestically produced fish in Nigeria account for about 42% of the total fish supply out of which only 5% (some 1.2% increase from 2004 to 2017) is from aquaculture and 37% from artisanal fishery production, suggesting 58% imports (Oladimeji, 2017). These indicates that progressive aquaculture development is important in meeting the annual demand for fish. Aquaculture can contribute greatly to the nation's domestic fish supply and has the potential to reduce the cost of importing fish (Azionu, *et al*., 2005). In addition, local fish farmers have begun to recognise the potential of small-scale aquaculture using production systems like tanks, plastic, raceways, and earthen ponds to culture fish in urban and *peri*-urban areas of Nigeria (Ayinla, 2007). However, compared to industrial and artisanal marine and inland capture fisheries, the aquaculture sub-sector in Nigeria is still in its infancy. For example, in 2010, aquaculture production was 200,000 metric tonnes and capture fisheries was three times more at about 600,000 metric tonnes. Overall, by 2015, the total fisheries production in Nigeria has risen to about 1,027,000 tonnes, accounting for 0.5% of the country's overall GDP and a source of employment for approximately 1.4 million people (FAO, 2017).

Aquaculture productions continue to rise geometrically because of better awareness in tilapia and catfish farming using water re-circulatory and flow-through cultivation systems (Nakazawa, *et al*., 2013). Polyculture of clariid catfish (North African catfish *Clarias gariepinus*, vundu *H. longifilis*, *Heterobranchus bidorsalis*) with Nile tilapia (*Oreochromis niloticus*) are the most common species cultured in Nigeria (Ayinla, 2007). Despite significant breakthrough in aquaculture technology and seed production in Nigeria, catfish farmers occupy about 90% of the market and dominates the majority of the national investments in fish farming (Udo & Umanah, 2017).

In spite of having approximately thirteen million hectares of cultivable water including marine and brackish water resources as well as freshwater systems such as rivers, pond (about 687), dams, lakes and reservoirs (about 365), and floodplains that can be used for fish farming (Udo & Umanah, 2017; MOA, 2007), the Nigerian aquaculture industry is yet to meet the domestic demand for fish. In the same vein, the River Niger (4,184 kilometres long) enters Nigeria in the northwest and flows southwards to join River Benue in the middle of the country at Kogi State, Lake Chad also flows into the country and is responsible for the production of 60,000 m.t. of non-fed fish annually with an established potential yield of about 200,000 m.t. (Ibeun, 2005). There seem to be some evidence to suggest that lack of cultivatable water is *not* a major issue for fish farming in Nigeria, however, as pointed out by Emmanuel *et al*. (2014), quality feed production is pivotal to the success of fish production in aquaculture and constitutes around 60% of the total operational cost.

The aqua-feed industry in Nigeria is constrained by a lack of quality ingredients for producing feed, which has led to fish mortalities, low productivity and low rate of return on investment or ROI. Moreover, recent rise in the foreign exchange (see PESTEL analysis - economic factors in Chapter 2) rate has increased the prices of imported feed and feed materials such as fishmeal (Udo & Umanah, 2017). A report by the Central Bank of Nigeria, claims that the present consumption rate of fish is over 1.5 million tons annually and concludes that for the country to achieve food security, the gap between fish supply and demand must be filled (Essien, *et al.*, 2015). Important resources required to fill this gap include aqua-feed and aqua-feed ingredients such as fishmeal, corn, soybean meal etc., which currently competes in the marketplace of both animal husbandry and human food (Rana, *et al*., 2008). Moreover, the CPI (Commodity Price Index) of these ingredients is also rising along with the prices. For example, global CPI of fishmeal, soybean meal, wheat and corn increase by 50% from 2005 to 2008. The aqua-feed industry in Nigeria is, thus, susceptible to changes in international price of ingredients, suggesting that global fallout may contributes to rural farmers and smallholder's vulnerability.

4.3.1 Feeding Trials of Dietary Microalgae in Aquafeed

Microalgae is considered one of the promising alternatives to high quality fishmeal and fish oil that could ensure sustainable standards in the aquaculture industry in developing countries. Chemical compositions of *Spirulina* sp. *Scenedesmus* sp., *Nanofrustulum* sp., *Chlorella* sp., and *Tetraselmis suecica* in particular are closely compatible with commercial feed materials commonly used in the aquafeed industry, which has led to numerous studies into their utilization as valuable sources of supplementary protein and/or partial replacements for dietary fishmeal in both carnivorous and omnivorous fish species feed (Shah, *et al*., 2018). Several studies involving *Spirulina* inclusion in carnivorous fish diets has found positive results. For example, Teimouri *et al*. (2013) substitutes fishmeal with "0, 2.5, 5, 7.5 and 10% *Spirulina platensis* powder in a Rainbow trout (*Oncorhynchus mykiss*) diet and found significant increase in blood carotenoid concentration (BCC) with increasing levels of the microalga (i.e. 7.5% to 10%). The authors also found a positive relationship between BCC and overall weight gain as well as Specific Growth Rate (SGR), and a negative relationship between BCC and Feed Conversion Ratio (FCR). Moreover, in an eight-week feeding trial using 5, 10 and 15% *Spirulina* to replaced fishmeal in Parrotfish (*Oplegnathus fasciatus*) diet, significant ($p<0.05$) weight gain, feed intake, and protein efficiency ratio were observed together with lower feed conversion ratio in fish fed with 5% *Spirulina pacifica*. The authors also report a significant ($p<0.05$) increase in haemoglobin, haematocrit and respiratory activities, concluding that *Spirulina* can replace up to 15% fishmeal protein (26% dietary inclusion) "in the presence of relatively high soybean meal contents in diets for parrot fish" (Kim, *et al*., 2013). See Table 10 below. Similar results were found in two months feeding trial conducted by Hajiahmadian *et al.* (2012) using 0, 5, 10 and 20% *Spirulina platensis* to feed Golden Barb fish (*Puntius gelius*). The authors demonstrated that the level of microalgae used in fish diet can affect the final weight gain, specific growth rate and feed conversion ratio of fish (up to $p>0.05$) when 20% of fishmeal is replaced with *Arthrospira*.

Table 10: Responses of parrotfish dietary Spirulina as substitute to fishmeal (Kim, *et al*., 2013).

Diets	**Different levels of Spirulina for 8 weeks (% of dry matter)**			
	0 (Control)	5	10	15
Initial body weight (g)	56.91±0.05	56.96±0.25	57.14±0.12	57.07±0.23
Final body weight (g)	83.47±2.10	89.44±0.24	86.67±0.83	84.03±3.07
Absolute weight gain (g/fish)	26.60±2.06	32.50±0.35	29.50±0.77	27.00±2.90
Specific growth rate (%)	0.68±0.04	0.81±0.01	0.74±0.02	0.69±0.06
Protein efficiency ratio	0.91±0.05	1.04±0.01	0.92±0.02	0.91±0.08
Feed conversion ratio	2.25±0.12	1.98±0.01	2.23±0.04	2.27±0.18
Condition factor	2.19±0.05	2.20±0.08	2.22±0.19	2.32±0.29
Hepatosomatic index	2.29±0.27	1.94±0.31	2.66±0.52	2.48±0.22
Viscerosomatic index	2.53±0.37	3.13±0.64	2.53±0.34	3.53±0.08
Survival (%)	100	100	100	100

Studies concerned with the replacement of plant protein sources in omnivorous fish diet with *Spirulina* have also shown positive results. Hussein *et al*. (2013) incorporated *Spirulina* at 0, 25, 50, 75 and 100% with 1.5% lysine and 0.5% methionine as replacement for corn meal in the diet of larval/juvenile stage of Nile tilapia (*Oreochromis niloticus*). "The results indicated that algae positively affect feed consumption and fish growth up to the 50% replacement and then performance was depressed" and conclude that "up to 50% of dietary corn gluten meal protein can be replaced with microalgae which significantly enhance fish growth".

Taken together, *Spirulina* enriched aquafeed lead to higher (or at least similar) growth results for both carnivorous and omnivorous fish. However, some studies have shown that more than 30% microalgae inclusion in aquafeeds could lower growth rates in fish (Shah, *et al.*, 2018). However, "the results of feeding trials with filamentous green algae for *O. niloticus* and *T. zillii* (not *Arthrospira*) indicated that SGR (Specific Growth Rate) of 60–80 percent of the control diet could be achieved with dietary inclusion levels as high as 50–70 percent" (Hasan & Chakrabarti, 2009). Yet, previous research by Appler (1985) found that total replacement of fishmeal with these filamentous green algae (i.e. *O. niloticus* and *T. zillii*) causes extremely poor growth responses.

4.4 Concluding Remarks

Recent evaluations of the Nigerian livestock industry suggest that that the national herd comprises of 43.4 million sheep, 18.4 million cattle, 180 million poultry and 76 million goats. Commercial holdings of livestock are currently rare, and most of the animals are kept under extensive production systems made up of nomadic herders and smallholders. However, commercial holdings in the poultry subsector are gradually expanding. It is important to recognise that it is not impossible to reach all potential segments evaluated above. However, due to differences in customer (i.e. livestock farmers) preferences as well as animal's feed needs and requirements, the microalgae biotechnology needs to consider the demographic, geographic, psychographic and behavioural variables within the market segmentation. Based on the findings above, it can be argued that the psychographic, demographic and behavioural influences are the most important segmentation variables when designing market strategies for producing microalgae-based feedstock for livestock and aquaculture. This is because the algae producing industry need to consider, amongst others, the species of the potential livestock targets and what feed ingredient to replace, to promote their offerings accurately. Furthermore, understanding the benefit(s) sought, or problem solved, and the volume of use or purchase occasion together with other psychographic and behaviour variables are necessary to realise in order to develop the appropriate market strategy. Table 11 below summarises the potentials of the Nigerian livestock and aquaculture segment's stability, validity and attractiveness by evaluating the different options of measurability, accessibility, action-ability and profitability based on the findings of this chapter.

Table 11: Qualification Criteria for Segmenting the Nigerian Livestock and Aquaculture Industries (Were **(✓)** and **(×)** represents the **qualified** and **not qualified** respectively).

Animal Market Segments	**Market Segmentation Qualification Criteria**				**Sources**
	Measurability	*Accessibility*	*Action-ability*	*Profitability*	
1. Poultry	• Poultry population in Nigeria was estimated around 150 million in 2006 and 180 million in 2019. **(✓)** • Commercial and local production is responsible for 40% and 60% of the total poultry production respectively in Nigeria. **(✓)**	• The industry comprises of four sectors, namely, commercial (> 10,000 birds), medium-scale commercial (2,500 to 10,000 birds), small-scale commercial (500 to 2,500 birds), backyard (a few to 2,500 birds) and rural sectors (a few to 200 birds or more). **(✓)**	• Domestic poultry production is responsible for about 100% of the nation's poultry products; however, up to 21% have been attributed to undocumented imports. **(✓)**	• With 65.4% of poultry feed being commercially produced the sub-sector accounts for about 9-10% of the nation's agricultural GDP. **(✓)**	(Fagbenro & Adebayo, 2017) (Salawu , *et al.*, 2014) (Pagani, *et al.*, 2008) (Killebrew, *et al.*, 2010) (FAO, 2019b)
2. Ruminants	• In 2016, the nation's ruminants are made up of around 19.5 million cattle, 72.5 million goats, 41.3 million sheep, and 28000 camels. **(✓)**	• The pastoral system accounts for half of the small ruminants and one third of the cattle farming, supplying 40% of small ruminants' meat and 60% of cattle meat in the Sahel and West Africa. **(×)**	• The price of sheep fluctuates in the country during religious festivals season and this provides opportunity for feed sellers. **(✓)** • Women carry out the bulk labour of sheep management, which is mainly subsistence operation were the animals feed freely on local grazing. **(×)**	• Less than one percent of the cattle population are managed commercially. **(×)** • Goats can thrive on any forage even in extreme weather conditions like rain and drought and thus, only 13-17% of goats are reared commercially in high input production system in the country. **(×)** • Economically, the segment presents a 'substantial' opportunity for the feed industry with an annual demand growth of 4% and supply growth of only 2% as of 2008. **(✓)**	(Premium Times, 2016) (Kamuanga, *et al.*, 2008) (FAO, 2004)

3. Aquaculture	• Nigeria's total fish demand in 2016 was 3.32 million metric tonnes, and in 2004 fish supply was approximately 1.16 million metric tonnes of which 56% were from imports, 37.6% from inland fisheries, 2.6% from industrial trawl fishery, and 3.8% from aquaculture. **(✓)**	• The sub-sector is divided into small-scale, medium and large practices, with small-scale commercial and subsistence (i.e. non-commercial) farmers accounting for more than 70% of the producers. **(✓)**	• The total domestically produced fish in Nigeria account for about 42% of the country's total fish supply out of which only 5% (some 1.2% increase from 2004 to 2017) is from aquaculture and 37% from artisanal fishery production, suggesting 58% imports. **(×)**	• Aquaculture contributes about 3.5 to 4% of the nation's GDP, which translates to approximately 10% of the overall agricultural GDP. **(✓)** • In 2016, the Nigerian Fishery Statistics estimated the demand for fish in the country at about 3.32 million metric tonnes while the total domestic aquaculture, industrial and artisanal production was at 1.123 million metric tonnes, some 2.197 million metric tonnes less than the estimated demand. **(✓)**	(Oladimeji, *et al*., 2013) (Rana, *et al*., 2008) (Udo & Umanah, 2017) (Oladimeji, 2017)

Table 11 is quite revealing in several ways, as it assessed the three main animal market segments in Nigeria in order to determine the most suitable segment for potential microalgae feedstock inclusion for feed, based on the abovementioned segmentation variables and dimensions as found in the literature. What is interesting in this assessment is that despite poultry being the most suitable market segment to target, feeding trials results indicates that broilers (i.e. chicken bred for meat) might not responds positively to dietary microalgae. However, in layer chickens, dietary *Spirulina* could reduce both plasma and yolk cholesterol significantly. These suggest that only part of the poultry segment i.e. the layer chicken sub-segment could benefit from microalgae supplementation. another striking result to emerge from the assessment is that although the ruminants' segment is the largest quantifiable market in Nigeria, low-input subsistence farming and pastoral systems dominate the sector. Additionally, with less than 1% of the cattle (i.e. the largest sub-sector within the ruminant segment) being managed commercially, the ruminants feed market segment although very attractive is unstable and not viable in terms of accessibility and action-ability. Interestingly, despite being dominated by artisanal fishery and imports, aquaculture appears to present the highest economic opportunity contributing about 10% of the country's agricultural GDP, which is on par with poultry, the most commercialised livestock sub-sector. Aquaculture is also accessible since most of the operations are based on small-scale commercial systems with about 2.2 million metric tonnes untapped market opportunities. In addition, feed trials using microalgae in fish diets have being overwhelmingly positive in comparison to other segments, especially when it comes to animal body weight gain and palatability. Consequently, both poultry and aquaculture present the most attractive market segments for potential algae-based feed production by smallholders in Nigeria.

According to the literature, *Spirulina* stands out as the most suitable microalgae specie for use in animal feed because of the following:

- Poultry fed dietary *Spirulina* displays significant increase in egg production rate, daily egg mass and feed conversion ratio compared to those fed algae-free diets.
- Although no changes were found in eggshell and albumen percentages, the egg yolk percentage and colour score in poultry fed with dietary *Spirulina* shows positive result.
- As the level of dietary *Spirulina* increased, the plasma and yolk cholesterol in poultry reduces significantly.
- Dietary *Spirulina* also influences (positively) both redness and yellowness of poultry meat.

- In aquaculture, studies have shown that dietary *Spirulina* could increase blood carotenoid concentration (BCC) in rainbow trout (Oncorhynchus mykiss), which has positive impact on the overall weight gain and Specific Growth Rate (SGR) in fish.
- When *Spirulina* is used to replaced fishmeal in Parrotfish (Oplegnathus fasciatus) diet, significant ($p<0.05$) weight gain, feed intake, and protein efficiency ratio were observed.

The next chapter will focus on reviewing the literature to determine whether microalgae feedstock is of strategic relevance[21] and a potential source of competitive parity, temporary or sustained competitive advantage, as well as superior economic performance in the feed market industry of Nigeria. It aims to achieve the second research objective. By adopting Resource-Based View (RBV) and its subsequent business analysis framework of VRIO - value, rarity, imitability and organised model, microalgae feedstock is taken as a potential asset (i.e. resource) for feed production. For Nigerian farmers to transform microalgae feedstock into sustainable competitive advantage for animal production, microalgae must meet the four attributes (in comparison to conventional feeds and/or feed materials) summarised into the VRIO framework.

[21] Based on the VRIO - value, rarity, imitability, and organisational support model.

Chapter Five: The Competitive Potential of using Microalgae in Animal Diets

5 Introduction

In this chapter, the VRIO - value, rarity, imitability and organisational support framework is used to assess whether microalgae-based feedstuff is of strategic relevance and/or a potential source of competitive advantage in the feed market of Nigeria. The attributes of the framework in connection to microalgae feedstock are summarised in Figure 9 below.

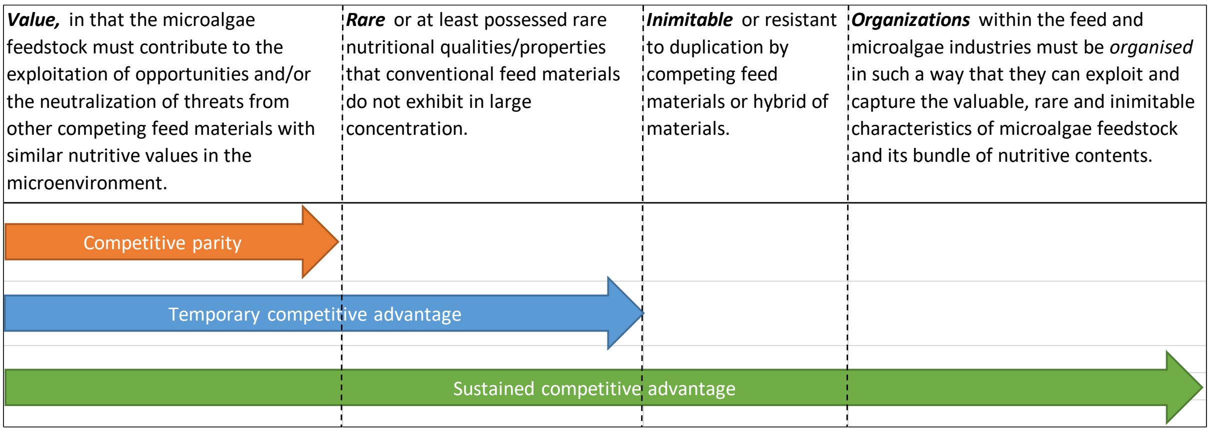


Figure 9: Attributes of the VRIO framework

Microalgae feedstock should be able to be exploited by animal farmers into their existing farming processes in Nigeria. These attributes form the VRIO framework, which point out the key empirical *question(s)* that need to be answered before the relationships between microalgae and SCA can be agreed. In this case, can microalgae be a "strategic resource" for feed customers to adopt whether as a feed material or supplement?

Although the VRIO framework is traditionally focused on assessing whether a resource or capability can minimise cost or create revenue or a mixture of both, it could also provide a model for assessing the potential benefits of feeding livestock with dietary microalgae to achieve parity or temporary competitive advantage over conventional feed materials used in Nigeria. Analysis of the importance of microalgae's nutritional contents in livestock diets in this study is centred on examining its biochemical compositions. In this sense, the application of VRIO model could highlight the advantages of using microalgae in feeds at the micro-nutritional level over conventional feed materials and subsequently aid in the replacement of imported feed materials in Nigeria and materials for which there is a tension/trade-off between using crops to either feed humans or animals (Fradj, *et al.*, 2016). To analyse microalgae's potential role(s) in animal feed composition, this chapter aims to identify those biochemical compositions of microalgae that could provide temporary competitive advantage or parity with traditional feed materials. However, with over 100,000 species of microalgae and approximately 30,000 species under study, this research is primarily focused on *Spirulina* (*Arthrospira*) as a potential new product into the feed market in Nigeria by way of highlighting a strategy for future growth of the microalgae biotechnology sector. The chapter also acknowledges other microalgae species with comparatively close biochemical properties to *Spirulina* such as *Chlorella sp*.

Finally, in line with Kotler's (1997) five levels of a product model, the potential benefits of using microalgae in animal diets and the resultant "values" derived from its nutritional composition were categorised into core, tangible, expected, augmented and potential products. Moreover, it is imperative to realise that the model centres on providing more customer value(s) at each level of microalgae's nutritional profile by adding more features that advance from satisfying basic livestock requirements to meeting feed standards and exceeding famer's expectations. This classification is based on what benefits each category of microalgae biochemical composition provides to livestock and/or aquaculture and whether these satisfy rudimentary, expected or above expected consumer needs.

5.1.1 Assessing the Nutritional Composition of Microalgae Based on the VRIO Model.

Within the VRIO framework, a resource is considered valuable if it enables the exploitation of external macro-environmental opportunity(s) and/or neutralize threat(s) (Barney, 1991). A valuable resource also enables firms to plan and implement strategies for efficiency and effectiveness improvements (Cardeal & Antonio, 2012). According to Johnson, *et al.* (2017), a valuable resource is that "which create[s] a product or a service that is of value to customers and enables the organisation to respond to environmental opportunities or threats" (Johnson, *et al.*, 2017). However, resources may include activities and capabilities that are not valuable by themselves but serve as enablers for exploiting opportunities and blocking the negative effects of threats (Bowman & Ambrosini, 2007; Cardeal & Antonio, 2012). Taken together, the value of a resource directly relates to; the opportunities and threats of the macro-environment; the focal firm's competitive condition and; its ability to contribute to the production of a product that user want at an affordable cost (Collis & Montgomery , 1995; Barney & Hesterly, 2007). Accordingly, microalgae's attributes in terms of its nutritional and biochemical composition could create value (and/or offer competitive parity) in as much as it enables smallholders to exploit the rising demand for animal products and may contribute to reduction of animal malnutrition in developing countries.

The next prerequisite for gaining sustained competitive advantage is rarity. No matter how valuable the nutritional composition of microalgae might be to animals, if they can be realised by conventional feed materials then it is an advantage for none. Because feed customers will most likely implement similar value-creating strategy by exploring their conventional feed materials in similar ways (Barney & Zajac, 1994). Thus, the fewer the conventional feed resources that have similar nutritional profile as microalgae such as fishmeal, soybean meal and rice bran, the higher the likelihood that microalgae inclusion as a feed additive or supplement will enjoy temporary competitive advantage in the animal feeds market. Commenting on resource rarity, Barney & Hesterly (2007) assert that valuable but "not rare" [e.g. nutritional biochemical compositions of microalgae] are sources of competitive parity. A situation under which no one feed material is able to create a competitive advantage.

Temporary competitive advantage based on value and rarity of microalgae mentioned above can only be sustainable if the cost of imitating [microalgae-based feed] product(s) by competitors is disproportionally high. This is perhaps the toughest criterion to evaluate, because given enough time and capital nearly any resource can be imitated (Arshad, *et al*., 2012). However, intangible or tacit resources (such as the unique biochemical composition of microalgae), could be considered as comparable to corporate culture or brand reputation which are very hard to imitate (Carpenter, *et al*., 2012). According to Barney & Hesterly (2007), direct duplication and substitution are the two forms of resource imitation. Competitors can attempt to directly duplicate a *resource* or bundles of potential services; however, if they face a disproportionally high cost to do this, then the *resource* may be a source of sustained competitive advantage. Conversely, if the cost of duplication is low, then the competitive advantage is not sustainable but temporary. Competitors can also try to create substitutes if the cost of direct imitation of the resources possessed by the product or business with the competitive advantage is too high. This form of imitation appeals to the target market of the business with the competitive advantage without requiring the same resources. For example, fishmeal is considered one of the key ingredients for formulating animal feeds, due to its high protein contents, which is hard to imitate. Thus, venturing into substitute sources of protein like microalgae could help to achieve parity in the market. Nevertheless, if the cost of substitution is disproportionally greater than the cost of obtaining the original source of competitive advantage (in this case fishmeal), then the resources (fishmeal) could be considered inimitable (Barney & Hesterly, 2007).

However, while microalgae may have the potential to create valuable and rare bundle of micronutrients for animal feed consumers, it will remain latent until both the livestock and the microalgae biotechnology industries have the capabilities required to deploy it (i.e. a question of organisational support) (Newbert, 2008). Chapter 4 and 7 of this report attempt to answer this question through market segmentation of the Nigerian animal industry as well as lean 6 sigma DMAIC analysis of an existing low-cost open pond microalgae production company. Figure 10 below summarises the fundamental micro-environmental questions that need to be answered about microalgae biomass concerning competing feed materials.

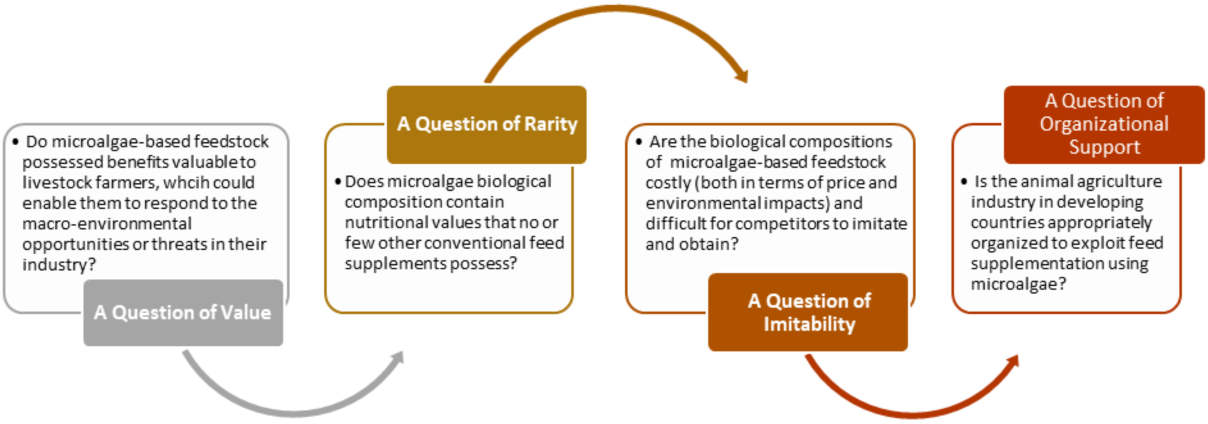


Figure 10: Key Questions for assessing microalgae Competitiveness as Feed Ingredient (VRIO Framework)

Prior to deciding which microalgae specie is best suited for animal feed inclusion and easily adoptable by local farmers in Nigeria (based on VRIO criteria for gaining parity and/or competitive advantage stated in Figure 8 above), it is important to identify and assess those species suitable for general animal consumption. This is possible by reviewing the literature that dealt with the biochemical characterization, toxicological analysis and feeding trials involving different species of microalgae. Moreover, the ideal microalgae specie should have such characteristics as high conversion ratio, palatability and high nutritive *value* for possible optimization of animal product qualities (Holman & Malau-Aduli, 2013). Thus, the biochemical composition of microalgae in comparison to conventional animal and plant feed material are discussed.

5.2 Nutritive Profile of Microalgae

5.2.1 Protein and Amino Acids

The word protein was coined in 1839 by the Dutch chemist Moulder from the Greek word "*proteios*" which stands for "of primary importance" (Schaefer, 1946). Proteins are polypeptide chains created by the end-to-end linking of up to twenty amino acids, which bends to give a 3-dimensional structure (Leung , 2005). They are "macromolecules found in all biological systems, from lower prokaryotes to higher eukaryotes" (Cozzone, 2002). Joshi (2015), referred to proteins as complex organic compounds containing hydrogen, carbon, oxygen, nitrogen and sometime sulphur, iron, copper, iodine and phosphorus. They are the building blocks of the body and the main constituents of endocrine glands, organs, fur, skin, nails, hair, blood, enzymes and antibodies in animals, representing more than 50% of dry cell weight (Cozzone, 2002; Joshi, 2015; Stanfield & Hui, 2010). In the literature, protein is the most common nutrient deficiency in livestock and aquaculture feeds, which calls for the exploration of alternative feed materials to supplement or partially replace traditional sources of proteins.

According to the FAO, "sources of protein for animal feeds are many and varied, with considerable opportunities for further diversification and substitutions". However, "more research is required on [the different] alternative sources before many of the opportunities can be exploited in practice" (FAO, 2004).

Plant based protein source materials, particularly oilseeds and cereal grains, have been the preferred alternatives to animal sources of proteins in feeds due to their low costs, and ability to partially substitute portions of animal proteins (non-essential amino acids) (Memon, *et al*., 2002). However, the quality of protein is greatly influenced by its amino acid composition and feedstuff deficient in any of the essential amino acids could cause depressed appetite and low growth rate of animals. Traditional plant-based protein feedstuff presently used in animal feed production can only provide some of the essential amino acids (FAO, 2004). According to the FAO, "of the approximately 2.3 billion tonnes of cereals currently produced, roughly 1 billion tonnes is destined for food use, 750 million tonnes is employed as animal feed, and the remaining 500 million tonnes is processed for industrial use" (FAO, 2010). Over the years, some researchers have suggested SCP (Single Cell Proteins) such as bacteria, microalgae and yeast (Ravindra, 2000; Anupama, 2000), as well as plant-derived proteins such as legume seed and nut meals as potential alternatives (Francis, *et al*., 2001). SCPs are gaining more attention in the literature over the higher plant-derived proteins because of their rapid biomass generation and versatility. Moreover, SCP microbes are reported to have short multiplication times and rapid protein synthesis giving them a higher protein content in comparison to plant-derived proteins (Ravindra, 2000; Anupama, 2000; Bharti, *et al.*, 2014; Adedayo, *et al*., 2011). However, their high concentration of nucleic acids (6-10%) could cause kidney stone and gout formation in animals by elevating the level of serum uric acid (Nasseri, *et al*., 2011).

Thus, this research has taken a stance to explore a single alternative source of protein, microalgae, which has attracted the attention of numerous scientists (Becker, 2007; Alvarenga, *et al*., 2011; Yaakob , *et al*., 2014; Radhakrishnan, *et al*., 2015). Its high level of quality proteins compared to conventional animal and plant products like fishmeal and soybeans meal makes it a potential contender as a sustainable feed supplement. Moreover, the microalga - *Spirulina* is reported to contain all the essential amino acids, vitamins and minerals, as well as fatty acids and carotenoids together with anti-parasite, anti-bacterial, anti-fungal, and anti-viral qualities (Khan, *et al*., 2005). Table 12 shows the detail protein profile of *Spirulina* powder composition by 100g. In addition to *Arthrospira* (*Spirulina*) biomass, Brown *et al*. (1997) investigation of about 40 microalgae species from seven classes of algae also found that all 40 species have an approximate amount of amino acid and relatively rich in essential amino acids. However, due to technical difficulties of incorporating the microalga into palatable foodstuff together with its high cost of production (D'Este, *et al*., 2017), the propagation of microalgae-based proteins is still in its initial stages with the majority of it marketed as health food supplements (Becker, 2007).

Table 12: Detail protein profile of Spirulina power composition by 100g (Gutiérrez-Salmeán, *et al*., 2015).

Protein and Amino Acids	**Composition by 100g of Spirulina Powder**		**Composition by 100g of Spirulina Powder**
1. Protein B	63		
2. Essential amino acids (mg)[22]		**3. Non-essential amino acids (mg)**	
✓ Histidine	1000	✓ Alanine	4590
✓ Isoleucine	3500	✓ Arginine	4310
✓ Leucine	5380	✓ Aspartic acid	5990
✓ Lysine	2960	✓ Cystine	590
✓ Methionine	1170	✓ Glutamic acid	9130
✓ Phenylalanine	2750	✓ Glycine	3130
✓ Threonine	2860	✓ Proline	2380
✓ Tryptophan	1090	✓ Serine	2760
✓ Valine	3940	✓ Tyrosine	2500

Studies into the economic, social and environmental effect of conventional sources of proteins in animal feed diets have shown that traditional sources of protein in feeds formulation are unsustainable and, in some cases, (e.g. blood meal and meat meal) may have negative effects on livestock growth and health (FAO, 2004; Seifdavati, *et al*., 2008; Cleeland, 2009). Proteins of high biological value (from microalgae) containing adequate amount of essential amino acids (see Table 12) for animal growth are categorized as "complete proteins", while conventional plant-based proteins with limited amounts of essential amino acids and low biological value are "incomplete" (Stanfield & Hui, 2010). Moreover, animal requirements for essential amino acids can only be met through dietary intake (either in feed or as feed supplements), since they cannot be synthesized by the body (Joshi, 2015). Consequently, plant-based proteins have received criticism in the literature for their inability to supply essential amino acids for feed supplementation. For example, both Fisher (1968) and Memon *et al.* (2002) maintained that only animal-based protein sources contain sufficient level of *lysine* and *methionine* essential for livestock growth. Memon *et al* (2002) and Seifdavati *et al* (2008) experiments on the effect of blood meal in animal diets also found that significant increase in

[22] "Animals, including humans and monogastric livestock that serve as human food, cannot synthesize all of the 20 amino acids that are required for the formation of proteins. Therefore, they must obtain the amino acids that they cannot synthesize (termed **essential amino acids**) from external sources, which are based on plants" (Galili, *et al*., 2016).

weight could be achieved when 3% blood meal is used as a protein supplement. The FAO also holds a similar view.

Reports on the protein level of microalgae varies depending on the source. For instance, Fujii *et al.* (2010) report that *Monoraphidium sp*. GK12 microalga cultivated in late logarithmic growth phase[23] (49 hours) typically contains 30 to 40 % protein. In the same vein, Falquest (1997) maintains that, of its dry weight, the protein content of microalgae (*Spirulina*) differs between 50 and 70 %. Moreover, in their study on the nutritional and toxicological aspects of *Spirulina* (*Arthrospira*), Gutiérrez-Salmeán *et al* (2015) found that, the protein content of microalgae ranges between 60 to 70 % of its dry weight. This finding is supported by both Ishimi *et al* (2006) and Tang & Suter (2011). Overall, the protein contents of microalgae can vary by 10-15% depending on amount of light at the time of harvest and the method of analysis and culturing conditions (Gutiérrez-Salmeán, *et al.*, 2015; Becker, 2007). The studies presented thus far provide evidence that microalgae contain an exceptionally *rare* level of *valuable* proteins that even the best vegetable protein source like soya flour (37% crude protein) cannot *imitate* (Moorhead , *et al*., 2011). Table 13 below summarises the nutritional composition in percentage of dry matter of selected popular microalgae biomass against conventional animal together with plant-based feedstuff commonly used in feed formulation in Nigeria, and typical Composition of Formulated feeds for livestock and aquaculture respectively.

[23] Where "cells will double with a generation time that is determined by the quantity and quality of available nutrients and energy sources." (Robador, *et al*., 2018).

Table 13: Nutritional Composition of Conventional feed Materials & Selected Microalgae Species[24]

	Composition, % of dry matter				
Feedstock	Protein	Lipid	Carbohydrate	Ash	Sources
Fishmeal	60-72	11	-	12.7-28.2	(Chapman & Miles, 2012; Shields & Lupatsch, 2012; Khan, *et al.,* 2012)
Blood meal	82.3	0.9	-	3.3	(Winter, 1929)
Soybean meal	44-49.4	2.2	39	3.40-6.1	(Shields & Lupatsch, 2012; Khajarern & Khajarern, 1992)
Wheat meal	12.2	2.9	69	1.6	(Shields & Lupatsch, 2012)
Maize	5.2-13.7	1.1	66-75.9	1.2-2.9	(Khajarern & Khajarern, 1992; Cortez & Wild-Altamirano, 1972)
Arthrospira maxima	60-70	6-7	13-16	-	(Gutiérrez-Salmeán, *et al.*, 2015; Phang, 1992)
Tetraselmis chuii (PLY-429)	46.5	12.3	25	16.2	(Tibbetts, *et al*., 2015)
Chlorella vulgaris	51-58	14-22	12-17		(Becker, 2007; Phang, 1992)
Spirulina platensis	43-63	4-9	8-14	13.4	(Becker, 2007; Phang, 1992; Shields & Lupatsch, 2012; Abd El-Hady & El-Ghalid, 2018)
Synechococcus sp.	63	11	15	-	(Becker, 2007)
Aphanizomenon flos-aquae	62			-	(Becker, 2007)
Dunaliella salina	49-57	6-8	4-32	-	(Shah, *et al*., 2018)
Chlorella pyrenoidosa	57	2	26	-	(Becker, 2007; Phang, 1992)
Chlamydomonas rheinhardii	43-56	14-22	2.9-17	-	(Barbarino & Lourenço, 2005)
Scenedesmus obliquus	48	12-14	10-17	-	(López, *et al*., 2010)

The above listed figures (Table 13) on the concentration of microalgae protein are based on estimations of *crude protein* (CP) published in the literature. According to Becker (2007), these figures are obtained from total Nitrogen level analysis and hydrolysis of the microalgae biomass, and since other constituents of microalgae such as *amines*, nucleic acids, cell wall material and *glucosamides* also contain Nitrogen, these results may represent an overestimated value of proteins. Nevertheless, these figures are sufficient for use in typical feed composition in both livestock and aquaculture diet (see Table 14 below). For example, 11.5%, 12% and 6% of the total Nitrogen in *Spirulina, Scenedesmus obliquus* and *Dunaliella* respectively are non-protein based. The highest protein values reported in the literature for microalga is hitherto that of *Spirulina (Arthrospira)* species, which also contains 20%

[24] Reported values presented here depends on the origin of the biomass (such as growth medium, production and method and time of harvest) and the analytical methods used in the studies.

phycobiliprotein as well as *phycocyanins* that gives it its health effects on animals and an attractive blue colour (Bhat & Madyastha, 2001).

Table 14: Typical composition of formulated feeds for animals and aquaculture (Shields & Lupatsch, 2012)

Livestock	% Crude protein	% Crude lipid	% Crude carbohydrate	Metabolisable Energy MJ/kg	Feed Conversion Ratio
Poultry	21.0	5.0	60.0	13.0	2.2
Pigs	16.0	5.0	60.0	12.50	3.0
Cattle	12.0	4.0	65.0	10.1	5.8
Salmon	37.0	32.0	15.0	21.0	1.0
Sea bream	45.0	20.0	20.0	19.1	1.6
Tilapia	35.0	6.0	40.0	13.5	1.5
Shrimp	35.0	6.0	40.0	13.5	2.0

Currently within the animal feed market, microalgae are one of the rarest plant-based protein sources that is on a par with fishmeal. Fishmeal although commercially made from fish is used in the literature as "a generic term for nutrient-rich feed ingredient used primarily in diets for domestic animals" (Chapman & Miles, 2012). However, even with the high cost of quality fishmeal (65% protein), it is approximately twice cheaper (£ 953.21/ton to £1,185.86/Mt (Rana, *et al*., 2009; Tantikitti, 2014)) in comparison to present price range of microalgae biomass (approximately £2,850 to £11,050/ton) (Tredici, *et al*., 2016). Fishmeal remains the principal protein source of many animal feed compositions in Nigeria and other developing countries especially in the sub-Saharan region of Africa. Yet, it is still predominantly an imported product and sometimes at prohibitively high prices, most likely due to its quality and/or patterns of importation (Moehl & Halwart, 2005). Another animal-based protein source material available to the animal and aquafeed industry in Nigeria is blood meal (approximately 82.3% crude protein (Winter, 1929)). Animal blood from slaughterhouses such as abattoirs, poultry processing plants and tanneries constitute major and low-cost sources of animal protein supplements, however, due to cultural and religious factors the exploitation of blood meal for feed is restricted in the country. Moreover, studies have also shown that the inclusion of more than 3% (i.e. up to 5%) blood meal in animal diets can negatively affect weight gain (Caires, *et al*., 2010). Another limiting factor associated to blood meal in the literature is its low level of *isoleucine* and *glycine* (Winter, 1929) compared to *Spirulina* and fishmeal.

5.2.2 Lipids and/or Essential Fatty Acids (EFA)

Although some researchers claim that the lipid content in *Spirulina sp*. can reach up to 11% of it dry weight (Hudson & Karris, 1974), most studies in the literature indicate that the lipid content in both

Spirulina (Arthrospira) species ranged between 4 to 10% of it dry weight (Becker, 2007; Phang, 1992; Shields & Lupatsch, 2012; Gutiérrez-Salmeán, *et al.*, 2015). The optimal requirements of EFA is considered to be 3-6% of ingested energy for linoleic acid and 0.5-1% for alpha-linolenic acid in adult animals (Bezard, *et al*., 1994). According to Zuliani *et al*. (2009), polyunsaturated fatty acids (henceforth referred to as PUFAs) are "a family of lipids including some subgroups identified by the position of the last double bond in their structure". They are fatty acids containing two or more *cis*-double bond disconnected by a *methylene* group (Lau, *et al*., 2013). A number of studies have found that *Spirulina* is a rich source of these PUFAs, which are *valuable* in promoting good animal health, developing healthy skeleton and performing other vital functions such as metabolism (Habib, *et al*., 2008; Moorhead , *et al*., 2011; Lau, *et al.*, 2013; Ciferri, 1983). According to Habib *et al*. (2008), the PUFA contents in *Arthrospira platensis* ranged between 25 to 60% of its total fatty acid. In 1983, Ciferri claims for the first time that *Spirulina* is the richest source of *Gamma-linolenic acid* (GLA) (*rarely* available in conventional feed materials) in comparison to other algal strains (Ciferri, 1983). Unlike other plant sources of fatty acids, algae can also produce highly unsaturated fatty acids (henceforth referred to as HUFAs), such as *eicosapentaenoic acid* (EPA, 20:5n-3) (Asgharpour, *et al*., 2015) (*Phaeodactylum, Nannochloropsis, Nitzschia, Diacronema, Isochrysis*), *arachidonic acid* (AA, 20:4n-6) (Ahern, *et al*., 1983) (*Porphyridium*), and *docosahexaenoic acid* (DHA, 22:6n-3) (Conquer & Holub, 1996) (*Schizochytrium, Crypthecodinium*). Although not being suitable for direct human consumption, these HUFAs might increase nutritional *value* (fat) when used to supplement livestock (Shields & Lupatsch , 2012). Moreover, the aforementioned γ-Linolenic acid (GLA) in microalgae could potentially replace conventional sources of HUFA, such as; fishmeal and fish oil in aquafeeds (Shields & Lupatsch , 2012), and flax seed in poultry feeds (Kassis, *et al*., 2010). This is particularly true of *Spirulina platensis*, which contains 40% (or 4% of dry matter) gamma-linolenic (18:3 omega-6) compared to 10 to 20% (or 1-2% of dry matter) of fatty acids in *Spirulina maxima,* as shown in Table 15.

In addition, the sustainability and impact on biodiversity of fishmeal and fish oil globally has geared researchers to investigate alternative sources of fatty acids for which microalgae biomass is an invaluable source (Shields & Lupatsch , 2012). The *Eicosapentaenoic* Acid (EPA) level in microalgae may also play a *valuable* role in higher animals as an antecedent of *eicosanoids*, which are important in regulatory physiology (Hemaiswarya, *et al*., 2011). Commenting on the importance of fatty acids in animal diets Shields & Lupatsch (2012) assert that HUFAs play the vital role of preventing and treating arthritis diabetes, hypertension, coronary heart disease, and other inflammatory and autoimmune disorders (Shields & Lupatsch , 2012). Moreover, Timmons *et al.* (2001) study of fatty acids in livestock diets in Ohio dairy herds found that 1.3 to 2.6 % of dry matter in animal diets containing 0 to 15% of roasted whole soybeans is made-up of linoleic acid, which is one of the essential fatty acids present in microalgae.

Similar to the "essential" amino acids, the animal body depends on supplements for "essential" fatty acids such as alpha linolenic acid (C18:3 n3) (ALA) and linoleic acid (TI, 2019). Up to 1.0g/100g of dry matter of *Spirulina* contains these *valuable* essential fatty acids, which are important for healthy skin structure, cell growth, reproduction in rats as well as guinea pigs, and maintaining normal cell-to-cell permeability in aquatic organisms (Burr & Burr, 1930; Palmquist, 2010; Santos, *et al*., 2013; Habib, *et al*., 2008). Suggesting that *Spirulina* is the plant source of essential fatty acids with the highest amount of linoleic acids, representing about 20% of its cumulative fatty acid content (Gutiérrez-Salmeán, *et al*., 2015). Although alpha linolenic acid (ALA) (C18:3 n3) biosynthesise naturally in plants, most dietary sources of ALA such as vegetable oils (e.g. soybean oil) and seeds and nuts (e.g. walnuts) are food materials for which humans compete directly (Rajaram, 2014). Microalgae is thus one of the *rare* sources of ALA that do not directly contribute to the feed-food competition in developing countries. Moreover, linolenic acid levels in *Spirulina* (especially GLA) can be increase between 1.2% to 1.6% by cultivating the *cyanobacterium* under light-dark cycles in both open and closed ponds systems (Tanticharoen, *et al*., 1994). In support of these findings, experimental studies on 19 different strains of microalga carried out by Cohen, *et al*. (2000) found that light intensity (and temperature) during culture can affect the GLA level in *Spirulina*, which can reach up to 1.4% of it dry weight depending on the strain. Guedes *et al*. (2010) found similar results using low light intensity of $9Wm^{-2}$ to cultivate microalgae. Another way the fatty acid level in microalgae could be increase is by random mutagenesis using genetic engineering concepts with UV-light as a mutagenic agent (Meireles, *et al.*, 2003). Consequently, microalgae may be considered one of the *rare* sources of *valuable* essential amino acids including ALA and linoleic acid, which do not compete directly with food materials for human as well as having the *inimitable* characteristic to be manipulated into yielding higher level of EFA. An overview of the principal fatty acids' contents in *Spirulina maxima* and *Spirulina platensis* according to Pascaud's study on "essential polyunsaturated fatty acids of *Spirulina*" are shown in Table 15 below.

Table 15: Distribution of fatty acids in two strains of Spirulina (Pascaud, 1993).

Fatty acids	**Spirulina maxima (% of total fatty acids)**	**Spirulina platensis (% of total fatty acids)**
Palmitic (16:0)	63	25.8
Palmitoleic (16:1 omega-6)	2	3.8
Stearic (18:0)	1	1.7
Oleic (18:1 omega-6)	4	16.6
Linoleic (18:2 omega-6)	9	12
Gamma-linolenic (18:3 omega-6)	13	40.1
Alpha-linolenic (18:3 omega-3)	Traces	Traces

5.2.3 Minerals and Vitamins

According to Lukuyu *et al*. (2009), minerals are the inorganic materials (commonly referred to as Ash) that remains after burning feed samples. The mineral components in feed can be classified into microelements and macro-elements. The former is usually supplied as proprietary premix and the latter are considered individually during feed formulation process (Parr, 1988). Habib *et al.* (2008) assert that, the microalga (*Spirulina*) contains an average of 2.76 to 3.00% "essential minerals" of its total weight under laboratory conditions and about 7% in commercial production. These *valuable* mineral elements play a metabolic role in animals that can be verified when purified diet lacking such minerals causes symptoms of deficiency in animals (McDonald, *et al*., 2011). *Spirulina* contains all the essential minerals (see Table 16 below), due to its bioaccumulation capacity and mechanism of salt tolerance. The accumulation capacity of microalgae has been investigated experimentally and found to be high at different temperatures using copper and cobalt. *Spirulina subsalsa* also shows signs of salt adaptation when cultivated in fresh seawater (Zeng & Vonshak, 1998). It was found that the intercellular sodium and chloride content in the microalga "developed the capacity to initiate sodium and chloride efflux in the light" and remains active in the dark. Similarly, *Spirulina platensis* is able to grow in medium at high-level pH and containing as high as 70g/litre of salt (NaCl), thus likely to be a hygienic feedstock, since only limited number of microorganisms can survive such extreme conditions (Habib, *et al*., 2008).

Phosphorous, iron and calcium are the most relevant inorganic nutrients found in microalgae. Traditionally, animal-based feed material such as blood meal provide these nutrients in livestock diets, however, *haemoglobin* is not sufficiently present in their erythrocytes (Denic & Agarwal, 2007). In comparison to other good plant sources of iron like cereal grain (containing between 150 to 250 mg of iron per kg), microalgae contain triple to seven times the iron content ranging between 580 to 1800 mg of iron per kg. Moreover, unlike say spinach algae do not present *phytates* and/or oxalates that could form a chelate with iron and lower its absorption (Walter, 1997). Likewise, the phosphorous and calcium level in microalgae is on par with animal sources. These micronutrients reduce the risk of decalcification and thus, are important in maintaining animal bone health (much like milk in human diets). Commenting on the micronutrients content in microalgae Craig & Mangels (2009) assert that oxalate-free plant feedstock from *cyanobacteria* with excess amount of the aforementioned elements may improve their absorption when used in animal diet. Another micronutrient present in algae worth noting is its potassium content, which is considered by many nutritionist to be valuable but *rare* in majority of feedstock materials used in animal diets (Singh & Kumar, 1994).

Table 16: Minerals and Vitamins Composition of Spirulina (Arthrospira) Powder (Gutiérrez-Salmeán, *et al.*, 2015; Challem, *et al.*, 1981*)

Minerals	**Composition by 100 g**	**Vitamins**	**Composition by 100 g**
Calcium	468 mg	Vitamin A (as β-carotene)	352.000 IU
Iron	87.4 mg	Vitamin K	1090 mcg
Phosphorus	961 mg	Thiamine HCL (Vitamin B1)	0.5 mg
Iodine	142 mcg	Riboflavin (Vitamin B2)	4.53 mg
Magnesium	319 mg	Niacin (Vitamin B3)	14.9 mg
Zinc	1.45 mg	Vitamin B6 (Pyridoxine HCL)	0.96 mg
Selenium	25.5 mcg	Vitamin B12	162 mcg
Copper	0.47 mg	Vitamin E*	5-19 mcg
Manganese	3.26 mg		
Chromium	<400 mcg		
Potassium	1,660 mg		
Sodium	641 mg		

Depending on the method of drying, up to 80% of the carotenoids present in *Spirulina* are beta-carotene with *cryptoxanthin* and *physoxanthin* accounting for the remaining 20%. Moreover, dry *Spirulina* contains about 100mg of *cryptoxanthin* and 700 to 1700mg of beta-carotene per kilogram, which when absorbed can be bio-transformed into *valuable* Vitamin A by mammals. Thus, with only 1 to 2g of *Spirulina* the Vitamin A requirements of less than 1mg/day for an adult animal can be sufficiently covered (Evets, 1994). Additionally, unlike commercial Vitamin A supplements, the beta-carotene found in *Spirulina* with retinol is not cumulatively toxic, which makes overdose non-probable (Bujard, *et al.*, 1970). Trial studies have also demonstrated that the risk of blindness and neurological damage due to Vitamin A deficiency in humans can be considerably reduced by taken low amounts of *Spirulina*. Its bioavailability in other animals has also been verified (Mitchell, *et al.*, 1990; Falquet, 1997).

Spirulina also contain 50-190mg/kg of Vitamin E (tocopherols) (Challem, *et al.*, 1981), which helps prevents severe muscular myopathy in calves in case of excess intake of unsaturated fatty acid (Palmquist, 2010). The daily Vitamin E requirements for an adult animal is estimated at about 15mg a day. While *Spirulina* is on par with wheat germ in the amount of group E Vitamins, which have *valuable* antioxidant properties, tocopherols can be easily found in many readily available natural sources like nuts, oils and vegetables and its thus neither *rare* nor *inimitable* compound. However, the high Vitamin B12 (cobalamin) content of *Spirulina* is exceptionally *rare* and “difficult to imitate” by any meatless feed material, as no common plant-based feedstock contains it (with the exception of macroalga such as seaweed) (Gutiérrez-Salmeán, *et al.*, 2015). Hence, this microalga might be considered to be a potential source of *inimitable* plant-based biologically active cobalamins in feeds in place of meat meal or fishmeal.

5.2.4 Carbohydrates

According to Falquet (1997), carbohydrates account for approximately 15 to 25% of *Spirulina* dry matter, with traces of sucrose, fructose and glucose. The total carbohydrate in grams per 100g of *Spirulina* powder is 17.8g containing 7.7g dietary fiber, 1.3g sugars, and <0.1g lactose (Gutiérrez-Salmeán, *et al*., 2015). Polymers such as glycogen (0.5%), glucosamine (1.9% of dry weight) and rhamnosamine (9.7%) constiture majority of the assimilable carbohydrates in microalgae. The presents of the aforementioned glucosamine couple with muramic acid makes the cell walls in *Spirulina* fragile enough for digestive enzymes to access the cell contents even though the cell walls themselves are not digestable (Skrede, *et al*., 2011). This is a major advantage for *Spirulina* as a potential feedstock ahead of *Chlorella* and/or yeast, both of which have cellulose cell walls.

As mentioned earlier, low digestibility is considered one of the major shortcomings of microalgae other than *Spirulina* in feeds (Skrede, *et al*., 2011). In the same vein, Madeira, *et al*. (2017) asserts that, the recalcitrant cell walls of *eukaryotic* (kingdom: *Plantae*) microalgae such as *Trebouxiophyceae* defy solubilisation and creates anti-nutritional effects that reduces digestibility of the feeds. These makes it difficult for monogastric animals such as pigs, humans, and dogs to ingest. However, attempts to include *prokaryotic* (Bacteria) microalgae species such as *Cyanophyceae* or blue-green algae in livestock and aqua-feeds have shown positive result. For example, lactating cows shows an 8.5-11% improvement in their body condition (i.e. get fatter (P<0.01)) and a 21% increase in milk production by adding 1.18% dry matter of *Arthrospira platensis* in their diet for 90 days (Kulpys, *et al*., 2009). Other studies have also shown increased in ADG (average daily gain) and FCR (feed conversion ratio) in pigs by adding 0.1-0.2%, 0.2%, and 0.39-1.94% dry matter of *Chlorella Vulgaris*, *Arthrospira Platensis*, and *Schizochytrium sp.* respectively in their diet for 14 days (Yan, *et al*., 2012; Šimkus, *et al*., 2013; Abril, *et al*., 2003). Moreover, microalgae species such as *Isochrysis, Chlorella, Pavlova, Tetrasemis, Haematococcus, Thalassiosira, phaeodactylum, Chaetoceros, and Skeletonema* have shown positive effects in animal diets and are considered some of the most important species for aquaculture especially in fish larvae diets (Madeira, *et al*., 2017).

In the literature, only meso-inositol phosphate stands out as a sufficiently enough carbohydrate in microalgae. Organic phophorus and inositol in algal mesoinositol phosphate ranged between 350-850mg/kg dry matter (Challem, *et al*., 1981), which is several hundred times more than other plant sources and eight times that of meat (e.g. beef) (Falquet, 1997). Such extremely high level of cyclitol phosphate in microalgae is rare and hard to imitate by other plants and/or animal feedstock. However, this could have decalcification effect in livestock. Fortunately, sufficient intake of calcium rich milk or *Spirulina* could eliminate this effect (Challem, *et al*., 1981).

5.3 Summary

Based on the information collated here on microalgae’s nutritional profile, digestibility and palatability, compared with conventional feed materials used in developing countries presented in this chapter, it is now posible to identify microalgae’s strategically relevant biochemical compositions from those that are just necessary to support the daily dietary needs of livestock. The researcher has prepared in Table 17 below a completed VRIO worksheet containing the three main biochemical categories, relevant livestock species, typical composition in feeds and a comparison to microalgae feedtock. For each of the biological compositions, an assessment was made whether they are valuable, rare, inimitable and that the livestock industry is in a position to take full advantage of this potential feedstock to achieved the required animal diatery needs. In the right column, the researcher comments on the results of the VRIO analysis. At first glance, the amount of strategically relevant micronutrients in microalgae are relatively high and that a temporary advantage maybe attainable, as a true SCA is a rare phenomenon.

Table 17: Assessing the Competitiveness of Microalgae with Typical Feed Composition Requirements

Animal feed resource compositions	Livestock	Avarage composition in formulated feeds	Comparison with microalgae biomass nutritional composition	VRIO Criteria				Comments
				V	R	I	O	
Crude protein	Poultry Cattle Fish (Tilapia) Pigs	21% 12% 35% 16%	• Protein contents in microalgae (*Spirulina*) is extremely high and ranged between 46-70%. • They contain all the essential amino acid needed for animal growth such as isoleucine and glycine. • However, animal-based protein sources contain higher level of lysine and methionine for livestock growth and remains the most common supplier of protein in feed formulations.	+	-	-	+	Although microalgae is one of the few plant-based protein source that is on a par with fishmeal the amount of proteins necessary for feed formulation can easily be met by convetional vegetable sources. Moreover, the present price of microalgae feedstock is twice that of fishmeal and about five times that of conventional plant-based protein sources e.g. soybean meal.
Crude lipid	Poultry Cattle Fish (Tilapia) Pigs	5% 4% 6% 5%	• The lipid content in both *Spirulina* (Arthrospira) species ranged between 4 to 10% of it dry weight. • *Spirulina* is a rich source of PUFAs, which are valuable in promoting good animal health, developing healthy skeleton and performing other vital functions such as metabolism. • *Spirulina* platensis has the highest amount of linoleic acids in comparison to other vegetables, which does not directly compete with food, representing about 20% of it cumulative fatty acid content.	+	+	+	+	Microalgae can be considered one of the rarest plant source of valuable essential amino acids including ALA and linoleic acid, which do not compete directly with food materials for human as well as having the inimitable characteristic that allow it (i.e. microalga) to be manipulated into yielding higher level of EFA

Crude carbohydrates	Poultry Cattle Fish (Tilapia) Pigs	60% 65% 40% 60%	• Carbohydrates account for about 15 to 25% of *Spirulina* dry matter, with traces of sucrose, fructose and glucose. • *Spirulina* has higher digestibility than other microalgae like *Chlorella*, due to the presence of glucosamine and muramic acid, which makes its cell walls fragile enough for digestive enzymes. • Only meso-inositol phosphate stands out at an extremely (rare and inimitable) high level in microalgae carbohydrates, which consist of organic phophorus and inositol at approximately 350-850mg/kg of dry matter.	**-**	**+**	**+**	**+**	The typical amount of valuable carbohydrates in grams per 100g of *Spirulina* powder is 17.8g, which is less than half the amount required for a standard feed formulation. Nontheless, *Spirulina* contains meso-inositol phosphate at a rare and inimitable amount compared to other sources from both plant and animals.
Minerals and Vitamins[25]	Poultry Cattle Fish (Tilapia) Pigs	0.6%P, 1%Ca 0.6%P, 1%Ca - 0.6%P,0.8%Ca	• Microalgae contains an average of 2.76 to 3.00% "essential minerals" of its total weight under laboratory conditions and about 7% in commercial production. • The phosphorous (P) and calcium (Ca) level in microalgae is on par with animal sources, which could reduce the risk of decalcification and by so doing maintain animal bone health. • The exceptionally high Vitamin B12 (cobalamin) content of *Spirulina* (i.e. 162 mcg/100g) is rare and "difficult to imitate" or replaced by other vegetable sources.	**+**	**+**	**+**	**+**	Microalgae (*Spirulina*) is rich in valuable vitamins and minerals on a par with animal sources. Morever, its rare P and Ca content gives it a the uniques feature to remove minerals from animal bones and/or other calcified tissues. In the same vein, microalgae contains inimitable level of vitamin B12 which could serve as a source of compettitive advantage compared to traditional feed ingredients.

[25] (FAO, 1992)

The findings of this chapter can be used to define microalgae feedstock using Kotler's five product levels, as shown in Figure 11. According to Kotler (1997), product or service (in this case microalgae-based feedstuff) can be classified into 5 models of levels based on the benefit derived by the customer and final consumer. The first level is the *core benefit*, that is the fundamental benefit(s) that livestock farmers are actually buying. The second level is the *basic* or *tangible product*, which encompasses all describtive features of the product such as the algae biomass, colour, features (e.g. nutritive profile) and so forth. The third level is *expected product*, which includes a set of attributes that animal feed customers normally expect from feed products and their minimum expectation. The fourth level is the *augmented product*, which includes rare and inimitable benegits that differentiate microalgae feedstock from conventional feed materials. Finally the *potential product*, which is the fifth level that focuses on the value added with regards to new ways of satisfying customers by exceeding their expectations (Kotler, 1997).

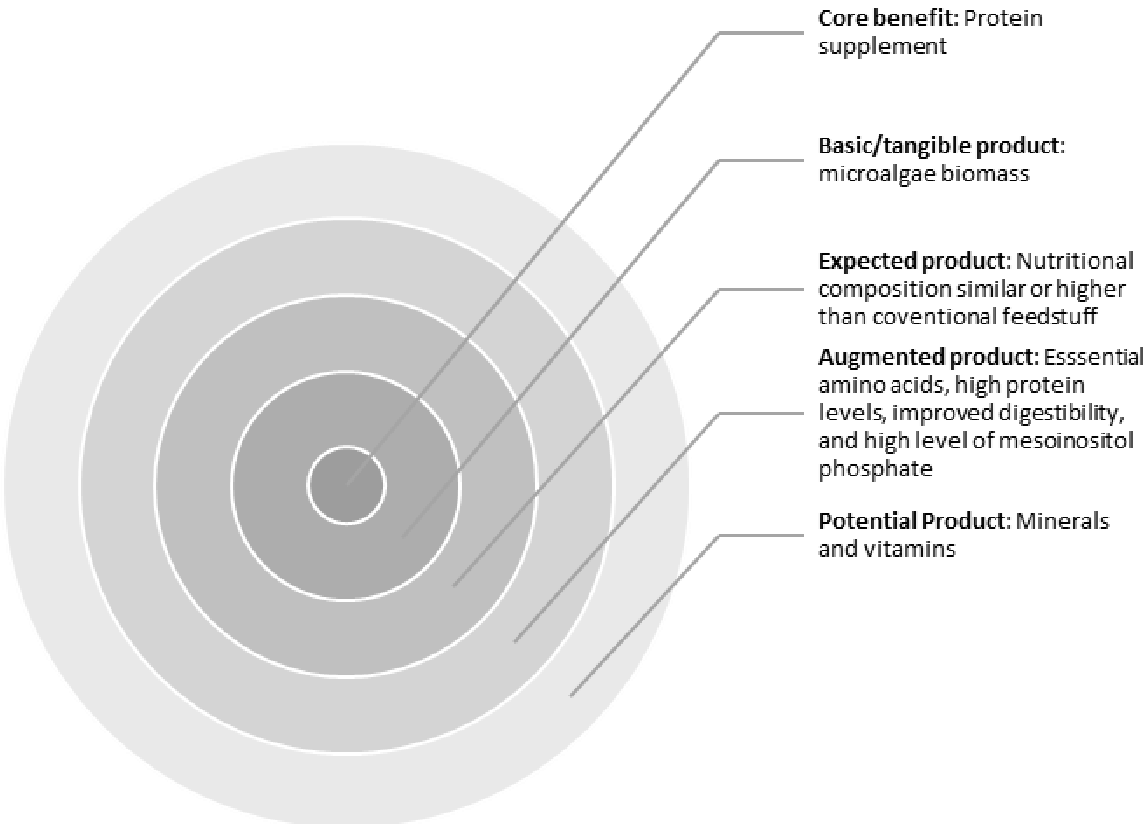


Figure 11: Product Levels of Microalgae Feedstock for Animal Feed usage

5.3.1 Business-level Strategy

Moving from the choice of potential target market segment(s) to the choice of strategy on a market (i.e. how do we compete?). Business-level strategy is concerned with decisions about how microalgae biotechnology positions itself in the animal feed market of Nigeria. Traditionally, either a firm position itself as the cheapest in the market or else must provide a value-added uniqueness perceived by the customer and whether the target customers are a particular segment or an entire industry. To address this challenge from a strategy perspective, Porter (1985) offers a set of generic strategies a business venture could pursue to achieved competitive advantage in a given market. Namely the **cost-leader strategy**, the **differentiation strategy** and the **focus strategy**. Since microalgae feedstock cannot deliver the cheapest competitive offering to livestock farmers, it is important to figure out the non-price features of algae that are vital to smallholders (as discussed above) (Porter, 1985). Thus, rather than predominantly focusing on price and costs (of course these are still important), the animal feed producers (either on-farm formulation by farmers or commercial) and the microalgae biotechnology could pursue a differentiation strategy devoted to understanding the unique value of microalgae-based feedstock.

5.3.2 Concluding Remarks

From the nutritional standpoint, microalgae offer a variety of compound necessary for the improvement of animal growth parameters such as lipids, proteins, carbohydrates, antioxidants, and vitamins and minerals. Thus, justifying microalgae's ability to add value in local feed formulations for livestock and aquaculture production. Moreover, the nutritional quality of meat consumed in Nigeria could be improve through carotenoids, antioxidants, iodine and n-3 LCPUFA provided by microalgae, which would ipso facto have positive impact on local food safety. However, it is imperative to conduct chemical test on the biomass before use, as microalgae culture is prone to heavy metal accumulation such as lead and arsenic that can be harmful to animal health.

It should also be clear that from the market-orientated standpoint the ability for microalgae to create value rest not only on its value-adding protein contents and supporting rare and inimitable level of essential fatty acids but also on the way the organization producing it (or looking into producing it) is designed and adapt to change. Chapter 7 of this report analysed the entire production process of a microalgae farm in India using lean 6 sigma's DMAIC framework to identify bottlenecks and develop process improvement strategies for potential low-cost cultivation and/or use of microalgae in the livestock industry of Nigeria.

In the next chapter, the researcher examines the Nigerian livestock and aquaculture subsectors in order to obtain farmers feed needs and requirements i.e. the "Voice of the Customer" (VoC). The VoC is a product development technique used in business to produce a detailed set of customer wants and needs. In the next chapter, livestock farmer's wants, and needs are organized and prioritised in terms of relative importance for microalgae-based feedstock production. The chapter provides a detailed understanding of the Nigerian livestock farmers requirements for feeds and key inputs for the setting of appropriate design specification for open pond microalgae culture systems. Overall, there are four aspects of the VoC covered using quantitative market research steps (survey - questionnaires). They are as noted earlier – potential livestock farmers want and needs, a hierarchical structure of the needs and priorities (i.e. critical to quality) and farmers perception of performance.

Chapter Six: The Voice of the Customer of the Nigerian Animal Market

6 Introduction

Although new product development (NPD) is an important business process for many companies, lack of "customer understanding" is one of the main reasons for product failure (Eliashberg, *et al*., 1997). The term *voice of the customer* originated from Quality Function Deployment (QFD), which integrates the need for new products by involving employees (and subsequently the VoC) to participate in product design (King, 1987). According to Alam (2005) VoC research is "a process of eliciting needs from consumers […] through a series of situations in which they have experienced and found solutions to the set of problems being investigated. Needs are obtained through indirect questioning by coming to understand how the consumers found ways to meet their needs, and more important, why they chose the particular solution they found". The method(s) used to elicit the consumer's need depends on the amount of known preliminary consumer requirements. For example, if no preliminary consumer information is available, then general ideas may be obtained through interviews and/or focus groups research method. However, when qualitative consumer information is available and well prioritised, then survey, telephone, or email data collection method may be used to quantify the consumer wants and needs. According to Katz (2007), VoC inputs are used in the early stages of NPD to clarify customers' requirements, which makes it suited for identifying and structuring livestock farmers' need as well as providing priorities for feed requirements with regards to microalgae production. A livestock farmer's need in this study is a description of the benefit(s) to be fulfilled by microalgae feedstock. The benefits of collecting and integrating the VoC through market research has been well documented (Flint, 2002; Davila, *et al.*, 2006; Cooper & Dreher, 2010). Studies (for instance Cooper *et al*., (2004)) have also shown that NPD projects (much like the present research) founded on clearly defined customer wants and needs (creating better value propositions) are more likely to be successful. A product success is a function of the amount of market information a business has and how it uses that information in developing new product (Ottum & Moore, 1997; Ernst, *et al*., 2010).

6.1 Study Area: Nigeria

The Federal Republic of Nigeria is considered by the FAO to be a food deficit country (FAO, 2017). It operates under a federal system of government, with a Federal Capital Territory (FCT) controlled by the Federal Government and 36 states. Moreover, there are 774 LGA (Local Government Areas) each with a significant degree of autonomy (FAO, 2018). The nation is divided into six geopolitical zones based on their language, ethnicity, culture diversity and the socioeconomic activities customary in each zone. This study is conducted across four out of the six geographical zones of the country, namely, North Central (or middle belt), North West, North East and South East, with the other zones being South-South and South West. Three states per zone were selected in the North Central and North West. Two states were selected in the North East Zones, and only one state was selected in the South East Zone as shown in Figure 12. See Figure 13 below for the geographical distribution of the respondents.

Figure 12: Map of Nigeria showing States across Geographical Zones Sampled (Source: Adopted from UN (2019).

The researcher focused on the aforementioned zones because of the presence of reachable small-scale livestock farmers. Moreover, all the states in these zones have some form of farming activities as major occupation and source of income especially in the rural areas. Maize, millet and sorghum are traditionally cultivated in the northern regions along with most ruminants and poultry, whereas in the south, yam, cassava, plantain, pigs and aquaculture are traditionally cultivated. The majority of the states in these zones have tropical climate with high temperature, dry wind between the months of November and March, and heavy rainfall from April to October (Ugbah, *et al*., 2019). These favourable yearly variations in weather conditions have led the majority of the inhabitants to take on some form of agricultural practice for their livelihood. Within the selected zones, livestock farmers from at least two-member states[26] are selected to take part in the survey. Farmers with social media accounts were sent the questionnaire via private messaging/email (i.e. SAQ - self-administered questionnaires), while others were contacted via telephone by the researcher (i.e. RAQ - researcher-administered questionnaires). The total sample size for this section of the study was 104 small-scale[27] poultry, fish, and ruminants' farmers distributed across four geographical zones.

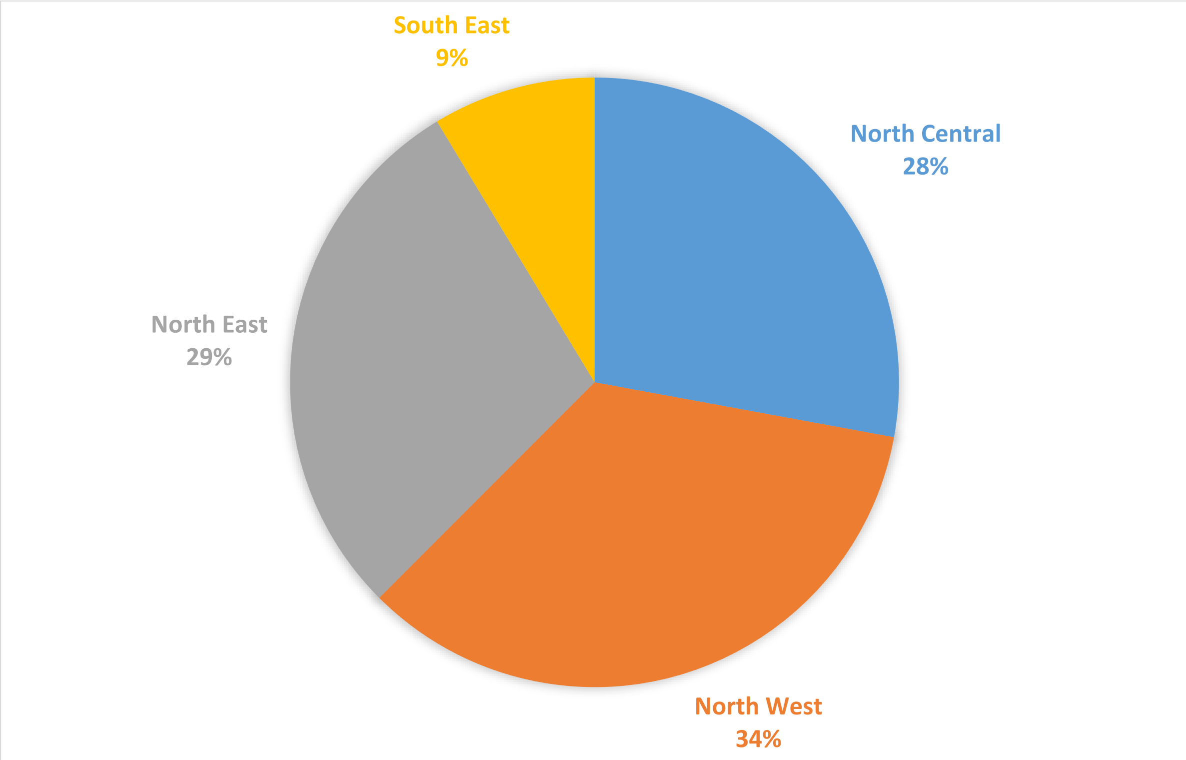


Figure 13: Geographical Distribution of Respondents

Agriculture in Nigeria is still underdeveloped characterised by low technology adoption, low productivity and high labour intensity (IITA, 2017). The FAO attributed these to the oil boom of the 1970s when investment in agriculture (both crop and livestock) started to deteriorate as the government began to prioritise the oil sector, leaving the country vulnerable to changing oil prices. In addition, the domestic animal production does not meet the country's demand for livestock and livestock products and thus, Nigerians rely on large imports of feeds and/or feed materials such as fishmeal and maize. In 2015, Nigeria achieved the first United Nations Millennium Development Goals to "eradicate extreme poverty and hunger" (FAO, 2015), yet, by 2016, approximately 13 million Nigerians are reported to be suffering from hunger, associated to low agricultural growth, inadequate education services and poor infrastructure (FAO, 2017).

[26] ★regions sampled

[27] Also referred to as backyard farming in Nigeria, is referred to the production of animals and crops on a small piece of land without employing expensive or advanced technologies.

With an estimated population growth rate of 2.38%, the country's population is expected to reach 206 million by 2025 (Udo & Umanah, 2017). Both the FAO and the CBN (Central Bank of Nigeria) agreed that with only 2kg and 4kg of beef and egg per capita per annum respectively, the protein supply in Nigeria is insufficient (CBN, 2016; FAO, 2014). Similarly, local milk production is also insufficient and remains stagnant at about 0.57 million metric tons since 2013, while the estimated national milk requirement is at 1.45 billion litres (Udo & Umanah, 2017). This shows a deficit of 1.4 billion litres. Egg production is also not sufficient at 10.3 billion per annum to supply the growing population. In the same vein, the 2016 Nigeria Fish Statistics Report shows that the domestic production of fish from aquaculture, artisanal and industrial fisheries remain at 1.12 million metric tons, some 2.2 million metric tons less than the estimated demand of 3.32 million metric tons (FCWC, 2016). In light of all these, the average Nigerian is considered malnourished with regards to essential amino acids and protein intake. To ameliorate this issue, the federal government and other stakeholders must focus on improving the production of all protein-based agriculture products such as quality feedstuff, so that they can be available at an affordable price that the average Nigerian can afford.

6.2 Materials and Methods

6.2.1 Data Collection and Analysis

Primary data is used in this research. Preliminary data were collected by interviewing 31 smallholders involved in any of fish, poultry and/or ruminants farming from selected communities in the North Central part of the country. This involves random selection[28] of small-scale farmers in the states of Nasarawa, Niger and Abuja. The information collected from these farmers along with the literature review provide the basis for the design of the structured questionnaire used to collect data for this section. These were then used to obtain relevant data on geodemographic, psychographic (i.e. benefit sought, problem solved or perceptions), behavioural characteristics (i.e. brand loyalty, purchase frequencies etc.) of the respondents in connection with feedstuff, and other predispositions that farmers may have towards different types of feeds or feed materials. Data collected are subjected to mostly descriptive statistics; means, SD (standard deviations), frequency and percentages are used where appropriate to help describe the socioeconomic characteristics of livestock farmers among other qualitative variables related to animal farming.

[28] Based on nearness to the where the researcher is based, security (as some regions in Nigeria are currently unsafe due to terrorist attacks and tribal wars) and affordability to travel.

6.2.2 Results and Discussion

6.2.2.1 Socio-economic Characteristics of the Respondents

The percentage distribution of the socio-economic characteristic of the respondents are presented in this section. The sex, age, farm size, animal type and training/educational status of the animal and aquaculture farmers are expected to have some implications on their productivity, innovativeness, and technology adoption.

6.2.2.1.1 Gender of Respondents

The importance of the respondent's gender cannot be over emphasized, as it shows the sex dominance in the livestock farmer market within the study area. Despite the "sex ratio of the total population is 1.026 (1026 men per 1000 women)", the survey result (Table 18) showed that majority (83.7%) of the livestock farmers are male. This result corroborates the findings of a great deal of the previous work involving the socioeconomic status of farmers in Nigeria (Yunusa, 1999; Afolabi, *et al*., 2013; FAO, 2018; Mafimisebi, *et al*., 2013). For example, Afolabi *et al*. (2013) suggested that the heavy participation of Nigerian men over women in animal production (poultry) could be associated with the stress and rigor that characterises the animal production business, noting that in some cases however, the role of the proprietor is not labour intensive but managerial. Mafinisebi *et al*. (2013) research on cattle production in Nigeria supports this view asserting that "[...] considering the rigorous work involved in cattle marketing and the resultant stress to market participants, […] only active and strong women who are physically strong are able to cope with the operations in cattle marketing will dare to take part in cattle marketing". In contrast, the FAO (2018) asserts that women contribute 60-79% of agricultural labour in Nigeria and argues that their economic role continues to be inadequately recognised in the development of agricultural policies and programmes because of; "male-dominated cultures, which place women in inferior positions". As well as "custom, taboos and sex-based division of labour, which keeps women subordinate to men" and "the problem of the land tenure system and the inability of women to meet basic collateral security as bank requirements for loans intended for agricultural production" (Mtsor & Idisi, 2014). According to the FAO, maximum benefits could be amassed by appropriately addressing the prevalence of gender stereotypes and gender disparity – especially regarding women involvement in Nigeria's livestock sector. Assan (2014) holds similar view.

Table 18: Gender Distribution of Respondents

Farmers characteristics	**Total Responses**	
	f	%
Sex		
Male	87	83.7%
Female	17	16.3%

6.2.2.1.2 Age of the Respondents

In marketing research, the age bracket of the respondents is a vital factor since it could impinge on the efficiency level of individual market participant. In line with Mafimisebi, *et al*. (2013), it is logical to assume that the efficiency and/or productivity of an individual respondent will decline with increase in age due to the labour-intensive nature of livestock farming. Table 19 indicates that the majority of the respondents are between the ages of 25-44 years while 7.7% are between the ages 18-24 years. This implies that small-medium scale livestock farming in Nigeria is common among younger people unlike those above the age 55 years, which represents 8.7% of the respondents. The ages range from 25 to 44 years indicates that a majority of the respondents fall within the proportion of Nigeria's population that is involved in the production and distribution of goods and services (i.e. economically active age), which is expected due to their efficiency and productivity in the energy sapping and rigorous livestock farming occupation. Yunusa (1999) in his study of rural livelihood in the north central or middle belt of the country referred to Nigerians in this age bracket as motivated, innovative and adaptable. Aromolaran *et al*. (2013) holds similar view. Similarly, the low response rate from the age group 18-24 years can be associated with fact that the majority (70% according to the FAO (2019)) of the unemployed population in the country are youth, due to inadequate skills.

Table 19: Age Distribution of Respondents

Farmers characteristics	Total Responses		Mean
	f	**%**	**(x)**
Age group			
18-24	8	7.8%	21
25-34	38	37.3%	29.5
35-44	33	32.4%	39
45-54	14	13.7%	49.5
55-64	9	8.8%	59.5
Sample Mean (x̄)	**37.3**		
Standard Deviation (SD)	**10.5**		

6.2.2.1.3 Livestock Sector of the Respondents

The distribution of the livestock sectors of the respondents as revealed in Figure 14 shows that the majority (48%) of the respondents were poultry farmers while 29% and 23% are ruminants and fish farmers respectively. These findings are consistent with of Kryger et al. (2010) who found that approximately 80% of farmers in sub-Saharan Africa (including Nigeria) are engaged in smallholder poultry production. According to the USDA (2016), the dominance of poultry farming over say aquaculture or ruminants (found in this study) might be attributed to government support through initiatives such as the Agriculture Promotion Policy (APP), which is concerned with improving the poultry sub-sector value chain activities in the country. Moreover, this can also be because poultry have the highest population of all the livestock in the country, with chicken being the most common (Pagani, *et al*., 2008).

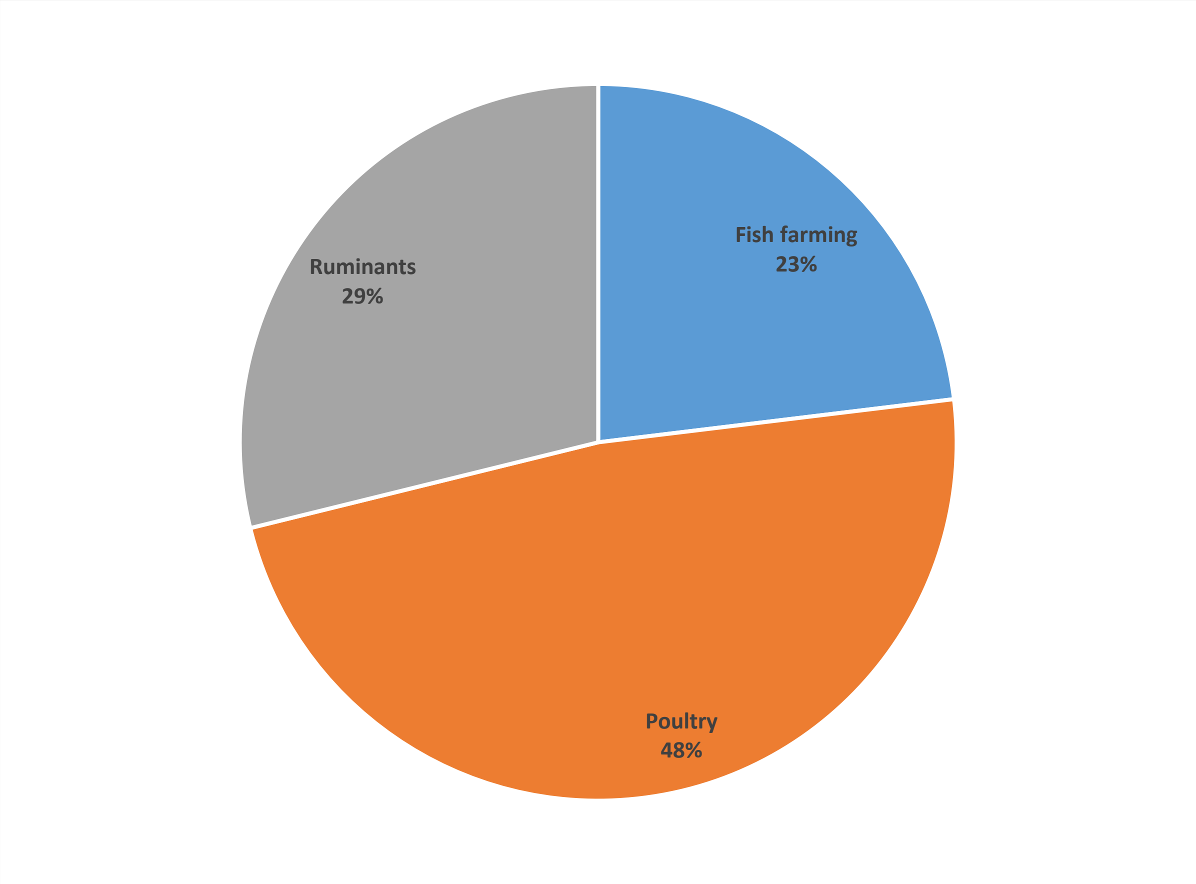


Figure 14: Animal Farming Sectors of the Respondents.

In accordance with the present results, previous studies have demonstrated that ruminants are as ubiquitous as poultry in Nigeria, but not as numerous (PT, 2016). Results from the survey also showed that the minority (23%) of those who responded to the survey were fish/aquaculture farmers. This low response rate from fish farmers matches those observed in earlier studies. For example, in 1984, UNCTAD/GATT reported that the approximate shares of livestock farming and the resultant feed production in Nigeria were poultry (90%), cattle (7%), pigs and other animals including fish (3%). Similarly, Fagbenro & Adebayo (2005) assert that the Nigerian aquaculture industry represents less than 1% of the national animal/feed production while Poultry represents an approximate 68%. In the same vein, studies by AIEP (2004) and Udo & Dickson (2017) shows that fish farms are mostly concentrated in the South-South and South West Zones of Nigeria (see Figure 15 below), not covered in this study due logistics, security, time and financial limitation.

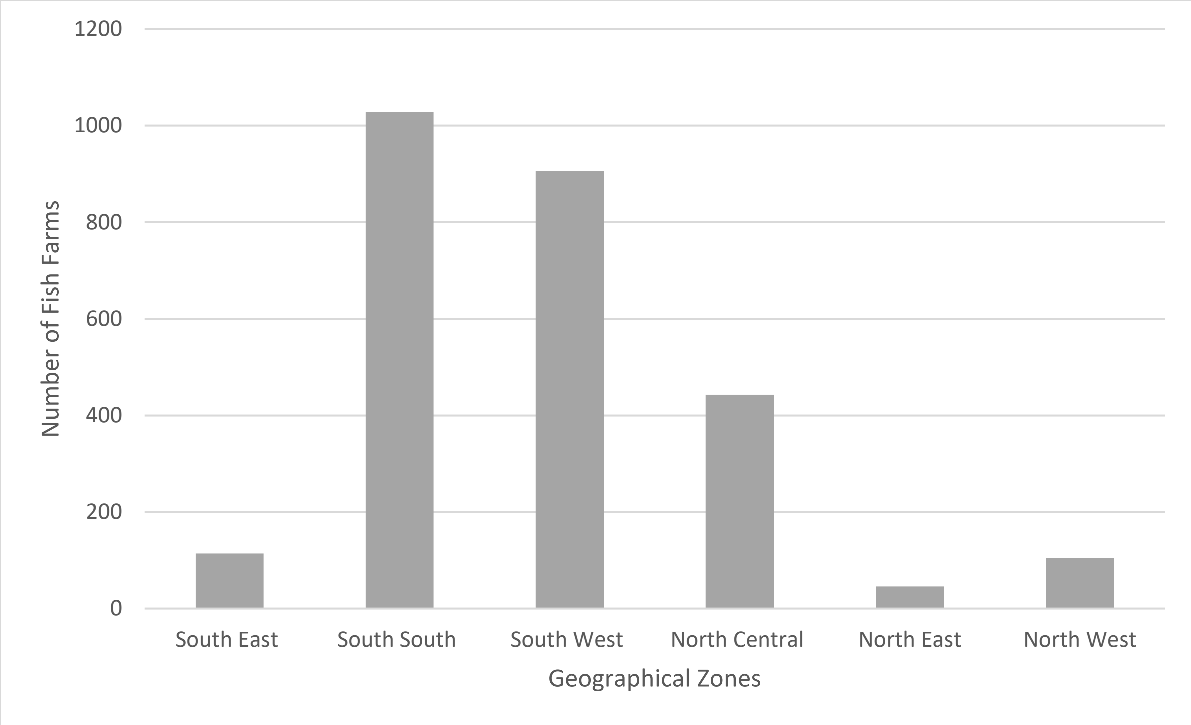


Figure 15: Distribution of Fish Farms in Nigeria by Geographical Zones (Adopted from Udo and Dickson (2017))

6.2.2.1.4 Farm Size of Respondents

It is reasonable to assume that the larger the number of animals in a farm, the more the feeds utilised as well as the commitment of the respondents to the farm. Therefore, the size of the farm determines the quantum of animal feeds available for use by the respondents. Thus, information on the number of animals can be of value as an indicator of the volume of feeds purchased per head of livestock. The results presented in Table 20 showed that 91 and above livestock formed the majority (31.7%) of the total number of the respondents, closely followed by those with 31-60 (flagged 30%) and 61-90 (flagged 24%). Respondent with 1-30 livestock constituted the lowest proportion of the sample (flagged 13.5%). Taken together, the implication of these results is that a significant amount of the respondents operates in small-scale commercial and “backyard” farming sub-sectors (Pagani, *et al.*, 2008). According to Hale *et al*. (2011), in small-scale livestock production feed is the largest investment in the long run. The authors went on to say that “feeding an animal correctly (the right amounts of nutritious feed) and economically is often a challenge, but proper nutrition is essential for health and productivity. Akanni (2007) associate the dominance of small-scale farming in Nigeria to lack of funds required to raise larger number of animals. Unfortunately, the number of animals (i.e. the scale of the business) also influences the cost of feed. Small-scale farmers that form the majority of the participants in this study would not be purchasing feeds by the ton due to the scale of their business, and thus, will lose some efficiencies of scale. Microalgae could make a great addition to the small-scale specialty livestock farming operations by helping in the enterprise diversification and income streams, through bioremediation of animal wastewater[29] and providing nutritious feed for livestock.

Table 20: Business Size of Respondents based on Number of Animals

Farmers characteristics	**Total Responses**		**Mean**
	f	**%**	**(x)**
Number of animals			
1 to 30	14	13.5%	15.5
31 to 60	32	30.8%	45.5
61 to 90	25	24.0%	75.5
91 or above	33	31.7%	105.5
Sample Mean (x̄)	**67.7**		
Standard Deviation (SD)	**31.6**		

6.2.2.1.5 Years of Experience in Animal and Aquaculture Production

Years of farming experience is one of the bases for success and progress in any endeavour and plays a pivotal role in business. In agriculture, lack of experience[30] has been shown to influence outcomes through low production and farmer's income (Mafimisebi, *et al.*, 2012). Anecdotally, the more experienced a respondent is in animal farming, the greater the efficiency of that farmer. Table 21 shows that 17.3% had less than 1 year, about 38.5% had 1 to 5 years, 26.0% had between 6 to 10 years, 9.6% had 11 to 15 years, and only 8.7% of those who responded have 16 years or more livestock farming experience. Therefore, approximately 44.2% of the respondents have animal farming experience of 10 years or more. The implication of this distribution is that respondents are expected to have extensive skills that are required for successful livestock farming, considering their years of experience (i.e. > 10 years). This is a desirable development as managerial knowledge, which is vital for profitable livestock production is achievable through years of experience of farmers (Fetuga, 1992).

[29] However, further research studies are required to develop cost-saving cultivation systems for efficient biomass production, the selection of microalgal strains with value-added components for both wastewater remediation and animal feed production, advanced harvesting technologies to simplify the harvesting process/cost, and feed standards as well as the effects of microalgae on the growth of animals should be fully understood.

[30] Experience here refers to knowledge and skill sets gained over time, which enables farmers to adjust the processes of livestock production to contingencies and unintended effects. For instance, every livestock reacts differently to a new type of nutrient supply, with different outcomes in health, meat and milk production. Farmers learn over time (i.e. through practical experience) to adjust feed intake to these diverse reactions of the animals, but also to the available feed that changes with seasons and with harvest of crops (Stuiver, *et al.*, 2004).

Table 21: Years of Animal Farming Experience of the Respondents

Farmers characteristics	Total Responses		Mean Age
	f	%	(x)
Years of farming experience			
0 – 1 year	18	17.3%	0.5
1 – 5 years	40	38.5%	3
6 -10 years	27	26.0%	8
11 – 15 years	10	9.6%	13
16 years and above	9	8.7%	18
Sample Mean (x̄) (yr)	**6.1**		
Standard Deviation (SD)	**5.2**		

6.2.2.1.6 Animal Farming Training/ Literacy and Education Attainment of Respondents

Livestock farming training offers a wider range of diversification opportunities and advantages for success to farmers over un-trained ones. Formal training in animal husbandry and aquaculture could liberate farmers from harmful practices and ignorance, making them more likely to adapt animal *cum* crop production system such as the one suggested in this study (microalgae). It is expected that higher level of training attainment by the respondents could lead to better indulgence to new feed and feed material as well as new integrated farming system with microalgae. The level of formal training and/or education will for example have an impact on the degree to which farmers will be proactive in using new feed material and/or feed supplements, and receptive to innovative integrated farming with algae that could increase animal growth performance (Afolabi, *et al*., 2013).

Table 22: Livestock Farming Training Level of the Respondents

Farmers characteristics	Total Responses	
	f	**%**
Animal farming training/education		
Yes	39	37.5%
No	65	62.5%

Table 22 revealed that approximately 62.5% of the respondents have no formal training with regards to animal farming, while 37.5% had some form of formal animal farming training. This is not the best outcome as the potential to adopt new feeds or feed materials, as well as make farming decisions that could enhance livestock production is challenged by low training/education/literacy factors. Chapter 7 of this report presents the researchers attempt to investigate the production process capabilities of an existing open pond microalgae farm operated by local Self-Help Group (SHG) women in India with little or no education analogous to the result in Table 22 from Nigerian livestock farmers. The DMAIC model is adopted to examine the production process reliability and reproducibility (and thus transferability) of the case study microalgae farm.

6.2.2.1.7 Source of Capital and Proprietorship of Respondents

Access to sources of credit and loans for financing livestock production could have a major influence on farm performances as interest rates can affect the amount of funds available for investment and the revenue generated from animal cultivation. As shown in Table 23, the majority of the respondents (77.9%) do not have access to credit or loans while 22.1% do. Moreover, 56.5% of the 22.1% that have access to credit and loans obtain their capital from commercial banks, about 30.4% from cooperative societies, and only about 13.0% from government sources (local or state). These suggest that large percentage (77.9%) of those who responded relied on informal sources of credit or loans (e.g. personal savings and/or friends and relations) for financing their livestock business. These results are in support of Mafimisebi *et al*. (2010), who finds that majority of farmers in Nigeria relied on informal sources of credit because of their inability to cope with the high interest rates charged by non-federal sources such as a commercial banks and credit unions, as well as inability to present the required collateral security for private loans. Kamuanga *et al*. (2008) also support these findings stating that: “bankers still do not see the advantage of adapting their loans to livestock production cycles. For example, an egg producer can only begin to repay his loan after nine months, while bankers often require payments begin the month following the loan”. Likewise, cattle producers “report that bankers require payments [to] begin the second month after the loan, while they need to complete at least three feedlot cycles a year (nine months) before they are in a position to repay”.

Table 23 also indicates that level of proprietorship of the respondents; 85.6% of the respondents owned the farming operation they are involved in while 14.4% are employed as managers or workers. These results support the aforementioned findings that majority of the respondents invest their own funds into livestock production. Moreover, studies such as Mafimisebi *et al.* (2013) have shown that most livestock farms in Nigeria are family operated were each household member contributes to the farming activities as a stakeholder and potential inheritor of the farm, not as an employee. The majority of the respondents do not belong to any cooperative societies (flagged by 76%). Okoli (2018), attributed this to “weak financial strength of the society, poor management of the society, lack of basic infrastructures, fraud and financial malpractice [as well as] limited loans and savings” [opportunities to farmers].

Table 23: Access to Credit/Loan and Livestock Proprietorship of Respondents

Farmers characteristics	Total Responses	
	f	%
Access to Credit/loans		
Yes	23	22.1%
No	81	77.9%
Source of Credit or loans		
Bank Loan	13	56.5%
Government sources	3	13.0%
Cooperative societies	7	30.4%
Farm Proprietorship		
Yes	89	85.6%
No	15	14.4%
Cooperative society membership		
Yes	25	24.0%
No	79	76.0%

6.3 Obtaining the Voice of the Customer & Critical to Quality Requirements

Throughout this report, the researcher makes several references to the "Voice of the Customer" (VoC) and "Critical to Quality" (CtQ). The VoC helps in examining farmer's feed requirements. In this research, moreover, it represents the information coming from the respondents (i.e. animal farmers) that enables the researcher to determine the farmer's CtQs. The CtQs are important elements in LSS that provides basis for assessing how open pond microalgae culture could be modified to accommodate animal farmer's requirements in Nigeria. This section looks at how the VoCs are obtained for this study and developed into CtQs for the case study analysis in Chapter 8.

6.3.1 Animal Feeds Purchase Behaviour of Respondents

Customers engagement in purchasing products is part of a complex decision-making process, as every purchase is different and requires different amount of time and effort. According to Armstrong *et al.*, (2012), a decision making process involves five stages during which customers recognizes the need, collect information, evaluates alternatives and make purchase decision before the actual purchase. Moreover, post purchase behaviour where farmers evaluate the product satisfaction level is also important. Although customer can skip some of the aforementioned stages during routine purchase such as feeds for daily operation in the farm, when faced with a new and innovative product like microalgae, all of these purchase stages need to be considered (Kotler & Keller, 2011).

6.3.1.1 Need Recognition and Problem Awareness of Respondents

Recogninsing a need or problem can be triggered by stimuli (i.e. internal e.g. hunger or external e.g. advertisement) (Munthiu, 2009). The survey results showed that the majority (62.5%) of the respondents prefer to purchase feeds for their livestock while 37.5% formulate their own feeds. In this connection, one farmer states: "*Its hard to make any sort of profit if i do not formulate my own feeds. However, the growth rate of the animal is not as good compared to branded commercial feeds. We have cases in this community (Abuja) were after selling the livestock, the farmers find it hard to break-even the amount of money they invested in feedstuff*" (interviewee No. 4).

Another participant of the preliminary interviews of this study added that: "*I use foreign brand feeds like Coppens or Skrettings when the animals (fish and poultry) are still young (for the first 4 months) because imported feeds demonstrate better growth (probably because the local brands marketed nutritional contents are not always correct!), and then switch to our own locally produced feeds when the animals are bigger*"(interviewee No. 1).

The aforementioned farmers' statements among others (see Table 49 in the Appedix for other farmers statements) coupled with the survey results indicate that animal farmers in Nigeria recognised both the need for better quality feeds as well as the problem of return on investment (ROI) when expensive branded feeds are used.

Figure 16 below indicates that most of the respondents who formulate their own animal feeds uses crop residue (flagged 71.8%) followed by sorghum/maize (flagged 41.0%), and vitamins and minerals premix (flagged 51.3%). While about 20.5% add groundnut cake, 15.4% add blood meal, 10.3% add soybean meal, and only 17% include fishmeal when formulating feeds. Abowei & Ekudo (2011) and Udo & Umoren (2011), support this results and assert that traditional low quality feed ingredients such as crop residues are commonly used in on-farm animal feed production in rural communities of Nigeria and among low income farmers actively engaged in livestock production. The implication of these results is that homemade livestock feeds do not contain adequate dietary amino acids (the building blocks of proteins), lipids and essential fatty acids due to low amount of feedstuff like fishmeal, soybean meal, and groundnut meal. According to Udo & Umanah (2017), poor quality local feeds (containing mostly crop residue) currently used by farmers sparks mortalities, aggravates low productivity and consequently lead to low rate of ROI. However, using locally available materials reduces the cost of producting feeds and has "impact on the innovations and growth of micro-technologies as most […] farmers are already making different [feed composition] trials on farms for increased output" (Ahmad & Ibrahim, 2016).

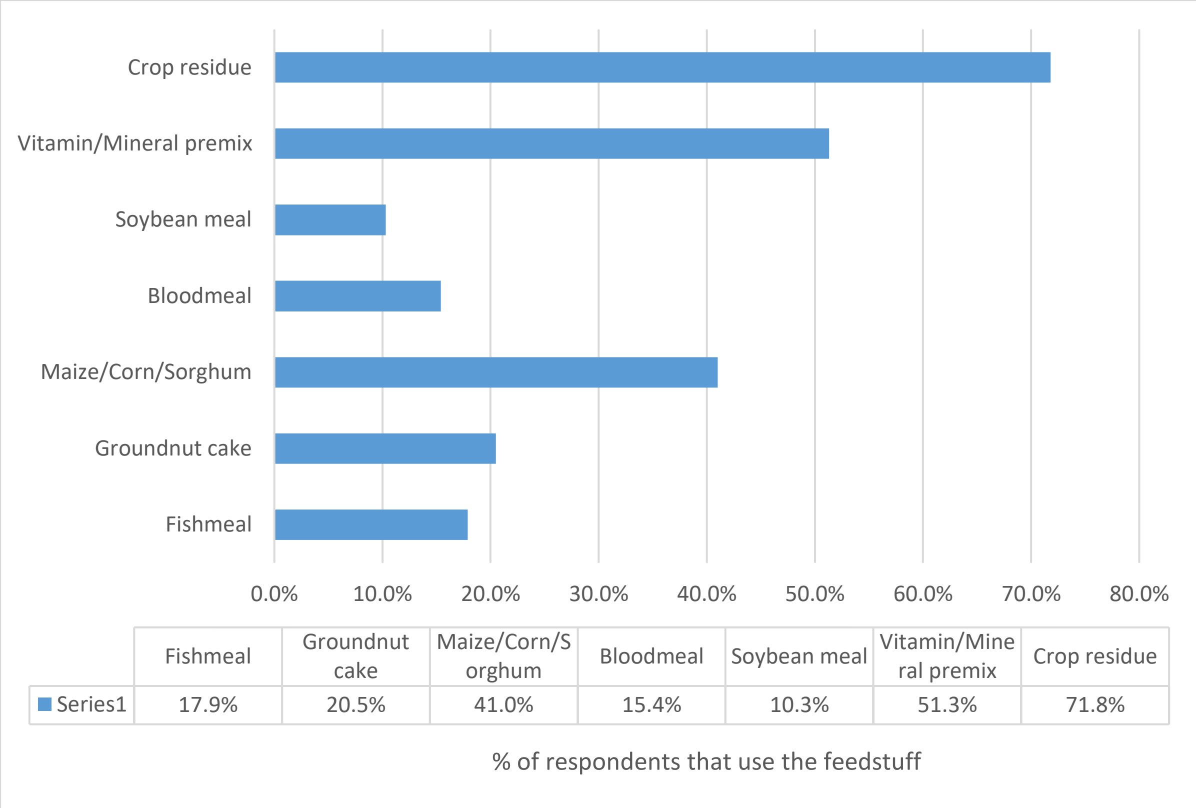


Figure 16: Levels of Feed Materials used in Local/on-farm Feed Formulation.

The survey (see Table 24 below) further shows that more than half (58.7%) of the respondents supplement their animals while 41.3% do not. The most common feed supplements according to the respondents are any type of straight, blend or compound concentrate (flagged 55.7%), followed by roughages (flagged 36.1%). Duguma & Janssens (2016) also found that 55.6% of livestock farmers in developing countries used concentrated supplements such as groundnuts cake (flagged 20.4%), cotton seed cake and molasses (flagged 7.4%). Other farmers (4.9%) use improved fodder crops e.g. wholecrop cereals and maize sillage while (3.3%) add vitamin supplements in their animal diets. On the other hand, 65.1% of the 43 respondents that do not supplement their livestock are interested in feed supplementation. These imply that, although crop residue accounts for an enormous 71.8% of on-farm or farm made animal feeds, the respondents appear to understand that this type of feedstuff is mostly made up of NFE[31] and low in proteins and lipids and thus understand the need for animal supplementation. Mustapha *et al.* (2014) supports these findings and asserts that local feeds are saturated with an inbalanced carbohydrate (69.90%) and crude fibre (2.88%) ratio resulting in mortality.

[31] Nitrogen-free extract (NFE): made of up sugars, carbohydrates, starches, and a high portion of hemicellulose in feeds.

Table 24: Types of Feed Supplements used by Respondents

Livestock Supplementation	Total Responses	
	f	%
Animal feed supplementation		
Yes	61	58.7%
No	43	41.3%
Types of supplements		
Roughages/fibre	22	36.1%
Concentrate (straights/blends/compounds)	34	55.7%
Improved fodder crops	3	4.9%
Vitamins	2	3.3%
Interest in supplementing animal diets		
Yes	28	65.1%
No	15	34.9%

6.3.1.2 Access to Information

Although in some cases consumers can choose a product or service without any information, most of the times information needs to be sought to identify alternatives (Solomon, 2016). Livestock farmers can obtain information from multiple sources by speaking with family members and fellow farmers, radio programs, and extension agents. Access to information by farmers in Nigeria has been extensively explored in the literature with consistent results and thus not part of the present survey (Olajide, 2011; Galadima, 2014; Adetimehin & Okunlola, 2018). For example Adetimehin and Okunlola (2018) found that the "key sources of information used by farmers in Nigeria were friends and relatives, and radio". Similarly, Olajide (2011) also found that "fellow farmers (76.3%), extension agents (63.3%), friends (49.2%), and radio (48.3%) readily served as information sources for farmers". Galadima (2014) also corroborate these findings and adds that "irrelevant information; delay on information delivery, extension workers' personalities, and lack of feedback mechanism […] [can] constrain […] farmers access to information [in Nigeria]". Nonetheless, access to information such as advertised (or labelled) nutrient constituents might help farmers to drop some brands and/or feedstuff when making final decision on what to purchase or use in feeds (Armstrong , *et al.*, 2012).

6.3.1.3 Evaluation of alternatives & Making Purchase Decision

Another important stage in the purchase decision making process is evaluating alternatives and making purchase decision. In this study, perceived benefit of key nutrients in livestock and aquaculture dietary feed compositions[32], (which farmers are generally informed about through any of the abovementioned information sources) were measured using the scaling choises; very beneficial = 1, beneficial = 2, somewhat beneficial = 3, neutral = 4, and not beneficial = 5. See Figure 17 below. Moreover, the distribution of the mode of purchase of the respondents as revealved by the survey of the study shows that 81.5% buy feed via cash at retail prices (locally referred to as cash and carry), indicating that only 18.5% acquire feeds on credit locally referred to as "pay as you go" by local farmers. In addition, the majority of the respondents (44.6%) purchase feed at least once a month while 41.5% purchased on a weekly basis, 9.2% biweekly and only 4.6% buy feeds twice a month. However, these responses on purchase frequency were complemented by comments from some of the farmers during the structured interviews. For example, Interviewee No.5 asserts that: "*It depends on the amount and age of the livestock I have in the farm. However, adult animals eat more feed. This is true for both my poultry and fish farms. It is one of the biggest challenge that "we" face here, as most of "us" make feed estimations based on early stage of the stock consumption rate only to find that adult animals consume more*".

Table 25: Mode and Frequency of Purchase of Respondents

Purchase pattern	Total Responses	
	f	%
Mode of Purchase		
Retail/" cash and carry"	53	81.5%
Credit/" pay as you go"	12	18.5%
Rate of purchase		
Biweekly	6	9.2%
Weekly	27	41.5%
Monthly	29	44.6%
Bimonthly	3	4.6%

The percentage distribution of the perceived importance of nutritional constituents of feeds as one of the criteria for evaluating alternative feed brands are presented in Figure 17 below. The majority (69.3%) of the respondents consider crude protein level as very benefial to their livestock performance, followed by information on the level of crude fibre (40.0%), lipids/fat (41.1%), and NFE (Nitrogen-free extract consisting of carbohydrates, sugars, and starches) level to decide what feedstuff to buy. In this vein, most (43.7%) of the respondents contemplate brand quality prior to feed purchase.

[32] Such as crude protein, lipids/fat, crude fibre, ash, and moisture labelled on all feed products.

The majority (73.1%) of them also described quality as “faster growth rate” or “high protein content”, 14.4% view quality feeds as that which improve animal immunity to diseseas, and only 12.5% describe quality feeds as containing balanced nutritional contents. Moreover, 25.2% consider brand availablity as their key deciding factor for purchasing feeds, 24.3% consider price of feed and only 6.8% are concerned with the logistics. See Figure 17 and 18 below. These results do not support previous research by Obe & Omojola (2015) and Udo & Umanah (2017), who found that, although feed “quality is considered to be one of the major factors influencing the success of [animal] production”, cost of feed and feed materials (due to devaluation of the naira, see economic factors in the PESTEL analysis in Chapter 2) has risen by up to 80 – 100% making feed price the most challenging factor facing the Nigerian livestock industry.

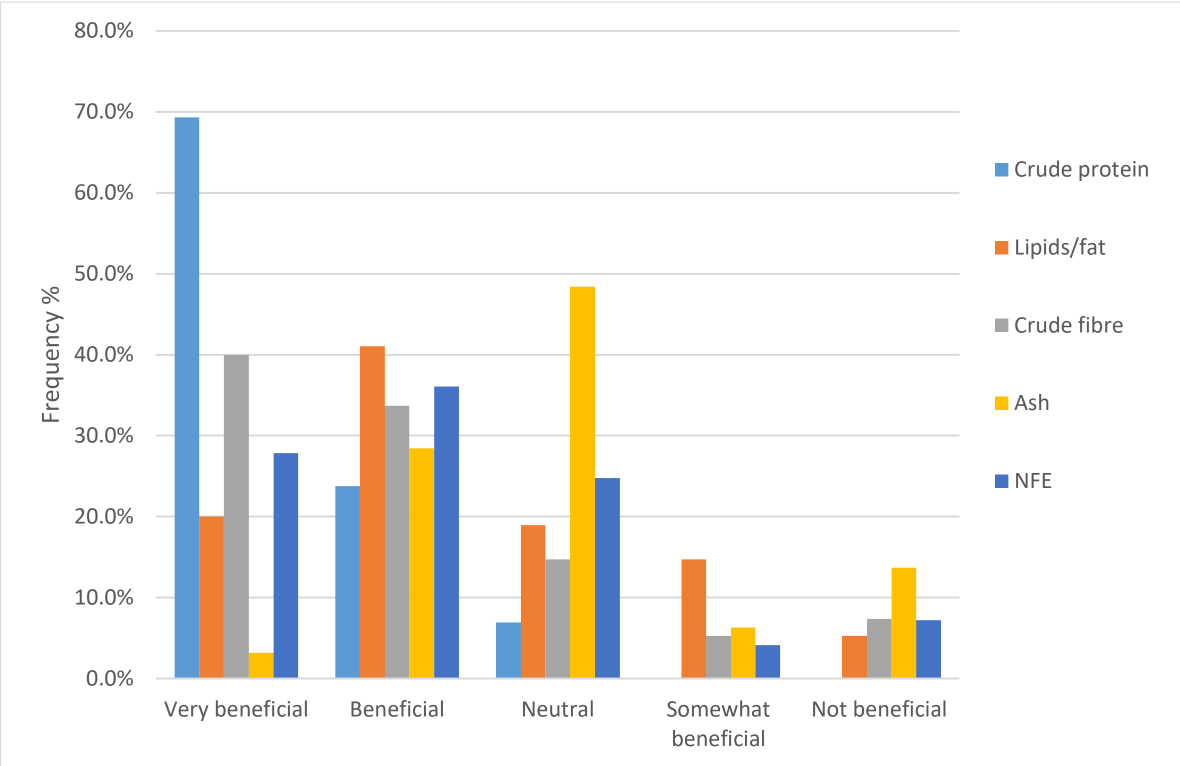


Figure 17: Perceived Benefits of Different Feed Nutritional Constituents

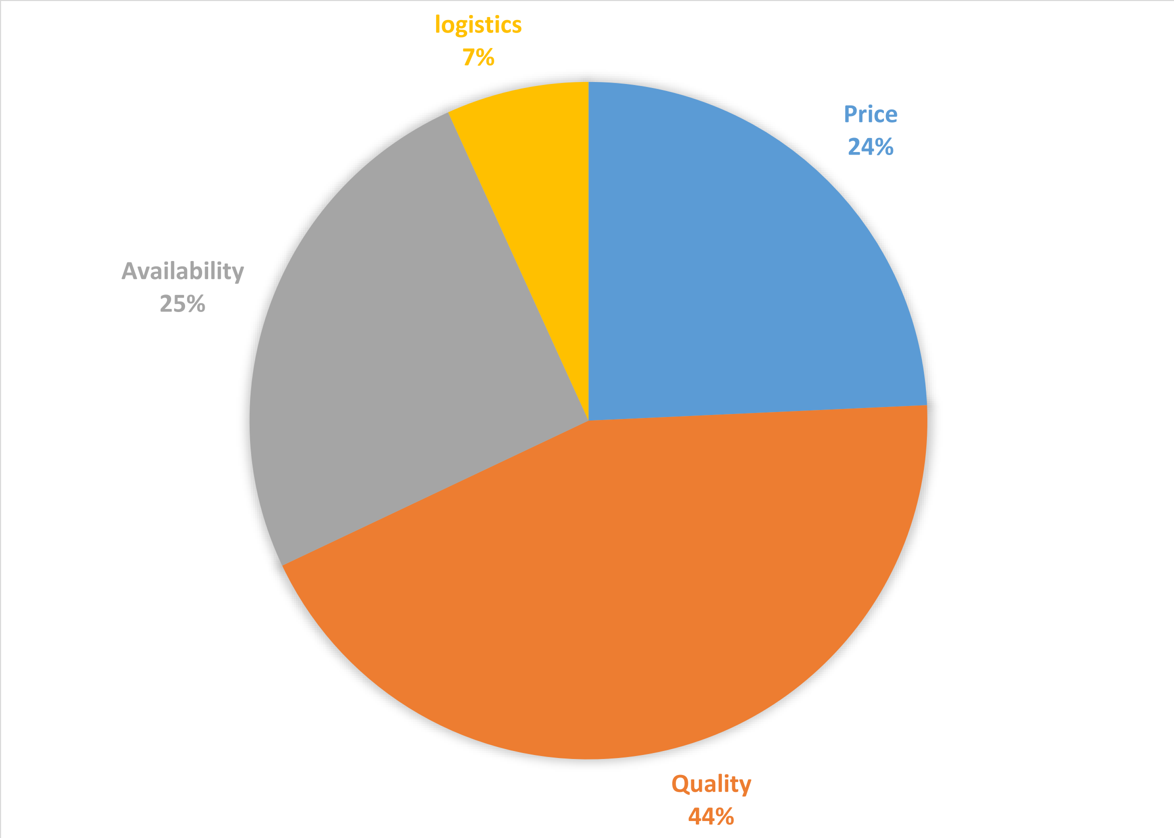


Figure 18: Respondents' Criteria for Choosing Feedstuff

Another criteria used to evaluate which feedstuff to buy is whether the brand is made locally or imported. The survey results shows that majority (83%) of the respondents use local feeds brands while only 17% use imported feeds. This is because farm made and/or locally manufactured feeds "are cheaper than commercial [imported feeds] […] little wonder [why] local farmers have preference for them [as] they remain the only option for semi-intensive farmers in Nigeria" (Udo & Umanah, 2017). Yet, significant amount of farmers used imported feed during the early stage of the animal life due to better growth performance compared to local feeds (Mustapha, *et al.*, 2014). The impact of imported feed brand (Coppens) as compared to local feeds can be seen Figure 19 below.

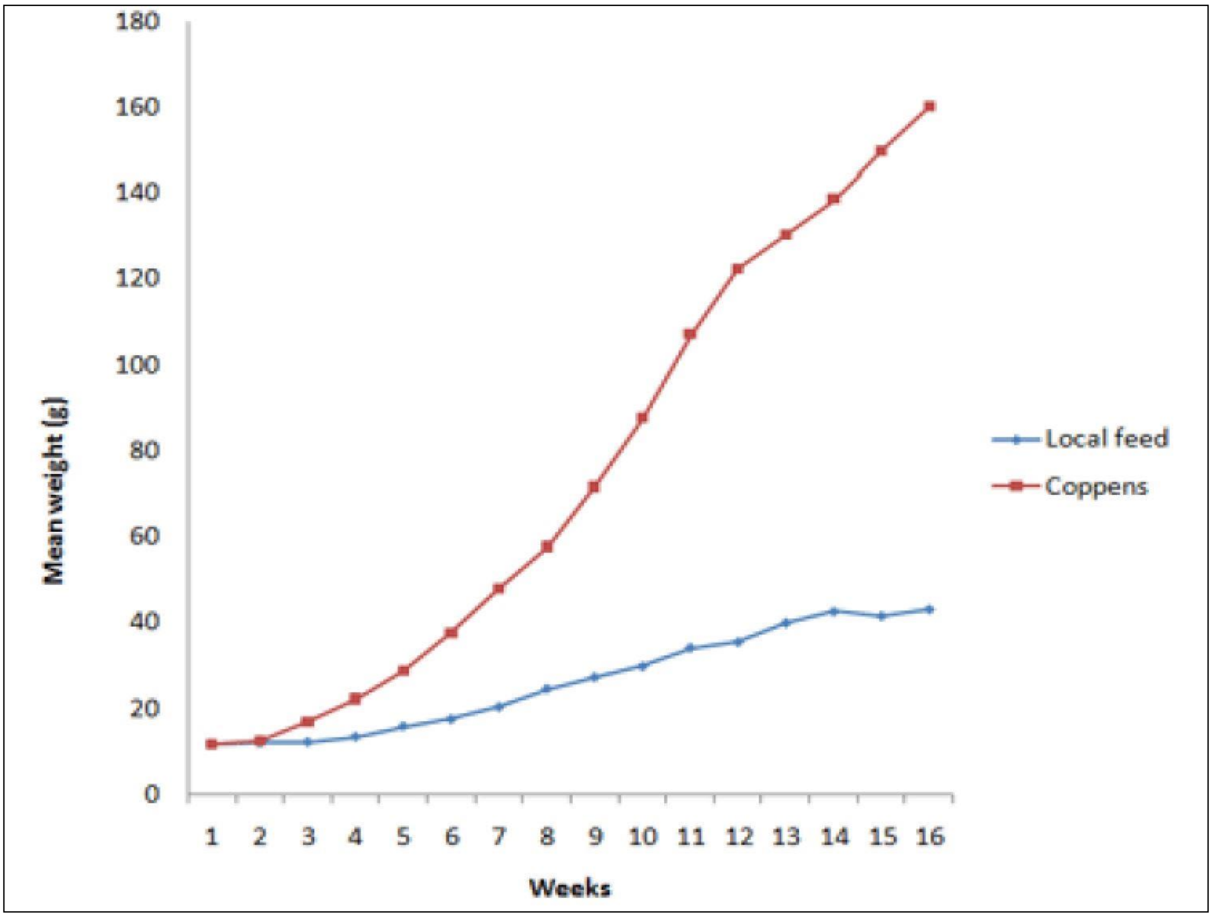


Figure 19: Growth Performance of Animals (fish) Fed with Local Vs Imported Feed (Coppens) (Mustapha, *et al.*, 2014).

Subsequently the brands' marketshare of the readily available animal feeds (especially in poultry and aquaculture) in Nigeria is highly influenced by the advertised/marketed level of the nutritional constituents and has less to do with whether it is imported or locally produced. Figure 20 below presents feed brands that are active in Nigeria (by marketshare in %). It can be seen that the top six brands that capture the market are evenly distributed between imported and local brands. The most common brand of feed used by the respondents is Coppens-imported (flagged 26.3%), followed by Skrettings-imported (18.4%), Topfeeds-local (17.1%), Aller Aqua-imported (13.2%), Bluecrown-local (11.8%), and Vital feed-local (7.9%).

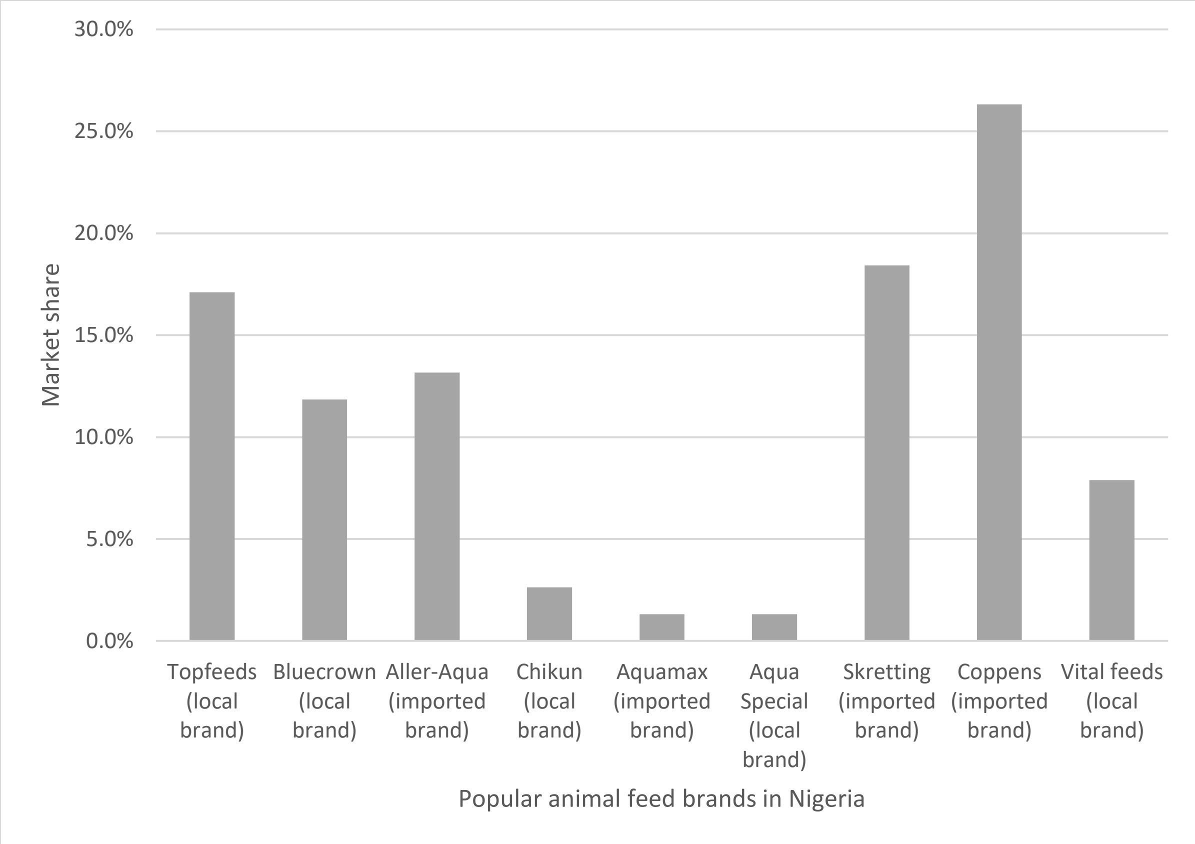


Figure 20: Animal Feeds Market Share Based on Rate of Purchase by Respondents (Source: Author)

The advertised nutritional constituents of the aforementioned feed brands are shown in Table 26 below. The results shows that the high/quality crude proteins and fat contents of the feedstuff correlate with the top six products with the highest marketshare shown in Figure 20 above.

Table 26: Nutritional Constituents of Animal Feed Brands in Nigeria (Source: Authors')

Feed Brands	**Type**	**Crude protein**	**Crude fat**	**Crude fibre**	**Ash**	**NFE**
Topfeeds	Local	_	_	_	_	_
Bluecrown	Local	40.0%	12.0%	12.0%	8.0%	
Aller-Aqua	Imported	45.0%	12.0%	26.4%	6.0%	26.4%
Chikun	Local	15.0%	4.0%	6.0%	_	_
Aquamax	Imported	40.0%	12.0%	2.6%	8.0%	_
Aqua Special	Local	_	_	_	_	_
Skretting	Imported	42.0%	10.0%	3.2%	7.0%	_
Coppens	Imported	56.0%	15.0%	0.2%	11.0%	_
Vital feeds	Local	_	_	_	_	_

According to Interviewee No. 8, "*quality is high protein content that can help build the body of the animal. Protein sources are the most difficult ingrediant (both in terms of availability and price) to attain when formulating my own on-farm feed. Other feed materials are easy to find locally and are* *not expensive. local feed manufacturers may say that their product contained 42% crude protein, however, out of this only 20% is actually real protein from fishmeal*". Mustapha *et al*. (2014) comaprative study on the effect of local and imported feeds on animal growth in Nigeria supports this claim. The authors find that animal "growth performance was a reflection of the proximate composition of the feeds, with local feed having low crude protein (10.95%), lipid (3.95%) and ash (4.92%) when compared to [foreign/imported feed] which had 42% crude protein, 12% lipids and 9.5% ash with protein being most significant".

6.3.1.4 Respondents' Familiarity with Microalgae

There are two approaches for operationalising and measuring product familiarity. One is by measuring the familiarity in terms of how much a consumer knows about the product; and two is to measure familiarity in terms of how much consumers think they know about the product (Park & Lessig, 1981). In this study, the former approach where the knowledge of a customer's long-term memory is examined is embraced. Table 26 indicates that most (83.5%) of the respondents were unfamiliar with microalgae while 16.5% are familiar with some type of alga (especially *Spirogyra)*. According to Prakash & Thukral (2015), "it is likely that varying levels of familiarity create varying levels of product expectations, and these expectations and their confirmation, in turn, create varying levels of satisfaction". The authors added that, "it is possible that familiar customers have more realistic expectations which lead to greater satisfaction than what less-familiar customers experience". Hence, the implication of these results is that, although farmers with higher levels of familiarity (with algae) will have more realistic expectations and take shorter time to decide on whether or not to try the new product (i.e. microalgae feedstuff or supplement), majority of the respondent (less familiar with algae) might create unrealistic expectations for the product. Moreover, the survey also shows that the majority (86.5%) of the respondents are interested in cultivating microalgae (plant) along with their livestock with 100% willing to undergo trainings in this regard. See Table 27 below.

Table 27: Familiarity and Interest of the Respondents to Microalgae.

Product Familiarity and Interest	Total Responses	
	f	**%**
Familiarity with microalgae		
Yes	17	16.5%
No	86	83.5%
Interest in livestock *cum* microalgae farming		
Yes	89	86.4%
No	14	13.6%
Willingness to undertake alga-culture training		
Yes	89	100.0%
No	0	0.0%

6.3.1.5 Potential Point of Market Entry

The point of market entry is the point where livestock farmers become receptive to new feedstuff. It is highly likely that farmers would not care about new feeds for their animals until periods when they experience feed shortage and/or higher market prices (Helfat & Lieberman, 2002). In order to find out which season(s) farmers are more likely to be susceptible to trying new feedstuff, the respondents were asked to choose the months in a year during which they experience feed scarcities. As shown in Figure 21, the majority (61.7%) of the respondents experienced feed shortages between the months of October and December while 18.3% between July and September. 16.7% of the respondents indicates that there are feed shortages between January and March, and only 3.3% farmers point to the months of April through June. These indicates that feed shortages in Nigeria occur during the dry season, which last from October to March in the North, and January to February in the Southern part of the country. During these months, the country experiences a fluctuating average maximum temperature between 28°C and 40°C (Terdoo & Adekola , 2014). Microalgae is said to grow in a range of temperatures from 5°C - 42°C with an optimum range between 20°C to 30°C[33] (Khatun, *et al.*, 1994), and thus, can be cultivated during the dry seasons when feed shortages are likely to occur.

[33] The optimum temperature for microalgae culture varies in the literature. For example, according to (Kitaya, *et al.*, 2005) it is between 27 and 31° C.

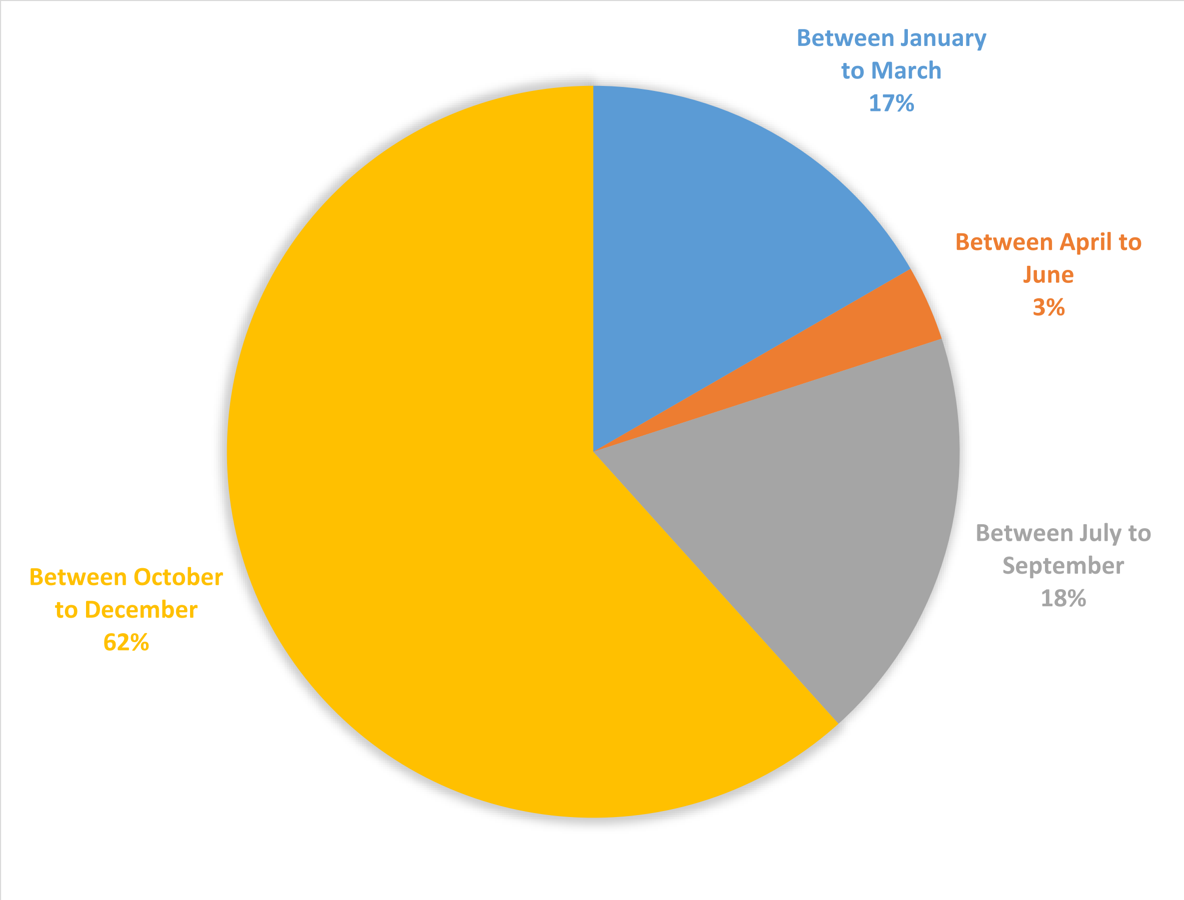


Figure 21: Potential Time of Entry into the Feed Market

6.4 Considering Critical to Quality Farmer's Requirements

After finding out what animal farmer's requirements are with regards to feeds through the survey results, the next step is to translate what the respondents say into measurable requirements or CtQ customer needs. The researcher gathers input from the survey respondents and preliminary interview participants in order to examine their needs and identify key issues, in order to translate them into meaningful and measurable terms in microalgae production. Collecting the VoC is about determining farmer's requirements for feeds, and not about determining solutions or jumping into conclusions about what they mean, since customers (farmers) may not be very clear about their needs. Hence, the researcher reflects on similar research findings in the literature to interpret the survey results. Table 28 shows the findings from the market survey sorted into various CtQ groups. Often during the researcher-administered questionnaires and interviews, respondents tend to jump to preconceived solutions and suggest them as part of their requirements. On these kinds of occasions, the researcher challenged the respondent's answers by asking them 'why?' until the requirement is clear. Below is an example from the market research of this study:

A local fish farmer said, "*We need access to more high-quality foreign feed brands in our area*". But why do you need this? "*Because I only use imported feeds. […] local brands and/or farm-compounded* *feeds require the use a lot of feeds in order to achieve the same growth rate as when I use Coppens or Skrettings* (both imported feeds)" (Interviewee No. 10).

Table 28: Determining the Voice of the Customer and Developing Critical to Quality

Voice of the Customer	Key issue(s)	Critical to Quality	CtQ Grouping	Measurements
1. Interviews (and additional comments during the RAQ surveys) with respondents indicates that livestock farmers tend to feed their young animals with imported commercial feedstuff viewed to have high quality ingredients up to around the 4th and 6th month and then turn to using self-compounded and/or local feeds to finish the growth cycle in order to safe on feed cost.	The price of high-quality feeds is too high for farmers to continue to use throughout the farming season(s).	Farmers' gets high quality feedstuff at a reasonable price. Or grow their own feedstuff to supplement the local affordable brands.	Economical	• Ratio of dry weight of microalgae (in kg) in cost terms to algae production risk rating. • Maximum RPN (Risk Priority Number) rating from the FMEA (Failure Modes & Effects Analysis) - a prevention technique covered in Chapter 8.
2. It was found from the market survey that; only a small percentage of the respondents have access to credit/loans. Majority of whom rely on informal sources of credit like family loans, due to inability to cope with the high interest rates charged by non-federal sources such as commercial banks and credit union, as well as inability to present the required collateral security for private loans.	Sufficient credit and/or loan facilities are not made available to livestock farmers in Nigeria.	Improve access to credit facilities through non-private government source for livestock farmers.	Political	• Percentage of federal credit/loan sources such as local and/or federal government. • Number of commercial banks and credit union with low interest rates.
3. Feed supplementation has become necessary as both local and on-farm feedstuff are found saturated with unbalanced nutritional constituents' ratio resulting in slow growth of livestock and/or mortality.	Farmers' want proteins and lipids rich feedstuff or feed supplements to balance the readily available NFE rich feed materials.	Farmer's livestock receives feed additives with high/required content of crude protein and fat.	Quality standards and Regulations	• Number of harvested microalgae biomass that meets the standard level of crude protein, lipids etc. • Number of contaminated microalgae slurry or inoculum (defects).

4. Although farmer's show high interest in microalgae and learning about alga-culture, the potential to adopt any new and/or innovative feedstuff such as microalgae, as well as make farming decisions that could enhance livestock production is challenged by low education/literacy/training level of farmers.	• Farmers' need to be adequately trained. • Need access to algae production trainings to assist with microalgae cultivation requirements and pond design.	Farmers' received algae farming training and mother culture strains to grow their own microalgae.	People	• Production processes repeatability and reproducibility (and therefore transferability). • Hours worked on training and learning with other daily obligations.

Livestock fed with local and/or on-farm formulated feeds ought to grow at a similar rate as those fed with foreign feeds, which comes under the Quality category of meeting the CtQ. Table 28 summarised and categorises the CtQs derived from the VoC process above. The researcher categorises the CtQs from the VoCs derived from the market survey into economic, political, quality and people. Chapter 8 employed lean 6 sigma's DMAIC cycle to analysis the production process of a microalgae farm in India focusing on the potential causes of failure[34] and repeatability and reproducibility of the processes[35] in relation to the literacy level of Nigerian farmers (people).

6.5 Concluding Remarks

The Interviewee's answer explained that the feed conversion ratio or feed conversion rate (FCR) is low when local or homemade feed are used compared to foreign feeds. This answer gives a real CtQ that farmers require feed materials with better efficiency with regards to how the bodies of livestock convert them into output. There are various solutions to meet this requirement without going to the expense of increasing feed importation and distribution within the country. But why do local or self-compounded feeds have low FCR? Figure 16 of this study shows that the majority of the respondents that formulates their own feed used unbalanced ratio of feed materials and subsequently nutritional composition of the feeds is not to standards. The results of the survey indicate that farmers used mostly crop residue (rich in carbohydrates and starch) to feed their livestock.

The next chapter presents the conceptualisation of a theoretical framework for implementing lean 6 sigma's DMAIC model in an open pond microalgae farm. The literature on LSS's DMAIC cycle as well as the process map of a small-scale microalgae production farm in India were discussed. The chapter further discussed the interrelationship between lean manufacturing and six sigma and demonstrates how the DMAIC cycle relates to the process map of a microalgae farm. The chapter also offers an introduction to the case study organization and defines and analyse its production processes. A capability six-pack analysis was undertaken on the harvesting processes (i.e. from harvesting through filtration to drying) to evaluate the major indices and to determine the stability of the processes undertaken, and whether they are "in control"/repeatable/stable and if the data follow a normal distribution or not.

[34] To examine activities that are "out of control" based on a capability sixpack analysis, which could lead to defectives products and high cost of failure.
[35] To examine transferability of activities from the human capabilities point of view.

Study Two: Process Analysis of Open Pond Microalgae Production System

Chapter Seven: Developing and Implementing Lean Six Sigma's DMAIC Conceptual Framework for/in a Case Study Open Pond Microalgae Farm

7 Introduction

Tight budgets and recurrent product innovations are some of the main indicators of a competitive industrial environment like the animal feed industry in Nigeria. In an attempt of achieve the fourth research objective – "to develop a conceptual framework for measuring process variation in open pond microalgae farm(s) based on lean 6-sigma (LSS) DMAIC model", the researcher conducts literature review on the evolution of Lean Six Sigma's (LSS) (see Chapter 2 for the theoretical background of lean and six sigma). The purpose of this chapter is to develop a conceptual framework for successful implementation of LSS's Define, Measure, Analyse, Improve and Control (DMAIC) cycle (pronounced də-MAY-ick) in a functioning open pond microalga-culture for human food so as to examine what process(s) could be eliminated (i.e. non-value adding), improved or modified to reduce the overall cost of production of the microalgae feedstock. LSS is a problem-solving methodology that has numerous approaches, depending on the issue being addressed. In this study, the method used is mostly from the six-sigma side (i.e. DMAIC cycle) supplemented by the lean approach. This chapter proposes a framework that is further implemented in a case study microalgae cultivation farm in India to bring about the required performance needed to compete in the animal production industry of developing countries.

The chapter also explore the transferability of an Indian open pond microalgae culture system for food into Nigerian feed market through the application of lean 6 sigma's DMAIC framework[36]. Process repeatability and reproducibility are measured and analysed using Capability Sixpack to assess the repeatability and/or transferability of the case study findings in India from the point of view of human capabilities – manpower in Nigeria. It is important to emphasise that the measurements taken and subsequently the capability sixpack results are predominantly focused on determining whether the processes are feasible from a human capability standpoint such as literacy level and skills required. The case study product quality (both in terms of protein level and sanitary requirements) is of higher standards compared to typical animal feeds products, as it is produced for human consumption (see Figure 57, 58, 59, 60 and 61 in the Appendix).

[36] Thereby attempting to answer the research fifth research question.

7.1 The Development of Lean Six Sigma (LSS)

Lean Six Sigma (LSS) is often viewed as a process improvement methodology that encompasses customer needs as well as business reinvention (Snee, 2010). Subsequently, conceptual insights from lean manufacturing and six-sigma management literature should provide insights to the optimisation of existing microalgae production system based on livestock feed requirements and/or farmer's preferences in Nigeria. In the late 1990s and early 2000s, the concept of lean and six sigma were integrated to become one of the international management phenomenon and process re-engineering methodology known as 'lean 6 sigma' (George, 2003). The concept combines lean's concerned with non-value added exertion to improve process efficiency with six sigma's focus on defects or non-conformities to reduce errors and improve effectiveness. In the literature, LSS implementation display a strong support for improving quality and productivity of a company. Alhuraish *et al*. (2016) assert that, implementing LSS is far more effective across financial and operational performance than implementing either LP or SS alone. However, the rate of performance improvement added Alhuraish *et al.* (2016), is contingent on the level of LSS tools utilised. See Figure 22 below for LSS tools.

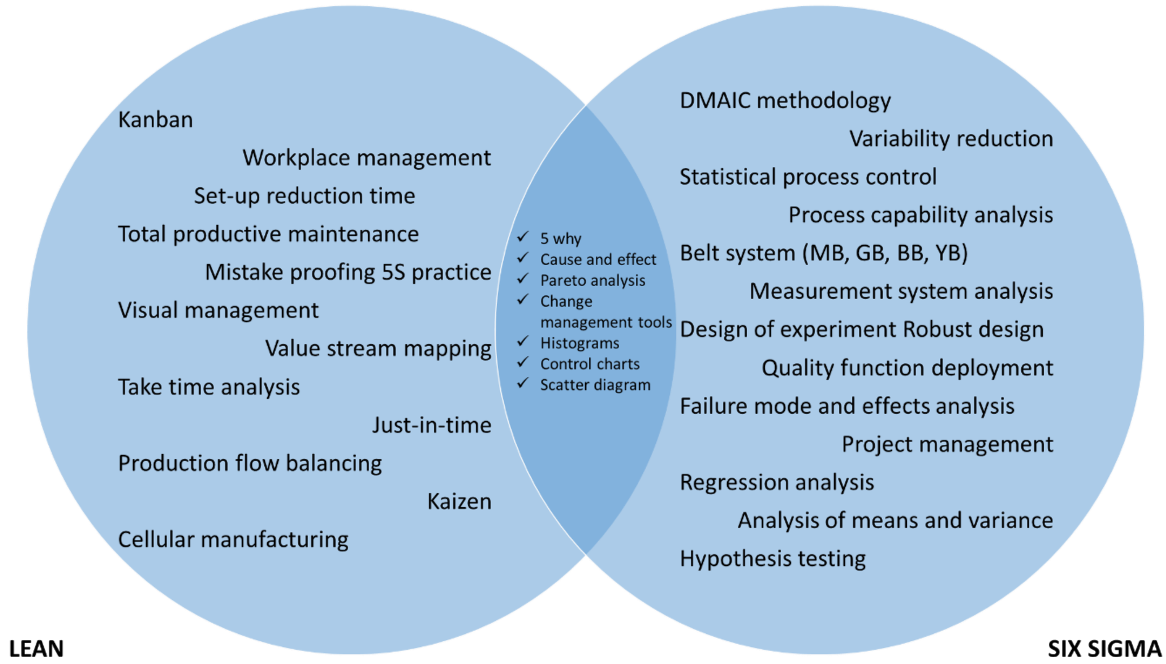


Figure 22: Lean and Six Sigma Tools and Techniques (Kumar, *et al.*, 2011)

According to Laureani & Antony (2012), LSS methodology focuses on business process improvement and targeted at improving customer satisfaction, speed, quality and reducing cost. Some researchers have argued that LSS is a repackaged form of TQM (Total Quality Management) (Kaynak, 2003) and JIT (Näslund, 2008), others however, such as Zu *et al*. (2008) indicate that although LSS uses common platform of practices, knowledge and resources from both JIT and TQM, it complements them with other tools and features to increase speed and accuracy. Thus, LSS is more of an evolutionary management methodology than revolutionary. Despite differences of opinion, there appears to be some agreement that LSS provides benefits such as increasing process performance (Snee, 2010); improving effectiveness and efficiency in operations; reducing waste and defects (Salah , *et al*., 2010); and improving process efficiency. Although developed to improve production/manufacturing quality, the methodology is increasingly been adopted and implemented by healthcare and other service industries (Waring & Bishop, 2010; Stanton, *et al*., 2014). For example, Stanton *et al*. (2014) examined an LSS based process improvement project in the emergency department of a large tertiary hospital where they considered the perspectives of both managerial and clinical employees. The authors found that LSS have positive implication on staff motivation and improves patient flow from the emergency department to the ward by reducing bottlenecks in other units. However, further analysis by the same authors indicates that these achievements tend to be the result of influential stakeholders and budget constraints, rather than LSS implementation. The authors went further to assert that LSS implementation in healthcare is more challenging and complex than in manufacturing due to relative autonomy and professional status of clinicians. Consequently, the questions of exploitation and/or empowerment are less applicable in healthcare LSS projects. Overall, despite some evidence of cost reduction, waiting time and error(s) along with increase customer satisfaction and workers motivation, whole production system improvements are influence by organizational structure, institutional and occupational demarcations, and the complexity of what constitutes farmers value(s) in relation to livestock feed quality.

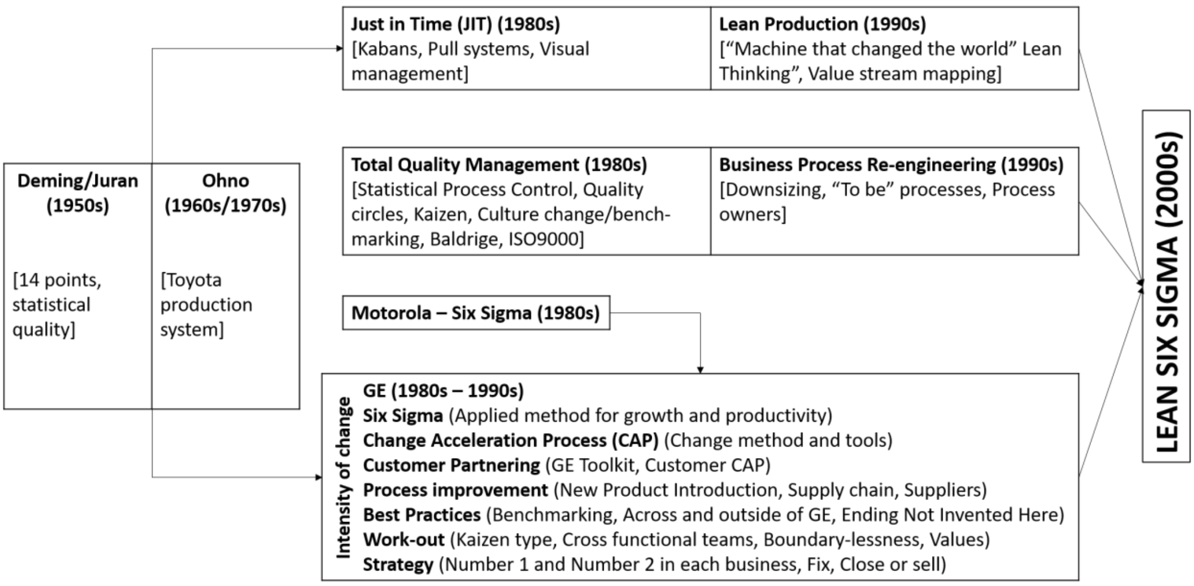


Figure 23: The Development of Lean Six Sigma from Different eras of Operational Improvement (Byrne, *et al.*, 2007).

Figure 23 above shows that after the introduction of the statistical methods by Deming's in the 1950s, the concepts where adapted and upgraded by Ohno in the 1960s and 70s within Toyota as the basis of their TPS program. Between the 1980s and 90s, techniques such as JIT, TQM, Six Sigma and Business Process Reengineering were developed. In the 2000s, LSS programme comes about as a synergistic amalgamation of the abovementioned improvement techniques. Large corporations have achieved great success through LSS implementation, as it helps in the discovery of innovation opportunities for new product introduction. This section of the research is focused on how the open pond microalgae cultivation industry that produces algae products for human consumption can introduce new product for animal feed.

The lean aspect of this study evaluates the production processes of open pond microalga-culture in India from the perspective of discovering and eliminating non-value adding activities (based on farmer's wants and needs) and processes as well as promote improved execution of the value-adding processes or tasks. Moreover, thorough investigation of the processes including the number of variations that occur over the period of a particular process and the way the processes are intended to work are also required for lean methodology. For instant, an open pond microalgae farm may have standard procedure for workers to harvest and dry biomass daily, however, because of drying machine failure or weather-related issues, the operation staff may have to develop numerous variations on the standard processes to accommodate customer preferences. These variations could reduce efficiency or increase cost, for example, resulted in high culture density, low light penetration in culture medium and slow growth. According to Lighter (2014), in nearly all production systems, process variation reduces efficiency by either increasing cost or decreasing throughput.

Complementary to the abovementioned lean concept, the six-sigma aspect in this study is concerned with detailed and accurate measurements of microalgae harvesting process and outcome variables together with analyses intended to discover those factors that are of great importance to meeting farmer's requirements and livestock needs. DMAIC cycle is an integral part of LSS's quality initiative and begins by studying the VOC (Voice of the Customer) that is then interpreted into CtQ (Critical to Quality) metrics (Gitlow & Levine, 2004), which serve as the output variables for the case study improvement project in this study. CtQs are influenced by the variables (critical x-values) of the process under scrutiny, which are the focus for intervention during the project *improve* phase. Knowing the relationship between the quality of microalgae biomass product and the critical x-values (process variables) could help to make predictions about the expected improvements in the outcome variables if/when future process change is deployed. Six sigma method persistently chase low level error rates as stated earlier, which are difficult to achieve, however, livestock and aquaculture CtQs may require less critical process variables and thus, could bring about the elimination of non-value adding process(es) compared to alga-culture for human food. LSS is therefore used in this study because it can help to address whether the cost/complexity of producing microalgae for food will reduce with change in target consumers from human to animals.

7.1.1 The DMAIC Cycle

Deming's plan-do-check-act (PDCA) cycle is the inspiration for the systematic six-sigma project management practice known as the DMAIC (define, measure, analyse, improve and control) cycle. According to De Mast & Lokkerbol (2012), DMAIC is a generic method that is versatile, but less powerful and specific in the guidance it can provide. However, the meta-routine nature of the approach is particularly vital for this study as it gives the opportunity to identify potential change within existing processes of an existing open pond microalgae production system. According to Mehrjerdi (2011), the empirical data-driven nature of the DMAIC approach together with its quantitative measures of the way a system performs to achieve a goal or reduce variation makes the method very powerful. Each stage of the framework has its corresponding tools and techniques for improving and sustaining process control. De Mast & Lokkerbol (2012) critically compares this method with scientific problem-solving theories to identify its limitation. The authors found that although DMAIC might be suitable to empirical well-structured and semi-structured problems tasks of a larger scope, it is not to pluralistic messes of subjective issues such as in people problem tasks of a smaller scope (i.e. ill-structured problems). Moreover, DMAIC is applicable to extensive problem-solving activities, requiring problem definition, diagnosis and remedy(s) design. Table 29 exemplifies the DMAIC steps taken in this study, tools employed and the deliverables.

Table 29: DMAIC Cycle, Tools and Deliverables for this Study[37] *(adopted from* Mehrjerdi (2011)

DMAIC stages	Prescribed Steps	Tools used by the researcher	Deliverable(s)
Define	**Define customer needs and requirements (CTQs)** Develop problem statement, goals and benefits Identify champion, process owner and team **Define resources** Evaluate key organisational support Develop project plan and milestones Develop high level process map	**SIPOC diagram** **DMAIC work breakdown structure** **CTQ definitions** **VOC**	Fully trained team is formed, supported and committed to work on improvement project Customers identified, and high impact characteristics (CTQs) defined, team charter developed, business process mapped
Measure	**Define defect**, opportunity, unit and metrics **Detailed process map of appropriate areas** **Develop data collection plan** **Validate the measurement system** **Collect the data** **Begin developing Y=f(x) relationship** Determine process capability and sigma baseline	**Process flowchart** **Data-collection-**plan/example Benchmarking **Measurement-system analysis** **VOC** **Process sigma calculation**	Key measures identified, data collection planned and executed, process variation displayed and communicated, performance base lined, sigma level calculated
Analyse	**Define performance objectives** **Identify value/non-value-added process steps** **Identify sources of variation** **Determine root cause(s)** Determine vital few x's, Y=f(x) relationship	**Histogram** Pareto chart **Time series/run chart** **Scatter plot** **Regression analysis** **Cause and effect diagram** whys **Statistical analysis** **Non-normal data analysis**	Data and process analysis, root cause analysis, quantifying the gap/opportunity

[37] The steps in bold have been adopted/tailored to the requirement of this research. while some of the prescribed steps do not apply for this research others require an extended period of time and money to implement, thus not adopted.

Improve	Perform design of experiments **Develop potential solutions** Define operating tolerances of potential system **Assess failure modes of potential solutions** Validate potential improvement by pilot studies Correct/re-evaluate potential solution	Brainstorming Mistake proofing Design of experiments Pugh matrix House of Quality **FMEA** **Literature review** Simulation software	Generate (and test) possible solutions, select the best solutions, design implementation plan
Control	Define and validate monitoring and control system Develop standards and procedures Implement statistical process control **Determine process capability** Develop transfer plan, handoff to process owner **Verify benefits, cost savings/avoidance, profit growth** Close project, finalise documentation Communicate to business, celebrate	**Process sigma calculation** **Control charts (variable and attribute)** **Cost savings calculation**	Documented and implemented monitoring plan, standardised process, documented procedure, response plan established and deployed, transfer of ownership

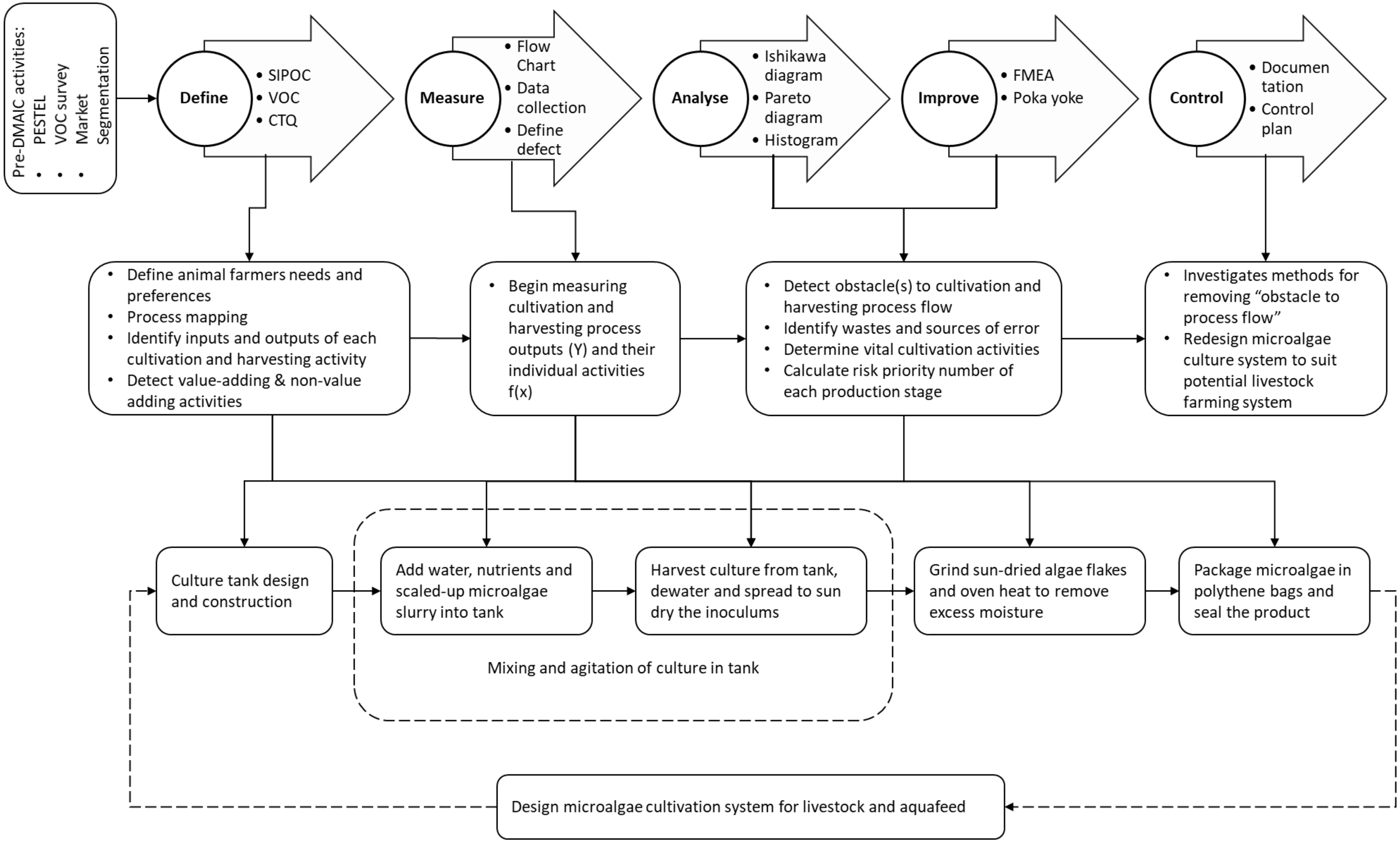


Figure 24: Lean 6 Sigma's Conceptual DMAIC Framework for Open Pond Microalgae Production Farm.

The conceptual framework shown in Figure 24 demonstrates the detailed process map of the relevant areas of microalgae production in an open pond culture systems and the different phases of the DMAIC cycle. The framework also shows the different steps to be taken along each phase of the DMAIC cycle across the microalgae production process map. In the define phase, input from the literature review, market survey, VRIO and market segmentation were taken into account to define the critical to quality factors (CtQs). The measure phase focuses on measuring the repeatability/stability of the activities in harvesting, filtring and drying processes in the case study microalgae farm. The analysis phase utilises capability six pack analysis and standard deviation to identify bottlenecks and areas that need to be improved and/or modified based on the customer requirements identified in the define and predine phase. In the improvement phase, processes with high risk priority numbers from the failure modes and effects analysis (FMEA) and low capability indices from the capability six-pack analysis are studied further using secondary data. The final phase is the control phase. In this phase, suggestions on how to improve the "out of control" activities are identified and recommended.

In the next section, The researcher adopt the above conceptual framework (Figure24) into a case study open pond microalgae production company that cultivates *Spirulina* for human consumption. The case study analysis focus on identifying process variations in connection to process repeatabilty and reproducibility as well as to identify potential causes of failure in the production system.

7.2 Introduction

7.2.1 About the Case Study Company

Spirulina Nutritech Foundation (SNF) is a section-8 Non-Profit Public Company (formerly section 25 companies CIN: U85110TN2010NPL074817) established to combat malnutrition among women and children through simple cost effective and easily adaptable solutions. This case study analysis investigates non-value adding activities or defects in the production process of microalgae in an open pond cultivation company - Spirulina Nutritech Foundation (SNF) India. The SNF and its technical unit Spirulina Production Research and Training Centre (SPRTC) have a strong network with approximately 20 Non-Governmental Organisations (NGOs) and a production capacity of approximately five metric ton of microalgae per annum, with the intension to double their capacity in the next two years, to reach up to about one hundred thousand beneficiaries. It facilitates the direct promotion of microalgae products and supports individuals, Self Help Groups (SHGs) and NGOs to produce their own small to medium scale microalgae biomass. Moreover, SNF is involved in NPD using *Spirulina* to produce candies (e.g. *crispies*, *chikkies*), capsule, tablets etc. as well as consolidation for micronutrient enrichment. The foundation is striving to discover possible ways of developing and promoting microalgae-based supplements to accommodate the nutritional requirements of various segments in the following marketplace:

- Medical marketplace through micronutrient rich products.
- Rural marketplace through cost effective and acceptable value-added microalgae products[38].
- Retail marketplace through affordable and effective micronutrients.
- Institutional marketplace through products to help children with malnourishment.

SNF's board is made-up of a managing director (Mr. D. Selvendran), two Directors (Ms. Helen Geetha and Mr. P. Balaji) and four members' in-charge of production (Dr. Geetha, Dr. Prabuthas, Ms. Arthi and Dr. J. Jayapradha). The technical unit SPRTC was established as part of a research centre to promote rural villages and enable women and through them children to progress towards the required amount of individual nutritional status. The product (*Spirulina*) is used to reach malnourished children and adults with about 1gm/child and 3gm/adult a day.

SNF adopts pond construction of rectangular tanks made of tarpaulins that are manually operated by farm workers daily. See Table 30 for details. Therefore, daily *Spirulina* harvest, culture agitation and sun drying are all carried-out manually. This type of alga-culture is not capital intensive compared to photo-bioreactors or raceway ponds and offers employment to the rural women of the SHGs and in some cases encourages nearby smallholders to start their own small-scale microalgae cultivation units (SPRTC, 2019). The farm is operated by trained rural women who starts early in the morning with harvesting followed by stirring the culture every 20 minutes throughout the day. Moreover, the state of microalgae culture medium is checked daily to monitor and ensure that no contaminants are present.

Table 30: SPRTC's Farm Size (SPRTC, 2019)

Case study company information	**Details**
Total Production area	180 square metres
Number of tanks	10 each of 18 sq.metre size
Direction of tanks	East -west (parallel to length)
Tank size	Length 6 metre x Breadth 3metre x Height 45cm
Gap between tanks	1 metre (approx.)

[38] Similarly, one of the objects of this research is to promote microalgae-based feedstuff/supplementation to accommodate the nutritional requirements of livestock and aquaculture through the development of cost effective and acceptable value-added alga-culture system and/or product for smallholders in Nigeria.

Surveys and interviews have been undertaken (see Chapter 6) to track which livestock farmer's requirement(s) are most connected to microalgae production. Feed and/or feed materials quality and cost are two of the most important factors influencing animal growth performance, as well as ROI and purchase behaviour of Nigerian farmers, respectively. Moreover, both feed quality (in-terms of product micro-nutritional constituents) and cost (in-terms of cost of failure[39]) can be connected to the production process of microalgae biomass. The entire farm operation of the case organization is summarised in Figure 25 (high-level process map) and Figure 26 SIPOC analysis (detailed process map) below. Since this study is concerned with improving and/or modifying open-air alga-culture for human food supplementation into a system, which livestock farmer can adopt, the researcher decided to explore the entire production processes except for retail packaging.

[39] Costs due to products or services (feedstuff) not conforming to consumer (livestock and farmers') requirements.

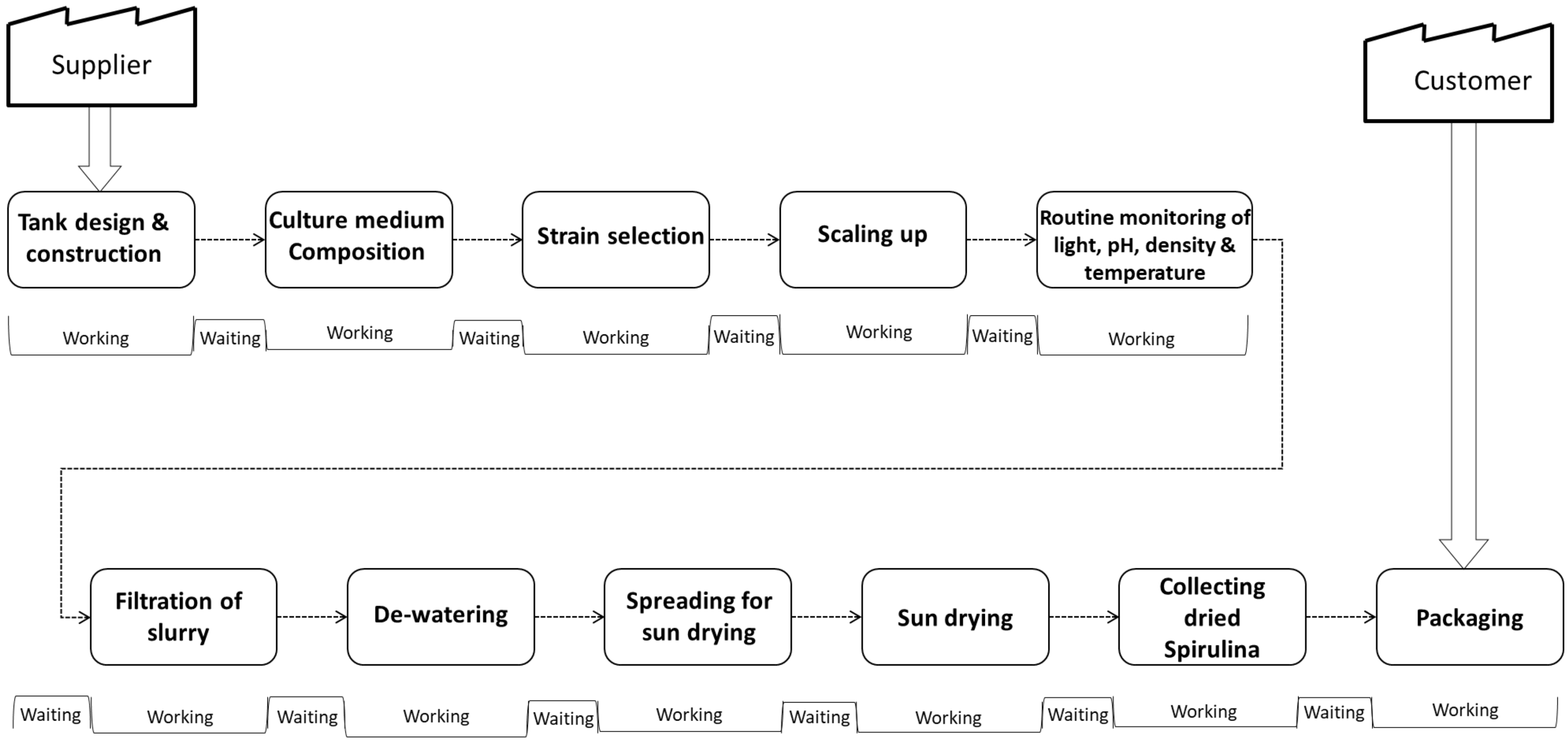


Figure 25: SPRTC Open Pond Microalgae Cultivation End-to-End Value Stream Map

In order to cultivate microalgae, it is important to provide the necessary range of suitable temperature and light for photosynthesis, as well as water and nutrients (Vonshak, 1997). Subsequently, SPRTC produced their *Spirulina* in the tropical region of Madurai in the South Indian state of Tamil Nadu. So that the required temperature range of 30-37 °C during the day and 25-30 °C at night are attained. Other important requirements include abundant water source, low humidity, at least 10 hours of illumination and low wind, needs to be ensured for decent biomass production. Moreover, organic and/or inorganic sources of nitrogen, carbon, and minerals must be provided to meet the nutrient requirement.

7.2.2 LSS Project Team Formation: Research Participants

In line with Furterer (2016), the LSS project team for this case study are formulated with the technical team of SPRTC case company who have a background and adequate knowledge of the processes and are responsible for performing the production activities. Therefore, the team (i.e. research participants) includes the production people in-charge; the managing director and randomly selected trained operators on duty. These operators are responsible for the daily activities of the algae farm such as culture agitation, harvesting and drying, whereas the production person in-charge and managing director provide technical support (including end-to-end training/details on production) and remove obstacles that may occur during production as well as responding to questionnaires and taking measurements for implementation of this LSS project with the researcher. Also, the production person in-charge/technical team supervises the workers and perform activities such as routine measurements of culture medium pH and density. The researcher was the lead of the LSS improvement activities using both interviews and questionnaires to elicit information from the team.

7.2.3 Defining Microalgae Production Processes in SPRTC Case Study

The purpose of the *Define Phase* is to identify the production processes (X's) that are to be investigated and the consumer's requirements on the output (Y) as well as the way current microalgae culture inefficiencies in the case organisation might affect prospective consumers and other stakeholders (Antony, 2006). It aims to define the goal and scope of the case study project to develop or conceptualise a microalga production system that could meet livestock farmers' feed CtQs. It is important to identify the output of the microalgae cultivation processes, their capabilities (e.g. C_p, C_{pk} and PPM indices), and to define how they can be improved or modified for an integrated livestock *cum* microalga-cultivation system (Magnusson, *et al*., 2003). The customers' requirements on the processes form the CtQ characteristics. Thus, examining them is very much about understanding the processes via data collection and analysis. The first step is to get to know the current situation of the case study company's overall cultivation process; to know how the internal Standard Operating

Procedure[40] (SOP) looks like (SIPOC diagram) and how they are performing (sigma level through process capability sixpack). To achieve these the researcher conducts semi-structured interviews with the technical team member(s) (during a series of training sessions) in SPRTC for seven weeks to learn about their production processes in detail. No measurements were taken during the define phase, however, general notes are taken about how microalgae (*Spirulina*) is produced in an open-air culture system; including tank design, culture medium, strain selection and scaling-up of the process; maintenance of open pond cultures such as light effect and pH control; and finally harvesting and drying.

7.2.3.1 Failure Modes and Effects Analysis

The Failure Modes and Effects Analysis (FMEA) also referred as Failure Modes, Effects, and Criticality Analysis (FMECA), is a systematic method of identifying, analysing, and documenting potential product or process design failures. This crucial reliability tool "can anticipate and prevent problems, reduce costs, shorten product development times, and achieve safe and highly reliable products and processes" (Carlson, 2016). In this research, both *design* FMEA concerned with examining potential failure modes of microalgae biomass contaminations during cultivation and their effects on the end product, as well as *process* FMEA concerned with variability in harvesting and drying microalgae biomass in the case company are utilised. Moreover, risks associated with the failure modes, effects and causes are assessed and prioritised using Risk Priority Number (RPN) for potential modifications of SPRTC's microalgae for food production system into a system suitable for producing microalgae for feed. This is done by allocating scores to the risks of potential failures, the effect of failures to the biomass and the detectability prior to failure occurrence in different designs and sub-processes in the case company[41]. For this research FMEA analysis is undertaken (Table 31) covering the pond design, medium requirements and mother culture. The FMEA also covers the routine culture maintenance activities like pH control, culture depth and nutrient concentration. The Final part of the FMEA is concerned with the process of harvesting and drying microalgae biomass in the case company.

The object of the three FMEA analyses undertaken for this research is to separate both design and process "noise"[42] from factors causing problems with regards to the focus areas and direction stipulated by the VoCs and subsequent CtQs. Table 31 summarises the key findings, which show high

[40] This describes the theoretical microalgae cultivation processes in the way Spirulina Nutritech Foundation defined them.
[41] See Table 46, 47 and 48 in the Appendix for the criteria for ranking severity, chances of occurrence and detection of failure mode
[42] A technical term relating to non-random and random causes of variation. The capability six-pack analysis undertaken in this chapter shows both major waste that could affect overall product quality and less impactful process variations or noise.

RPN for the sun drying process, but also issues with scaling-up inoculum or mother culture and medium concentration. The latter (i.e. scaling-up inoculum and medium concentration) are of minor nature but of high rating and could be adopted directly into microalgae *cum* livestock farming system, while the former (i.e. sun drying) would require changes in the working methods.

Table 31: FMEA Analysis of the Case Study Microalgae Cultivation System

Process/ Product Function Requirements	Potential Failure Mode	Potential Effects of Failure	SEV	Potential Causes/ Mechanism of Failure	OCC	Current Controls	DET	R P N
Microalgae cultivation tank: For culturing microalgae.	Sharp angles [on] container [corners].	Hindering culture agitation and cleaning that could lead to; the algae [been] trapped at the bottom of tank; milky culture medium.	**5**	Culture in sharp cornered ponds will be stagnated and leads to more bacterial growth contaminants, [which] will affect the growth of *spirulina* and quality of [the] product.	**1**	1. Fold and place the tarpaulin sheet gently in the corners in such a way that water cannot stagnate there.	**1**	**5**
Culture medium: To provides all essential nutrients to grow microalgae in a suitable environment.	Carbon, Nitrogen and Magnesium deficiencies.	Faded and Yellowish coloured culture with foam in the background of greyish or milky water.	**9**	1. Improper addition of Fertilizers 2. Poor quality of fertilizers 3. Depth imbalance	**2**	1. Regular monitoring of fertilizer addition by management 2. Buy good brand / supplier fertilizers 3. Proper depth maintenance	**3**	**54**
Mother culture and scaling up: To provide inoculates for the 6 x 3 metres tanks. To prevent the culture from becoming weak by reducing the culture vulnerability to open air microorganisms. Moreover, to scale up the culture into the cultivation tank(s).	Invasion by other microorganisms.	Competition for nutrients/resources leading to starvation and potentially death of the microalgae inoculum.	**10**	1. Bacteria, Protozoans etc. will be increased when there are more dust/dead particles present 2. *Chlorella* invasion through water and/or air	**5**	1. Regular cleaning of settled dusts 2. Use fresh bore well water and grow your mother culture in hygienic place to avoid air borne contaminants.	**8**	**400**

Process: Culture Maintenance								
Process/ Product Function Requirements	**Potential Failure Mode**	**Potential Effects of Failure**	**SEV**	**Potential Causes/ Mechanism of Failure**	**OCC**	**Current Controls**	**DET**	**R P N**
Light effects: light cycle imposes a unique physiological regime on the adaptation of outdoor microalgae cells to light.	Failure to receive enough light to saturate photosynthesis. Self-shading is increased as cell concentration of culture increases.	Decrease in the growth rate of microalgae.	**6**	1. Reduced photosynthesis, and growth during cloudy / monsoon season / culture density is high.	**3**	1. Increase the frequency of agitation. 2. Covering the tank with transparent polythene sheet during monsoon season to allow light through.	**6**	**108**
pH Control: Maintaining a pH of over 9.5 is vital for the culture to avoid contamination from other algae.	CaCO3 precipitation followed by flocculation and sedimentation of algae. Light absorption of about 25% of incident light by non-algal components that decomposed in the culture increasing the bacteria contamination.	Algae may die due to severe osmotic shock and the entire culture has to be replaced.	**9**	1. Depth imbalance due to rainwater addition / evaporation loss 2. Improper addition of fertilizers	**7**	1. Excess diluted medium to be discarded and replace the fertilizers [for] balance. Add water to compensate the evaporation loss daily. 2. Regular monitoring of fertilizer addition can correct it.	**2**	**126**

Culture nutrient concentration: Routine chemical analysis for major nutrients such as Phosphorus, Nitrogen, Magnesium and Potassium should be done.	Depletion of culture faded and/ or yellowish culture with foam	Decreased biomass concentration in the pond culture and output rate.	**10**	1. Culture nutrient dilution due to rainwater addition 2. Improper addition of fertilizers. 3. Irregular chemical test to analyse culture nutrient balance	**6**	1. Diluted culture medium are discarded, and the fertilizers replaced to balance concentration. 2. Regular monitoring of fertilizer addition can correct it. 3. Routine chemical test by SGS India pvt Ltd.	**4**	**240**
Depth of culture: To determine the amount of light that impinges on the cell as well as mixing of the ponds.	Reduced light penetration in the culture at high concentration of microalgae i.e. high population density, and subsequently milky culture medium due to poor agitation.	Slow growth rate. Gelatinous polysaccharides pull living algae filaments to the bottom of the pond where they die due to lack of light and nutrition.	**5**	1. lack of regular harvest of microalgae and/or irregular agitation of the culture medium	**4**	1. Increase the frequency of agitation 2. Routine cultivation of biomass from 9 out of 10 ponds every morning (the 1 pond unharvested will be harvested the following cycle to avoid over harvesting and high population density)	**5**	**100**

Processes: Harvesting and Drying								
Process/ Product Function Requirements	**Potential Failure Mode**	**Potential Effects of Failure**	**SEV**	**Potential Causes/ Mechanism of Failure**	**OCC**	**Current Controls**	**DET**	**R P N**
Filtration: to obtain the biomass containing approximately 10% dry matter and to remove 50% residual culture medium to obtain fresh microalgae biomass.	Culture contamination from foreign matter such as larvae, leaves, insects and lumps of polysaccharide or mud.	Algae cannot be consumed due to contaminants and the ash content of the product will rise over the maximum 7%.	**4**	1. Microalgae (*Spirulina*) wet mass will contain small and minute dust particles that leads to having poor quality of product.	**8**	1. Pre-filter cloth should be placed to avoid mixing of dusts 2. Washing of slurry with fresh water helps removing of tiny dusts.	**5**	**160**
Drying: to reduce the moisture content	Moisture content more than 8-10% due under-drying will lead to bacteria and moulds growth.	Moisture content exceeds the recommended 3-4%, which could lead to shorter shelf-live.	**8**	1. Flakes with more moisture will attract bacteria to grow and affects the quality & shelf life of the dried product.	**10**	1. Do not mix the moist flakes with well-dried ones. 2. We use hot air oven to reduce the moisture level of dried products and to maintain even moisture in flakes (55 degree Celsius – 1hour)	**10**	**800**
Drying: to prevent growth of moulds and bacteria	Over drying	Could results in loss of essential components like nutrients, pigments and vitamins.	**5**	1. Colour of the product will be faded. 2. Reduce the vitamin and pigment levels	**9**	1. Monitor the drying duration according to the climatic conditions	**9**	**405**

7.2.3.2 Defining the Suppliers, Inputs, Processes, Outputs, and Customers (SIPOC) in SPRTC

In SPRTC, specific set of employees are only responsible for part of the *Spirulina* production. Consequently, workers do not have a holistic view of the value stream and/or process map. SHG workers trained to undertake culture filtration and dewatering for example might not understand how much nutrients to replenish back into the culture medium after harvesting, or the interdependencies between culture density and frequency of harvest in the first place. Since LSS strive to satisfy customer wants and needs, drawing a SIPOC diagram gives the researcher an overview of how microalgae are produced in SPRTC and how customer requirements are being met through value-added activities, in order words the scope of the project. The term SIPOC is an acronym for Supplier, Input, Process, Output, and Customer. *Suppliers* here signify the processes, people, and departments that provide whatever is worked on in a process. The suppliers can be external or internal. *Inputs* refers to the materials such as fertilizer, tarpaulin sheets, water containers, algae strain etc., or information provided. *Process* determines all the steps taken to produce the microalga. Finally, *Outputs*, the product *Spirulina* biomass that is delivered to the customer.

The SIPOC diagram in Figure 26 provides a visual overview of microalgae production from a more detailed perspective in SPRTC to facilitate problem solving and/or modification in the processes to produce microalgae system for animal farming. The customers in this research project are small-scale animal farmers whom requirements for high quality and affordable feedstuff can be translated into measurable CtQs like number of defects (measured by the number of contaminated algae), processing time delays and cost of poor quality due to defects. By reducing the variations in the processes (i.e. through better C_p, C_{pk} and PPM values) and the quality of the identified input requirements stipulated in the SIPOC, the potential to achieve the aforementioned CtQs (see Chapter 6) could be increased. Measuring these processes and investigating how to improve or modify them for animal farmers to adapt is the reason for this chapter.

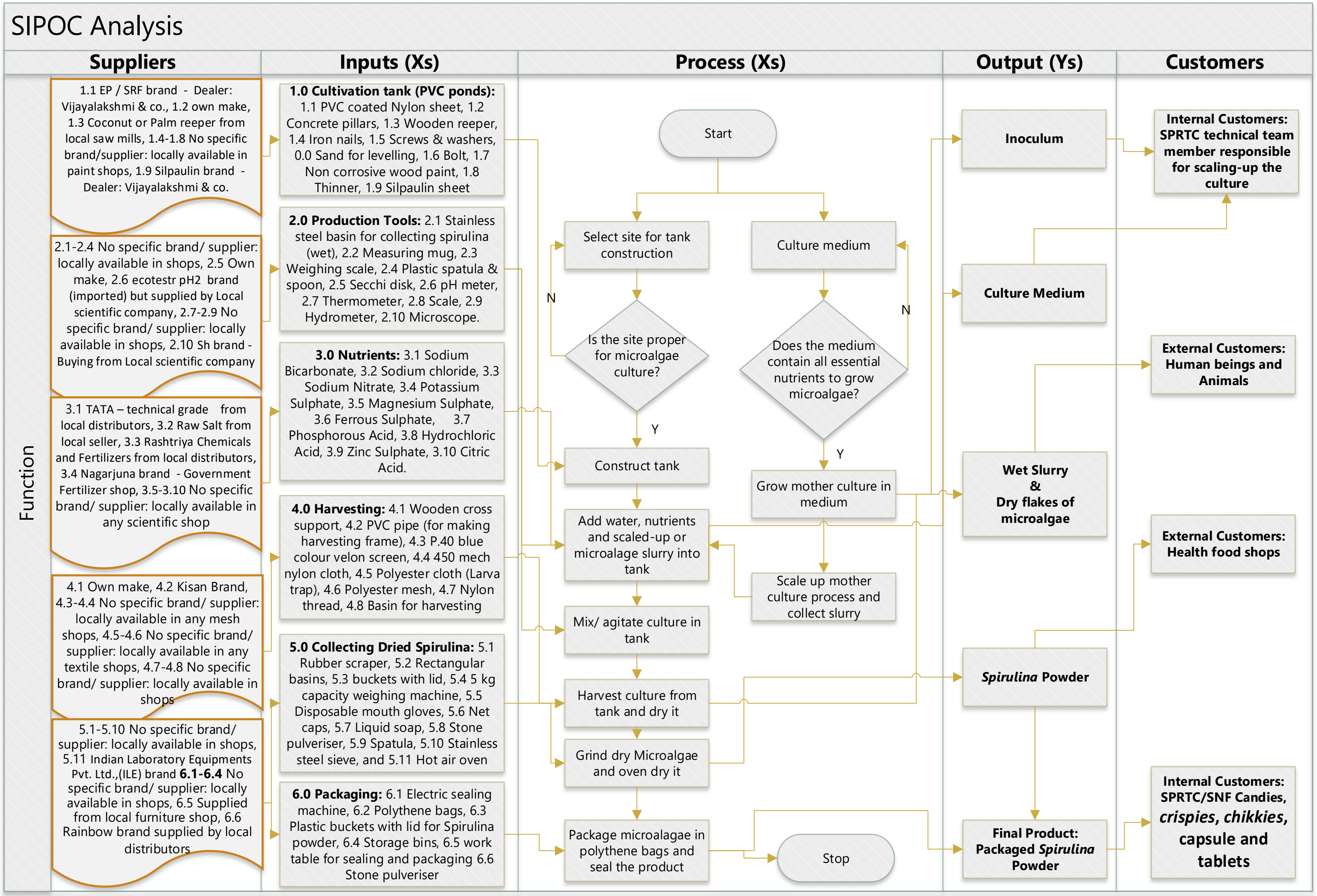
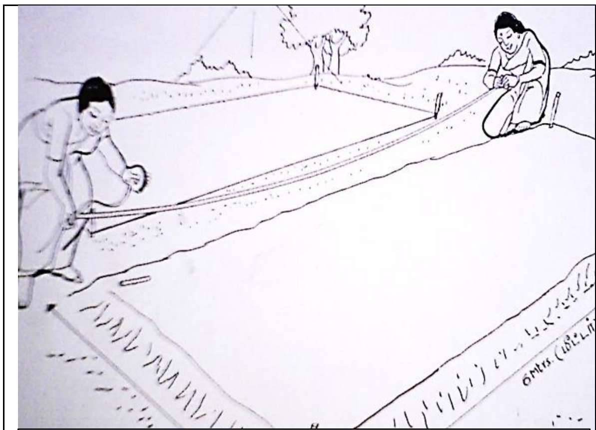


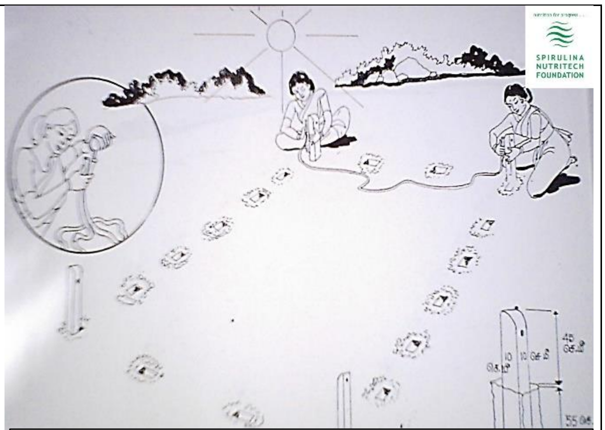
Figure 26: Detailed SIPOC Diagram of SPRTC Microalgae Production System

7.2.3.3 Production Tank Design and Construction in SPRTC

There are several types of microalgae production systems used by small to large-scale algae farmers around the world. For example, enclosed photo-bioreactors, tubular or tank systems; village farms in developing countries with the right technology; micro-farms, community and family-size production systems; commercial farms using open-air raceway pond systems and harvesting naturally growing *Spirulina* in natural lakes. Any watertight (preferably shallow) open container could be used to cultivate microalgae, as long as it is non-toxic and can withstand damage caused by oxidisation or other chemical reactions. According to the case organisation's technical team, the shape of the cultivation tank is immaterial! However, sharp angles are to be avoided to aid agitation and cleaning. Microalgae is grown in a six by three metres tarpaulin (transferable) tanks in SPRTC. Figure 27 below shows the steps taken in constructing an open pond with tarpaulin in the case company.

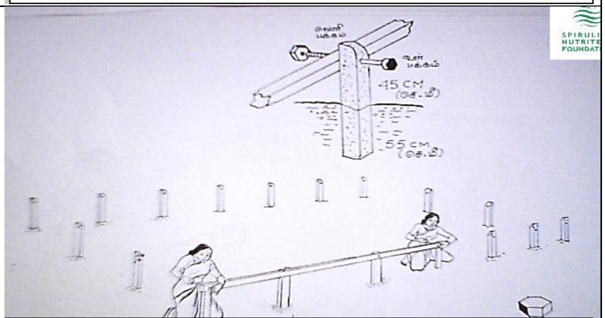


1. Preparing the site

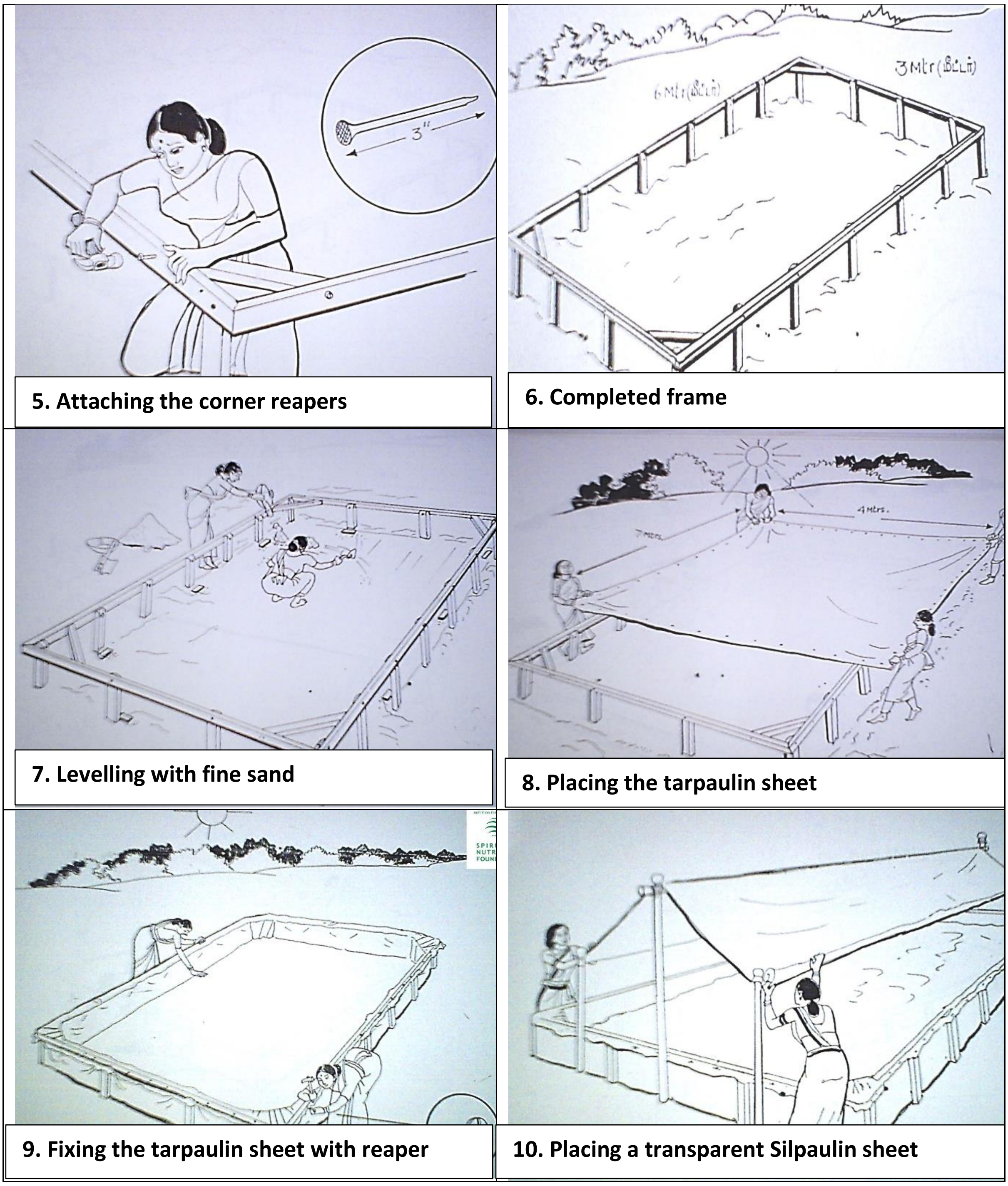


2. Fixing the corner pillars using level tube

3. Fixing the intermediate pillars



4. Attaching the reaper with the pillars



5. Attaching the corner reapers

6. Completed frame

7. Levelling with fine sand

8. Placing the tarpaulin sheet

9. Fixing the tarpaulin sheet with reaper

10. Placing a transparent Silpaulin sheet

Figure 27: Setting-up a 6X3 metre Growth Tank at SPRTC India (SPRTC, 2019)

Table 32: Average Microalgae Biomass Harvested at SPRTC[43] (SPRTC, 2019)

	January' 18		February'18		March'18	
Date	**Wet mass (gm)**	**Dry mass (gm)**	**Wet mass (gm)**	**Dry mass (gm)**	**Wet mass (gm)**	**Dry mass (gm)**
1	1,375	127.3	1,765	156.0	1,230	116.5
2	1,44	135.0	970	72.8	1,445	128.1
3	1,50	138.5	1,495	125.0	1,265	118.0
4	1,370	124.0	2,215	209.0	1,060	96.8
5	1,895	168.8	1,835	168.5	0	0
6	1,020	93.0	0	0	0	0
7	1,215	117.3	2,335	217.5	0	0
8	0	0	1,915	178.0	1,075	95.0
9	0	0	1,365	117.0	1,655	145.4
10	3,090	271.3	1,515	147.0	1,660	146.3
11	2,245	209.5	1,745	142.5	1,525	128.5
12	1,595	147.0	1,480	137.4	1,870	169.0
13	2,315	210.0	0	0	2,185	207.5
14	2,065	196.0	0	0	2,100	206.0
15	0	0	0	0	1,115	108.2
16	1,670	149.0	1,315	121.5	2,085	195.0
17	2,230	206.5	1,445	125.0	1,945	187.5
18	2,325	215.0	0	0	1,880	175.4
19	1,665	147.1	0	0	1,975	172.0
20	1,505	130.0	1,190	102.6	2,245	215.0
21	1,680	152.0	1,465	125.8	1,800	168.0
22	1,980	176.5	1,335	116.4	1,045	98.5
23	2,085	190.5	2,925	258.2	1,570	136.8
24	1,755	135.0	3,020	276.0	1,470	135.0
25	1,300	118.5	2,435	226.1	1,380	124.5
26	1,615	158.2	1,735	164.3	1,435	135.5
27	1,660	142.0	0	0	1,465	132.0
28	1,815	165.7	1,430	128.5	1,460	140.6
29	2,240	215.0	0	0	1,365	131.0
30	2,105	193.0	0	0	1,445	135.4
31	1,775	158.5	0	0	1,970	178.5
Total	**50,530**	**4590.2**	**36,930**	**3315.1**	**44,720**	**4126.0**

A total production area of 18 square meter is required per pond of six metres length, three metres breadth, and 45 centimetres height, producing an average of 1.650 g of wet *Spirulina* biomass daily. Table 32 summarises a three-month production records of the case study company over the period of the data collection phase of this research.

[43] Last available record (data collected by SPRTC team on researcher's request)

The exemplary quotes from the case study technical team and training material concerning site selection and pond design at SPRTC in-line with Oliver *et al.* (2005) continuum of de-naturalism are presented below:

"*The first and foremost aspect to be considered for microalgae cultivation is a flat site with adequate sunlight (i.e. free from shade) and sufficient water supply throughout the year. The site should have easy access to the nearby settlement(s). It should be free from pollution from industrial, drainage systems etc. Moreover, the site should have access to electricity and work force*."

"*Any non-toxic, non-corrodible and waterproof open container can be used to culture microalgae. Its shape is unimportant under the circumstances, however we used D-ended shaped tanks to avoid sharp angle (especially right angles) that could lead to culture contamination due to stagnation, and to make cleaning and agitation easier. Moreover, although microalgae can be grown in permanent concrete tanks, we used transferable tanks made from tarpaulin. We fold and place the tarpaulin sheet gently in the corners in such a way that the culture medium cannot stagnate*" (Manager in-charge of production/training notes).

This type of pond design is simple and easy to adopt. In Nigeria, for instance, similar designs are already in used for aquaculture as shown in Figure 28 below.

Figure 28: Fishpond Tarpaulin in Nigeria (Green Market, 2019).

Although the height of the sample image in the Figure above is higher than the case company's tank height of 45cm, they are adjustable and can be customised to meet farmers requirements.

7.2.3.4 *The Composition of the Growth Medium Used in SPRTC*

The culture medium used to culture microalgae in the case company mimics that of the natural system. SPRTC growth medium is a modified version of the original Zarrouk's medium. Thus, cultivation takes place in a nutrient rich alkaline aqueous medium at high pH to inhibit the growth of contaminating organisms, resulting in *Arthrospira platensis* monoculture. SPRTC gets their nutrients sources locally from reputable suppliers, no herbicides, pesticides, or toxins are used during production of the feedstock.

The culture medium should contain all the essential nutrients needed to grow microalgae. It is made-up of phosphorus, nitrogen sources, sodium carbonate, iron, trace metals as well as other micronutrients necessary for plant life. SPRTC achieved this solution by dissolving various combination of food grade chemicals, the choice of which depends on the cost and compatibility with the water been used. 15-25% of SPRTC's total initial production cost of approximately £3809.67 is spent on buying nutrients sources. A complete initial investment and cost of production in the case study organisation is shown in Table 43 and 44 below (page 201 & 202). Table 33 shows the growing medium composition used in SPRTC to grow *Spirulina*.

Table 33: Required Medium Composition for growing Spirulina (Das, 2015).

Medium composition		Quantity added
Anions	Carbonate	2800 mg L^{-1}
	Bicarbonate	720 mg L^{-1}
	Nitrate	614 mg L^{-1}
	Phosphate	80 mg L^{-1}
	Sulphate	350 mg L^{-1}
	Chloride	3030 mg L^{-1}
Cations	Sodium	4380 mg L^{-1}
	Potassium	642 mg L^{-1}
	Magnesium	10 mg L^{-1}
	Calcium	10 mg L^{-1}
	Iron[44]	0.8 mg L^{-1}
Total dissolved solids		12847 mg L^{-1}
Density @ 20 °C		1010 g L^{-1}
Alkalinity		0.105 N (moles strong base L^{-1})
pH @ 20 °C		10.4

[44] To prepare a $FeSO_4$ solution for 1 litre culture medium, the SPRTC technical team take 20ml of conc. Hydrochloric acid (HCl) in a plastic container. Add 50g of $FeSO_4$ and mix well. Then add 200ml of water and about 80g of citric acid. The volume is scaled-up to 1000ml by adding more water.

Figure 29: Adding Nutrients into Tarpaulin Tank of Length 6 m x Breadth 3m x Height 45cm at SPRTC

The concentration of the biomass together with the output rate and losses due to flow out and precipitation determine the actual concentration of the nutrients in the medium in a continuous open-air microalgae culture. Similarly, changing physical and biochemical environments in the culture from initial medium may alter the composition of the various nutrient elements. SPRTC perform routine chemical analysis to prevent depletion of nutrients, especially on major element like N, P, K, and Mg.

Table 34: SPRTC Modified Zarrouk's Medium for Cultivating Microalgae & Availability in Nigeria

***Spirulina* growing medium L^{-1}**		**After harvest (for 1g of dry *Spirulina*)**	**Availability/suppliers in Nigeria**
$NaHCO_3$	8g	5g	Readily available from suppliers such as Turraco industrials.
NaCl	5g	Nil	Common salt
Sodium Nitrate	2.5g	1g	Available from farm fertilizer suppliers such as Eltee International, Mekz Global Ltd etc.
K_2SO_4	0.25g	0.03g	Available from farm fertilizer suppliers such as Eltee International, Mekz Global Ltd etc.
$MgSO_4$	0.16g	0.03g	Available from farm fertilizer suppliers such as Dizengoff Nigeria
H_3PO_4	0.052ml	0.0325ml	Readily available from suppliers such as Turraco industrials.
$FeSO_4$	0.1ml	0.1ml	Readily available from suppliers such as Epoxy Oilserv
$ZnSO_4$[45]	0.1ml	0.1ml	Readily available from suppliers such as Agtho Fertilizer and Chemicals Limited, Primegold fertilizers & chemical industries limited etc.

[45] $ZnSO_4$ solution per 1 litre is prepared by dissolving 20g of $ZnSO_4$ in H_2O

When inquired about nutrient deficiency in the culture medium, a technical team member in-accordance with the company training material of the case company suggests that:

"*Faded colour of the culture can be due a number of factors and sometime mean different things depending on the pH. For example, faded colour at a pH>10.5 is usually because of CO2 or Bicarbonate deficiency. While, faded colour at a pH<10.5 indicates Nitrogen deficiency [in the medium]. In the same vein, when the culture turns yellowish, lysis has occurred and with foam – the cell walls have ruptured expelling polysaccharides on to the medium. Moreover, when the osmotic medium shock is severe, the culture can turn milky [in] colour. When fermentation odour is perceived from the culture, it is usually due to heavy bacterial load in the medium*."

"*To reduce and/or prevent these we shade [i.e. provide cover to] the culture to reduce dust, leaves and other debris from falling into the open tanks. Lower the pH with CO_2 and add Nitrogen and Potassium (fertilizer). Poor quality fertilizers are avoided. Moreover, we remove clumps and settled dust and Increased agitation of the culture to; keep the polysaccharides afloat; help the filaments to avoid been trapped in the polysaccharides*."

7.2.3.5 Strain Selection and Mother Culture

In most forms of microalgae farming, harvested biomass is subjected to further processing that requires the algae cells to be broken open for the desired products to be extracted. *Chlorella* for instance (another form of microalgae with positive health properties) has such a physically and chemically tough cell wall that can pass right through the digestive tract of animals unharmed. Conversely, unlike most plants *Spirulina* have digestible cellulose completely dissolves when eaten by livestock. It is rich in protein (about twice the density of beef), antioxidants (such as *phycocyanin* and *allophycocyanin*), and essential omega-3 fatty acids. Moreover, *Spirulina* has been researched far more than any other type of algae both for its many positive effects and for its lack of negative ones (Gutiérrez-Salmeán, *et al.*, 2015; Katoch, *et al*., 1999; Mao, *et al*., 2005; Moorhead , *et al*., 2011). Many clinical studies have shown benefits for improving and/or balancing the immune system of both animals and humans as well as increasing beneficial bacteria in guts, toxins protection, anti-inflammatory and anti-viral properties (Gershwin & Belay, 2007). Taken together, *Spirulina* is a highly nutritious commercial product that serve as a source of feedstock for food, pharmaceutical and chemical industry (Volkmann, *et al*., 2008). The key determinants in the selection of *Spirulina* strain at SPRTC were its biochemical composition, growth rate, and resistance to physiological and mechanical stress. Several researchers from different countries have studied a wide variety of *Spirulina* strains and species; see Pascaud (1993) for example. Continuous mass cultivation of *Arthrospira* platensis in the case company depends on its stability and suitability under prevailing conditions of the farm environment.

Inoculum is the starter culture used to "seed" the new culture. Growing of healthier *Spirulina* in small quantities indoors (or in a shaded area) free from contaminants is known as the mother culture. Growing of mother culture can be started even with as little as one ml of culture. The reasons for growing the mother culture in SPRTC includes:

- Mother culture is used as a 'seed or inoculate' for *Spirulina* production.
- When *Spirulina* is cultivated in open-air culture, other microorganisms will invade it and the culture will become weak. Regular inoculums of mother culture enhance growth (SPRTC, 2019).

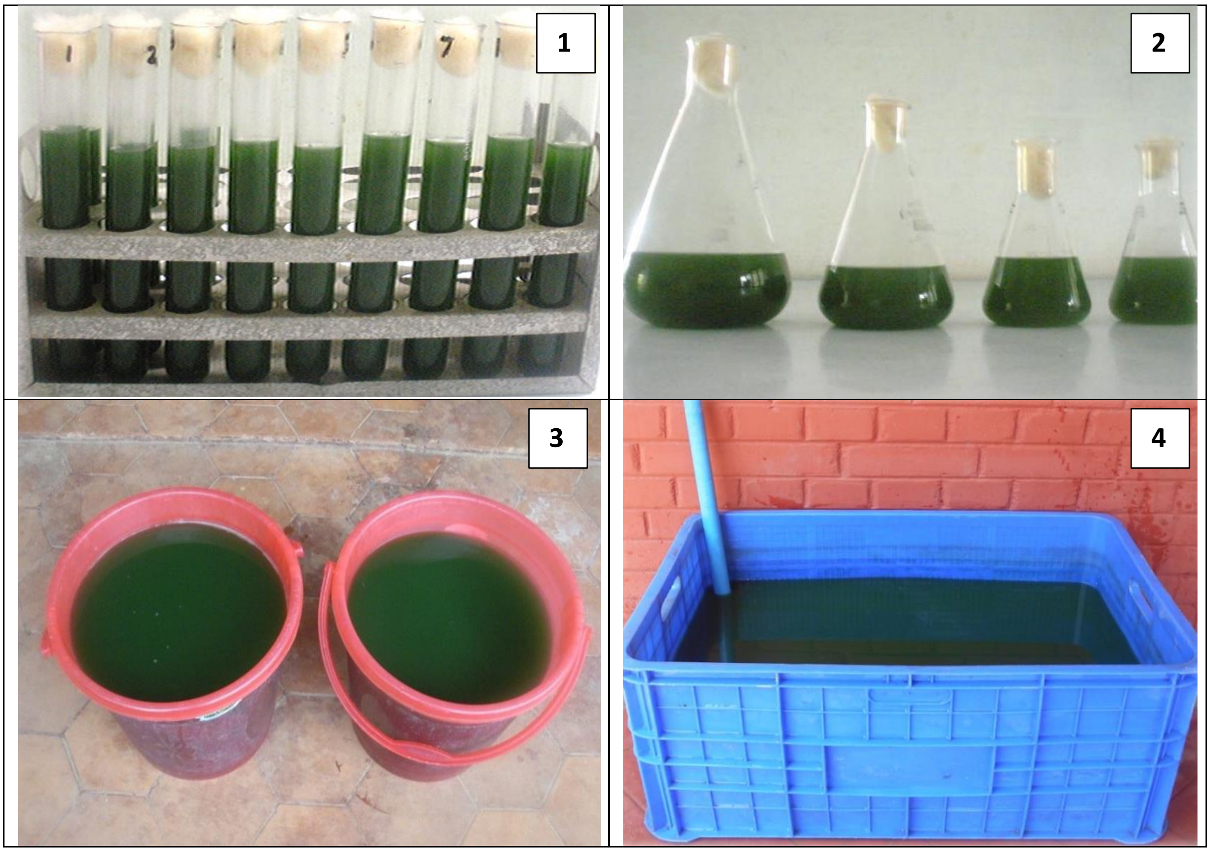


Figure 30: Indoor Mother Culture of Arthrospira Platensis *Strain at SPRTC (1 to 4)*[46]

7.2.3.6 Scaling-up the Culture Medium

This is where contamination by bacteria and other microalgae species poses the greatest threat due to the initial dilution of the inoculum (i.e. low density of inoculum). Vonshak (1997) supports this

[46] Images 3 and 4 in Figure 30 do not present the ideal scaling up containers (as they are usually shallow/see through plastics). However, at the time of the present data gathering these are the images of what are being used.

statement asserting that there is a direct correlation between the density of microalgae in the culture medium and the density of contaminants. That is, the amount of contamination increases with the low initial density of the inoculum and decreases as the microalgae culture build up in density. At SPRTC, careful manipulation of useful natural predators (e.g. rotifers could provide the *Spirulina* culture medium with significant amount of CO_2) and the nutrient concentration have made it possible to maintain monoculture of the microalga *Spirulina* even during the early period of inoculation. The inoculum strains are used to scale-up the size of the alga-culture. Two modes of expansion are utilised by the case organisation. First, the culture is scaled up from a smaller quantity mother culture inoculum strains stored in smaller plastic containers (see Figure 30 above). The scale-up follows an approximately "5:1 dilution ratio through successive volumes up to the 3.6 m^3 culture in the production ponds within 45 days". Secondly, "culture expansion to the entire volume of the 10 production ponds can be done from just a couple of ponds in less than a month" (SPRTC, 2019) at a concentration level of about 1g of inoculum per litre. The scaling-up standard process at SPRTC is shown in Figure 31 below.

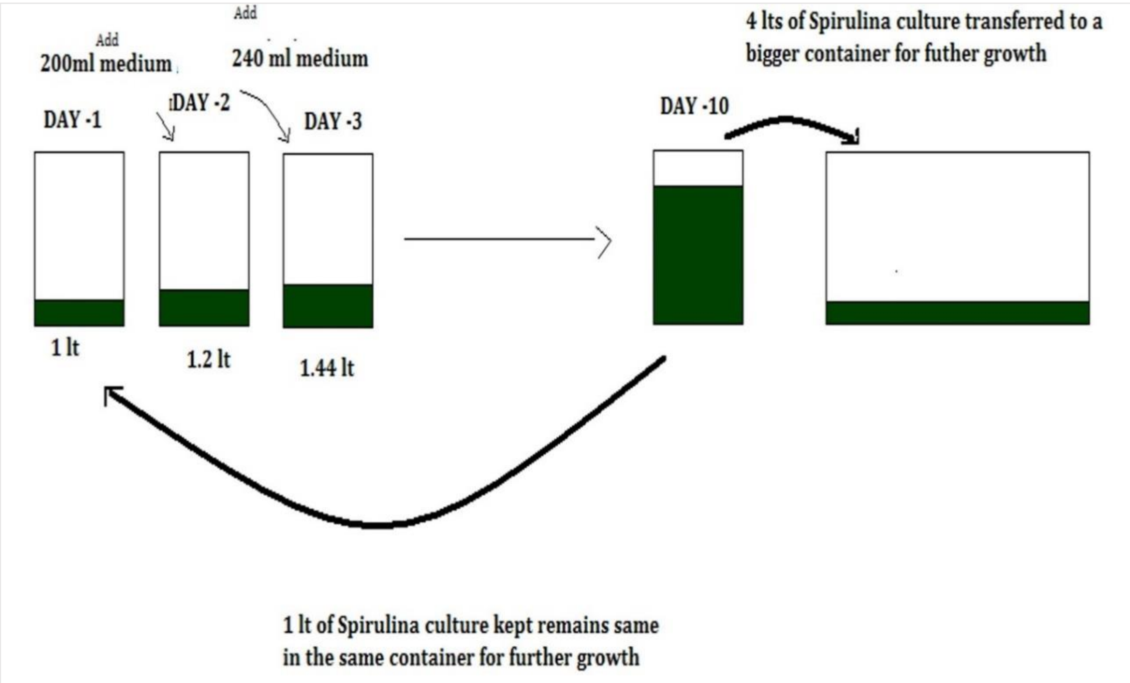


Figure 31: The Scaling-up Process of Microalgae at SPRTC Case Company

Figure 32: Self Help Groups Worker Transferring Spirulina Culture into an Open-air Pond for further Growth

According to the SPRTC technical team[47], after scaling-up the culture:

"*Many varieties of bacteria are commonly found. Their growth is inevitable and sometimes even useful in scavenging dead algae and other accumulates. Bacteria also helps in breaking down the tissues of other accumulations, which provides nutrients in the medium for further microalgae generation. However, since most of them grow within the pH range of 4.0 to 7.6 and very few can tolerate a maximum pH over 10.0, we operate our microalgae culture at pH from 9.5 to 10.5, which eliminates most pathogens*."

Similarly, "*Protozoa* [can] *also* [be] *found in the culture most likely from our water sources and/or windblown particles. It is a necessary part of the culture and add fixed nitrogen to the medium. Moreover, in dry algae, there are 74 varieties of amoeba, but only Entamoeba histolytica is pathogenic to man. Amoeba, like the other protozoan died at 40^{o}C. Regular cleaning of settled dust and the used of fresh well-water also helps*".

Moreover, "*sometime our culture can be invaded by rotifers despite the high salinity of the medium. They are a rich source of carbon dioxide to microalgae. We control rotifers by adding urea of 0.01g/lt to 0.02g/lt for two to three days*. *Viruses are usually* [eliminated] *by oxidation, when they pass into our microalgae culture medium, they are attacked by the high oxygen tension in the water, which is produced by the photosynthesis. In our dried microalgae product, the majority of the viruses are inactivated in about 20 minutes at 50-60^{o}C*."

[47] Derived from company documentations and discussion with regards to the subject with a team member.

"*Finally, contaminations by other algae such as Chlorella and the Diatom Navicula are frequent at the early stages of the culture* [i.e. during scaling-up]. *However, if the inoculum used to "seed" the tank is healthy, then invasion by other green algae and diatoms is minimal. We tend to maintain a good growth mono-algal culture in this farm and thus do not face serious difficulty from contaminating organisms*." [48]

7.2.3.7 Culture Maintenance at SPRTC

Routine monitoring of various biological, physical and chemical parameters such as light, pH, nutrient concentration and culture depth is important for proper culture maintenance in the case organisation.

7.2.3.8 Light Effect on Culture Cells

Outdoor open-air microalgae culture experiences two rhythms of light and dark regimes, one during agitation, and another during day and night cycle. The former is relatively quick as it is induced by the mixing of the culture medium in the pond, which causes turbulent flow dictating the rate of the light cycle. The microalgae cells are shifted from experiencing full solar radiation (in fraction of a second) at the upper culture during mixing process to complete darkness when they reach the bottom of the pond. The latter cycle, light regime is relatively slower as it is the result of solar irradiance caused by the earth's rotation around its own axis (i.e. day from sunrise to sunset). The acclimatisation of open-air microalgae cells to light is imposed by these two physiological regimes (SPRTC, 2019).

In SPRTC, *Spirulina* is grown in open ponds at a depth of 12 to 15 cm where self-shading governs the amount of light available to the cells in the culture. Hence, certain part of the cells in the pond will continuously be deprive of light for photosynthesis. However, these can be avoided by using much diluted culture that allows light penetration throughout the water column. Consequently, the technical team of SPRTC strive to maintain high turbulence flow through agitation to increase productivity at a higher cell concentration.

[48] More information on how contaminations are currently controlled in the case company can be found in the Table 31 FMEA analysis.

Figure 33: SPRTC Worker Agitating Culture Medium

7.2.3.9 pH Control & Culture Depth at SPRTC Open Pond Microalgae Farm

The balance between the acidity and alkalinity of the culture medium is represented by the pH, which ranges from zero to 14. A pH less than 7 signifies high medium acidity while greater than 7 means more alkaline and a value of 7 indicates neutral solution (a balance between acid and alkaline). Biochemical reactions are highly influenced by pH, since all organisms have a limited pH range in which they can survive. Unlike most bacteria and/or other algae species that cannot grow at a pH of 10+, *Spirulina* is adaptable to growing in high pH, up to 11 or higher. Thus, SPRTC maintain their culture between 9.5-11 pH to avoid contamination from other algae. The technical team adjust the pH by simply adding Carbonate salts into the culture to increase the CO_2 level. The CO_2 level of the culture is susceptible to simple exchange to the atmosphere, $CaCO_3$ precipitation, and loss from harvested slurry that is not recycled back into the culture. According to one production person in-charge at SPRTC, it is uncommon for the culture pH drop below 9.0; however, upward shift is quite common due to human errors such as improper addition of nutrients. When this happens, $CaCO_3$ precipitation follows, accompanied by microalgae flocculation and sedimentation, which has a negative effect on the culture. Moreover, these accumulations when left untreated can result in high light absorption (about 25% of the incident light) from non-algal components. In the same vein, the decomposition of these organic matters (accumulates) may result in the growth of microorganisms' especially *ciliate*. When this happens, the entire culture is replaced in compliance with quality guidelines of SNF (SPRTC, 2019).

The depth of the culture medium and cell density has a great effect on the agitation frequency and light penetration in the pond. Therefore, it is important to maintain an optimum depth (i.e. 20 cm at SPRTC) that will allow enough light to impinge on the algae cells, especially when the population density of the culture medium is high.

7.2.3.10 Voice of the Customer (VoC) and Critical to Quality (CtQ) Requirements

The final activity within the define phase corresponds to Chapter 6: market analysis, more specifically collecting and translating the wants and needs of livestock farmers (VoC) into measurable CtQs factors. These relates to factors that are critical to quality and cost and could significantly affect the final product (microalgae biomass). Figure 34 below shows the customer needs, the drivers and CtQ requirements based on the information collected from the livestock and aquaculture farmers in Nigeria.

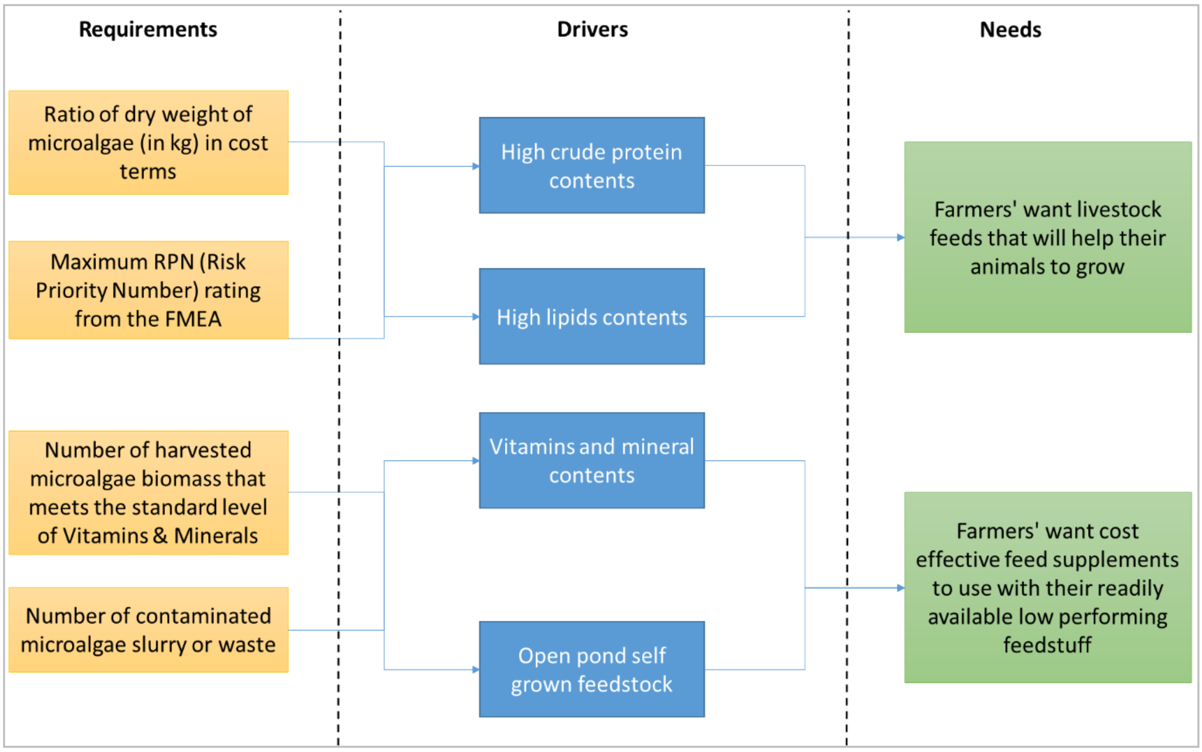


Figure 34: Feed Requirements and Needs of Livestock and Aquaculture Farmers in Nigeria

7.2.4 Measuring and Analysing the SPRTC production processes

In the *Measure Phase*, the raw data are collected by measuring the activities within the selected process (harvesting and drying) to examine and establish the baseline performance of the open pond microalgae production processes in SPRTC by statistically assessing, monitoring and comparing the current performance in terms of sigma rating or process capability (Pyzdek & Keller, 2014). In this stage of the DMAIC cycle, the researcher collects data about SPRTC production process and outputs to be analysed. The measure phase also provides first-hand data from related production activities along with output samples for proper analysis meant to provide insight for the improvement and/or modification of the culture system to support animal farming. In order to collect the data, total weight of biomass output (both before (wet mass) and after drying mass) in the case company are recorded for three months (see Table 32, page 172). Moreover, individual processes were recorded during the shifts of randomly selected SPRTC workers/operators labelled A, B C and D. Prior to collecting these data, six critical processes in the case company value stream were selected (based on the FMEA analysis) namely, setting-up filtration, filtration, washing wet biomass, spreading, sun drying and collecting dried microalgae flakes. All data collected are then computed in Minitab to identify individual process performance and sigma levels. Standard deviations of the measured data were calculated using the formula below:

$$s = \sqrt{\frac{\sum_{i=1}^{N}(x_i - \overline{x})^2}{N-1}}$$

s = sample standard deviation

N = the number of observations

x_i = the observed values of a sample item

$\overline{x}$ = the mean value of the observations

The data collected in the measure phase are reviewed and organised in the *Analysis Phase* to extract meaningful information for the process improvement or modification section. Based on the collected measurements, process capability is analysed to determined root causes of poor performance and defects (Albeanu, *et al*., 2010). Several tools and techniques can be used in this phase such as brainstorming, Ishikawa diagrams, FMEA, and capability sixpack. However, the nature of the LSS project conducted dictates what tool to adopt. In the present case study LSS project, statistical analysis, capability sixpack, FMEA, Ishikawa/cause-and-effect diagram are employed to identify, organise and validate potential root causes of defects.

7.2.4.1 Process Capability Indices

Process capability indices are divided into indices that measures the potential capabilities (C_p) and those that measure the actual capabilities (C_{pk}) of the processes (Brass, 2007). Process capability analysis relies on either historical data or sample data collected specially for the purpose (Arcidiacono & Nuzzi, 2017). It helps to quantify and monitor process variability by using the capability indices to compare outputs of the production processes in SPRTC to specification limits. According to Liu and Chen (2005), C_p and C_{pk} provides single number assessment of the process ability to meet specification limits for the interested quality characteristics. Consequently, in this study, it is used to identify opportunities for improvement or modification within SPRTC microalga-culture processes for developing a potentially low-cost animal *cum* microalgae production system.

To examine if a process is capable to be operated within specification limits, the C_p and C_{pk} capability indices are used. C_p or the process potential index “indicates the process’ potential performance by relating the natural process spread to the specification (tolerance) spread”. It provides information on the process under analysis because it does not consider where the mean of the process is located relative to UCL and LCL.

$$Cp = \frac{\text{USL}-\text{LSL}}{\text{UCL}-\text{LCL}} = \frac{\text{USL}-\text{LSL}}{6\sigma}$$

If C_p = 1, then the specified range and the range of the natural variations of the process under investigation are the same, suggesting that the process is *barely capable* and can potentially produce non-defective products as long as the mean of the process is centred to the specified target. Moreover, if the value $C_p > 1$ then the process is potentially capable if the mean of the process is centred to the specified target and it is perhaps producing products that meet or exceed the CtQs. In the same vein, if the range of the control limits is greater than the specified range then $C_p < 1$ and the process is incapable (Brass, 2007).

In response to this limitation, C_{pk} performance index “indicates the process actual performance by accounting for a shift in the mean of the process toward either the upper or lower specification limit” (Suozzi, 1999). C_{pk} tells us how much a process really conforms to the specification, were the k-factor is the level of deviation of the process mean from the target.

$$C_{pk} = (1\text{-}k)\ C_{pk}$$

Where $k = \dfrac{\frac{\text{USL}+\text{LSL}}{2} - \bar{\text{X}}}{\frac{\text{USL}-\text{LSL}}{2}}$

Table 35 offers the equivalent C_p value corresponding to capability percentage while Table 36 shows the C_{pk} equivalent sigma level and percentage out of tolerance for the process measured.

Table 35: equivalent C_p value corresponding to Capability percentage (Suozzi, 1999)

Equivalent C_p	Capability %
0.50	86.64
0.62	93.50
0.68	96.00
0.75	97.50
0.81	98.50
0.86	99.00
0.91	99.35
1.00	99.73
1.33	99.994

Table 36: The relationship among different process performance metrics (Arcidiacono & Nuzzi, 2017)

C_{pk}	Sigma level	% out of tolerance	PPM of tolerance
0.33	1.0	31.73	317310.508
0.50	1.5	13.36	133614.403
0.67	2.0	4.55	45500.264
0.83	2.5	1.24	12419.331
1.00	3.0	0.27	2699.796
1.17	3.5	0.05	465.258
1.33	4.0	0.01	63.342
1.50	4.5	0.001	6.795
1.67	5.0	0.0001	0.573
1.83	5.5	0.000004	0.038
2.00	6.0	0.0000002	0.002

The control limits, Upper Control Limits (UCL) and Lower Control Limits (LCL) of the collected measurements for the process capability six-pack analysis in Minitab are obtained from the actual results from the processes using the following formula:

- UCL = mean value of the observations ($\bar{X}$) + 3(standard deviations)
- LCL = mean value of the observations ($\bar{X}$) - 3(standard deviations)

These control limits represent the natural variation of the measured data. A process is considered stable and in statistical control if it exhibits natural variation. Such processes will be adopted the way they are in SPRTC for alga-culture by livestock farmers, since they are predictable and will mostly continue to produce the same result.

7.2.4.2 Harvesting and Drying the Biomass Processes

Harvesting is performed every morning in SPRTC because the percentage proteins in the microalgae is highest early morning, and work is easier (temperature wise) for the workers due to extreme day temperatures in Tamil Nadu. Moreover, morning harvest gives time for drying throughout the day.

The harvesting process in SPRTC involves two stages of filtration. The first stage is to obtain the slurry (wet biomass) with approximately 10% w/v dry matter and 50% w/v left over culture medium. Secondly, the residual culture medium is removed to obtain fresh cake-like *Spirulina* biomass for direct consumption by livestock and/or humans or dried further to practically remove the entire residual medium and stored.

7.2.4.2.1 Setting-up for Filtration and Filtration

To filter the biomass, workers simply pass the culture through a synthetic fibre cloth (mesh size approximately 30-50 μ) using gravity as the driving power. The workers support the cloth by using a fine net to accelerate the process and prevent rupturing of the cloth. The filter is set-up above the pond in order to recycle the filtrate back into the pond (see Figure 35). A 200 μ mesh size sieve is placed above the entire filtration set-up to remove any unwanted matter like leaves, insects, or larvae.

Figure 35: SPRTC Worker Preparing the Filtration Set-up for Harvest (SPRTC, 2019)

To accelerate the filtration process, the workers use a scraper to gently move the slurry until most of the water filtered through. This movement is continued until the biomass begins to agglomerate into a ball, leaving the filter cloth clean depending on the richness of the biomass (i.e. spiral form of the culture and cleanliness of the medium).

7.2.4.2.1.1 Capability Analysis of the Setting-up & Filtration Process

Table 37 shows the data collected during the filtration set-up by four different operators over the period of 16 days. The goal here is to measure and assess the performance of the process as it is being done in the case organisation. The mean ($\bar{X}$) of the process is 107.52 seconds per pond worth of harvested biomass with an overall standard deviation of 14.58.

Table 37: Statistical Data of Filtration Set-up at SPRTC

No. of observations (N)	**Operators**	**Filtration Set-up (sec) (X)**	**($\bar{X}$) (sec)**	**(X- $\bar{X}$)**	**(X- $\bar{X}$)^2**
1	A	106.67	107.52	-0.85	0.72
2	A	115.00	107.52	7.48	55.93
3	A	93.33	107.52	-14.19	201.36
4	A	103.33	107.52	-4.19	17.56
5	B	113.33	107.52	5.81	33.76
6	B	122.00	107.52	14.48	209.67
7	B	95.00	107.52	-12.52	156.75
8	B	96.67	107.52	-10.85	117.72
9	C	106.67	107.52	-0.85	0.72
10	C	126.67	107.52	19.15	366.72
11	C	133.33	107.52	25.81	666.16
12	C	106.67	107.52	-0.85	0.72
13	D	101.67	107.52	-5.85	34.22
14	D	120.00	107.52	12.48	155.75
15	D	106.67	107.52	-0.85	0.72
16	D	73.33	107.52	-34.19	1168.96
		Σ(X) = 1720.34		**Σ(X- $\bar{X}$) = 0.0**	**Σ(X- $\bar{X}$)^2 = 3187.44**

Figure 36 below shows the capability sixpack analysis in Minitab with the two capability indices (C_p and C_{pk}) used to assess the performance of the filtration set-up process speed. Process capability is the inherent ability of the process to generate similar output by four different workers (A, B, C, & D) within the same UCL and LCL.

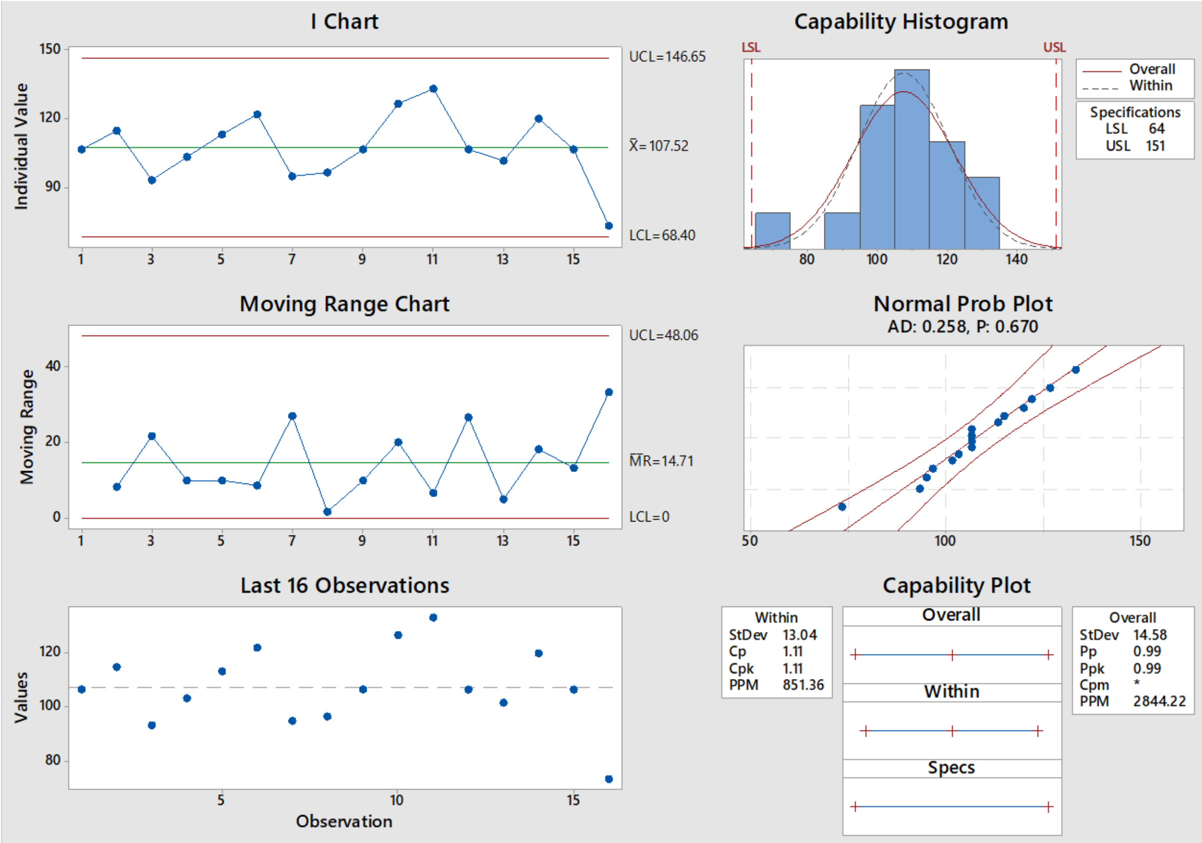


Figure 36: Process Capability Sixpack Report for Setting-up for Filtration Process.

Both C_p and C_{pk} for this process is 1.11 as shown in Figure 36. This indicates that the process is operating within 3σ limits. Similarly, all the points on the Moving Range (MR) Chart are within the control limits. The i-chart also shows only common cause variation, as no points appeared outside UCL or LCL limits (i.e. no special cause variation). Moreover, a C_p value of 1.11 further suggests a capability percentage of about 99.73% based on Suozzi (1999) scale (see Table 35 in page 185). The setting-up for filtration process mean ($\bar{X}$) is 107.52 seconds across four different operators and the overall standard deviation is 14.58.

Similarly, the filtration process is measured as it is being performed by the same four operators in the case company. Table 38 shows the filtration times (speed) collected across the four worker's shifts in the case company for 16 days. The mean ($\bar{X}$) of the process was 1319 seconds per pond worth of harvested biomass and an overall standard deviation of 322.9.

Table 38: Filtering the Culture Medium

No. of observations (N)	Operators	(X) in seconds	($\bar{X}$)	(X- $\bar{X}$)	(X- $\bar{X}$)^2
1	A	1000.00	1318.75	-318.75	101601.56
2	A	800.00	1318.75	-518.75	269101.56
3	A	1400.00	1318.75	81.25	6601.56
4	A	1000.00	1318.75	-318.75	101601.56
5	B	1100.00	1318.75	-218.75	47851.56
6	B	1300.00	1318.75	-18.75	351.56
7	B	1200.00	1318.75	-118.75	14101.56
8	B	1600.00	1318.75	281.25	79101.56
9	C	1300.00	1318.75	-18.75	351.56
10	C	1400.00	1318.75	81.25	6601.56
11	C	1300.00	1318.75	-18.75	351.56
12	C	1100.00	1318.75	-218.75	47851.56
13	D	1200.00	1318.75	-118.75	14101.56
14	D	1500.00	1318.75	181.25	32851.56
15	D	2100.00	1318.75	781.25	610351.56
16	D	1800.00	1318.75	481.25	231601.56
		Σ(X) = 21100.00		**Σ(X- $\bar{X}$) = 0.00**	**Σ(X- $\bar{X}$)^2 = 1564375.00**

The first thing to notice in Figure 37 is that the MR-chart that tells us about the process variation is in control (i.e. no point(s) outside of the control limits). However, the individual value chart (or i-chart) shows one point marked with a red symbol lying outside the upper control limit, indicating a special cause variation (this was due to rainy weather causing delays to the process). The process also has a C_p and C_{pk} indices of 1.37, suggesting a capability percentage of about 99.994% and a sigma level of 4.0. Taken together this process is stable and generally appears to be in statistical control but experiences occasional points outside of the control limits due to rainwater.

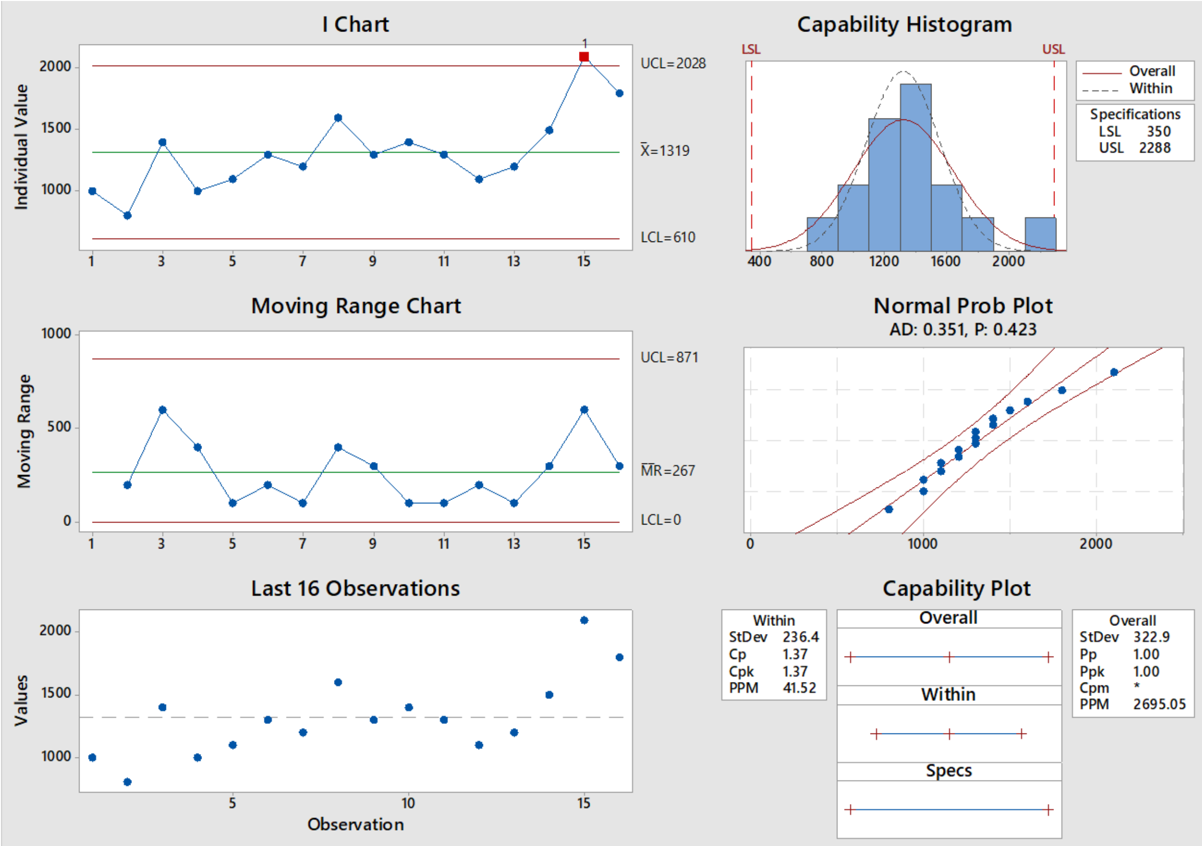


Figure 37: Capability Sixpack Report for the Filtration Process

7.2.4.2.2 Washing Harvested Slurry with Clean Water

After filtration, a slurry (containing 8 to 10% dry weight) is obtained, that is then washed with clean water to remove excess salt (approximately 20-30% of dry weight) from the biomass as shown in Figure 38. The biomass in the filtration cloth is then wrap in a piece of cotton cloth and pressed either by any type of press or by hand for final dewatering. In SPRTC, workers apply a pressure of about 0.15kg/cm^2 by placing heavy stone/concrete slab on top of the cloth containing the wet algae biomass. A colourless fluid is first expelled out of the cloth followed by green liquid, which indicates that it is time to stop; otherwise, much of the product will be lost. At SPRTC the pressing process last only about 15 minutes (when/if it is done) and a biomass cake of about 1 inch is obtained, which weight approximately 1.5 kg per pond. The reason for pressing the biomass is to reduce the drying time, as fast and proper drying is a critical feature of high-quality microalgae production.

Figure 38: Washing and Collection of Wet Spirulina in SPRTC Case Company (SPRTC, 2019)

7.2.4.2.2.1 Capability Analysis of the 'Washing and Dewatering Biomass' Process

Table 39 shows the measurements observed from the case company during the process of washing and dewatering the wet microalgae slurry. The mean ($\bar{X}$) of the process was 385.00 seconds per pond worth of harvested biomass with an overall standard deviation of 83.75.

Table 39: Washing Wet Biomass with Clean Water

No. of observations (N)	Operators	(X) in seconds	($\bar{X}$)	(X- $\bar{X}$)	(X- $\bar{X}$)^2
1	A	240.00	385	-145.00	21025.00
2	A	300.00	385	-85.00	7225.00
3	A	360.00	385	-25.00	625.00
4	A	400.00	385	15.00	225.00
5	B	300.00	385	-85.00	7225.00
6	B	500.00	385	115.00	13225.00
7	B	360.00	385	-25.00	625.00
8	B	300.00	385	-85.00	7225.00
9	C	400.00	385	15.00	225.00
10	C	400.00	385	15.00	225.00
11	C	500.00	385	115.00	13225.00
12	C	300.00	385	-85.00	7225.00
13	D	400.00	385	15.00	225.00
14	D	500.00	385	115.00	13225.00
15	D	400.00	385	15.00	225.00
16	D	500.00	385	115.00	13225.00
		Σ(X) = 6160.00		**Σ(X- $\bar{X}$) = 0.00**	**Σ(X- $\bar{X}$)^2 = 105200.00**

The MR-chart in Figure 39 shows that the LCL and UCL for this process are 0.00 and 318.0 respectively. In addition, none of the individual observations falls out of these limits, which indicates that this process variation is in control. The i-chart in the upper left-hand side of Figure 39 also shows no special cause of variation suggesting that the process results are predictable and will continue to observe variation within the control limits. Yet, the C_p and C_{pk} values are both < 1 (i.e. 0.97), which corresponds to about 0.27% out of tolerance and between 99.35 – 99.73% capable (see Tables 35 and 36 in page 185). Overall, this process shows no special process variation and consequently can be considered stable and predictable regardless of the operator in the case organisation.

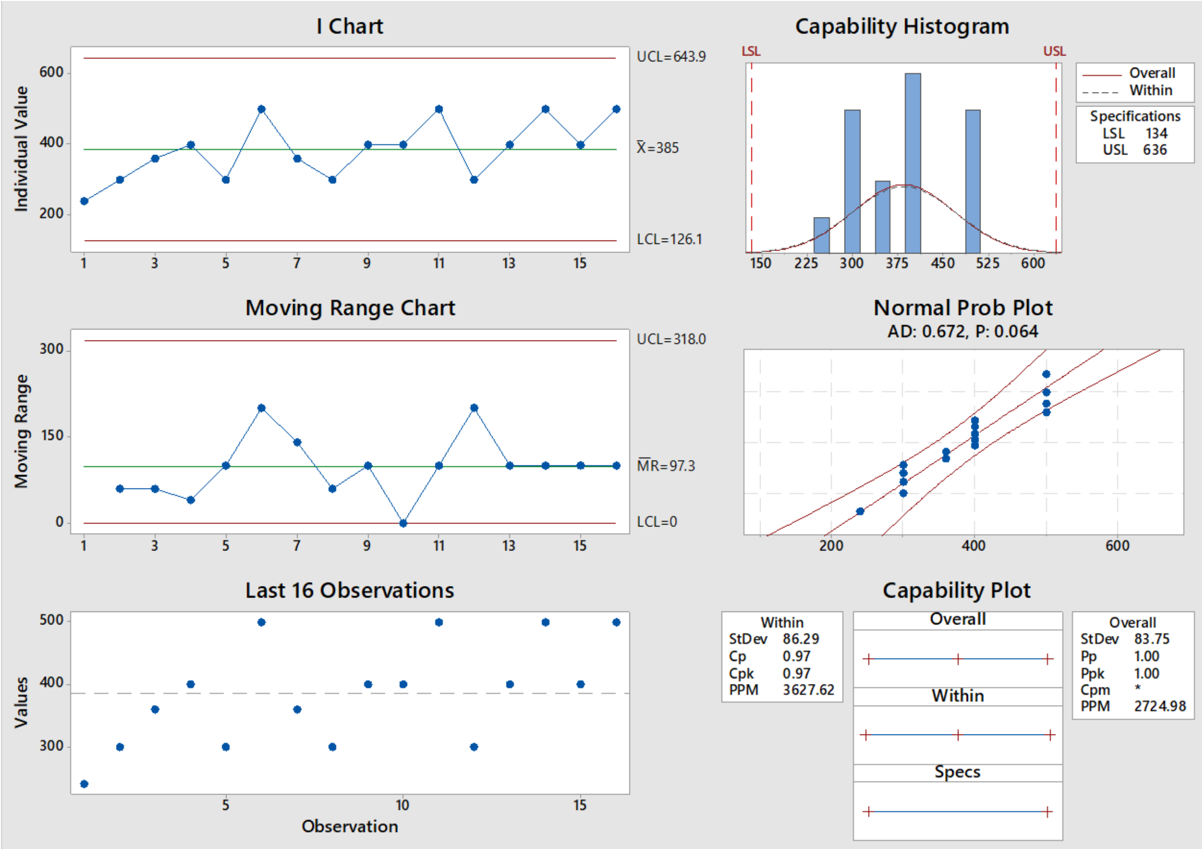


Figure 39: Process Capability Sixpack Report for Washing and Dewatering Microalgae Slurry

7.2.4.2.3 Spreading, Drying and Collecting Dried Microalgae Flakes

For economic reasons SPRTC, sun dried the concentrated biomass by spreading it thinly on a food grade polythene sheet under direct sunlight for approximately 4 to 5 hours. The dried flakes are collected using a scraper and then stored in a moisture free opaque container before grinding. It is important to properly dry the biomass since moisture content in excess of 8% could results in the growth of bacteria and moulds in the product. However, over drying often results in the vitamins and pigments loss. Other methods of drying include spray dying and freeze-drying. In spray drying, microalgae droplets are sprayed using a spray dryer into a drying chamber. It is a relatively fast process of drying algae (compared to hand spreading under the sun), which guarantees the preservation of heat sensitive pigments, nutrients and enzymes. Freeze-drying on the other hand is too expensive even though it would give better product quality (Becker, 1994).

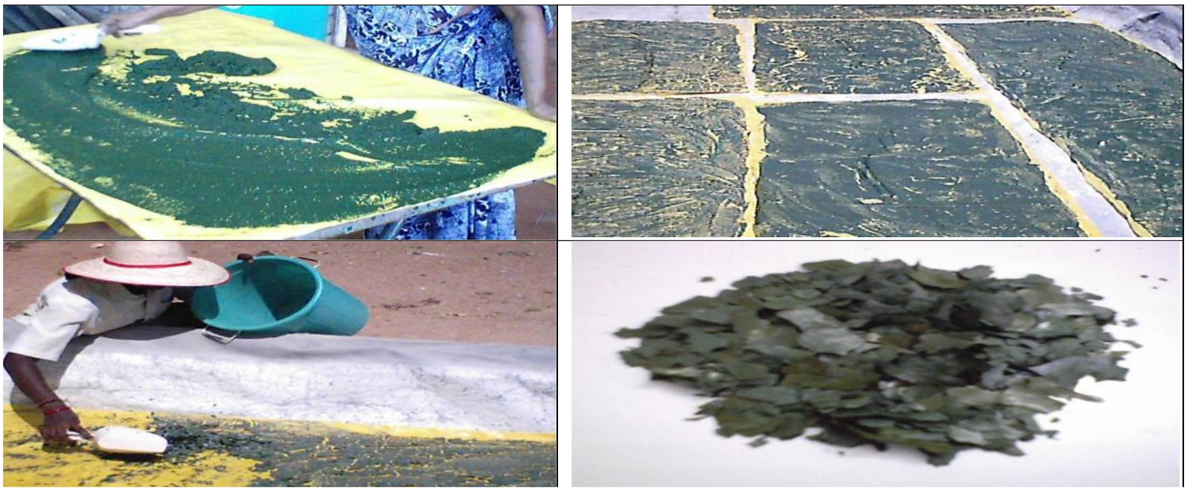


Figure 40: Spreading, Drying and Collecting Dried Microalgae Flakes at SPRTC (SPRTC, 2019)

7.2.4.2.3.1 Capability Analysis of 'Hand-spreading Wet Microalgae' Process

Table 40 relates to hand-spreading of wet microalgae slurry process prior to sun drying in SPRTC. The mean ($\bar{X}$) for this process is 222.50 seconds while the overall standard deviation was 49.46. The mean and the standard deviation do not tell us whether the process variation is natural or special. To know this, the researcher uses the control chart in Figure 41 below to see whether any changes are unusual or out-of-control.

Table 40: Hand-Spreading of Wet Biomass for Sun Drying

No. of observations (N)	Operators	(X) in seconds	($\bar{X}$)	(X- $\bar{X}$)	(X- $\bar{X}$)^2
1	A	200.00	222.50	-22.50	506.25
2	A	160.00	222.50	-62.50	3906.25
3	A	200.00	222.50	-22.50	506.25
4	A	300.00	222.50	77.50	6006.25
5	B	200.00	222.50	-22.50	506.25
6	B	300.00	222.50	77.50	6006.25
7	B	200.00	222.50	-22.50	506.25
8	B	200.00	222.50	-22.50	506.25
9	C	300.00	222.50	77.50	6006.25
10	C	200.00	222.50	-22.50	506.25
11	C	300.00	222.50	77.50	6006.25
12	C	240.00	222.50	17.50	306.25
13	D	200.00	222.50	-22.50	506.25
14	D	160.00	222.50	-62.50	3906.25
15	D	200.00	222.50	-22.50	506.25
16	D	200.00	222.50	-22.50	506.25
		Σ(X) = 3560.00		**Σ(X- $\bar{X}$) = 0.00**	**Σ(X- $\bar{X}$)^2 = 36700.00**

None of the individual observations or points in the i-chart falls out of control limits suggesting that this process variation is in control, predictable and will continue to observe similar variations within the control limits independent of operator. Nonetheless, the process potential to meet tolerance (C_p) and its ability to meet tolerances (C_{pk}) values are both < 1 (i.e. 0.87), which translate to about 1.24% out of tolerance and about 99.00% capable (see Tables 35 and 36). Overall, hand-spreading wet algae for drying in SPRTC shows no special process variation and can be considered predictable to be adopted for microalgae production for feed.

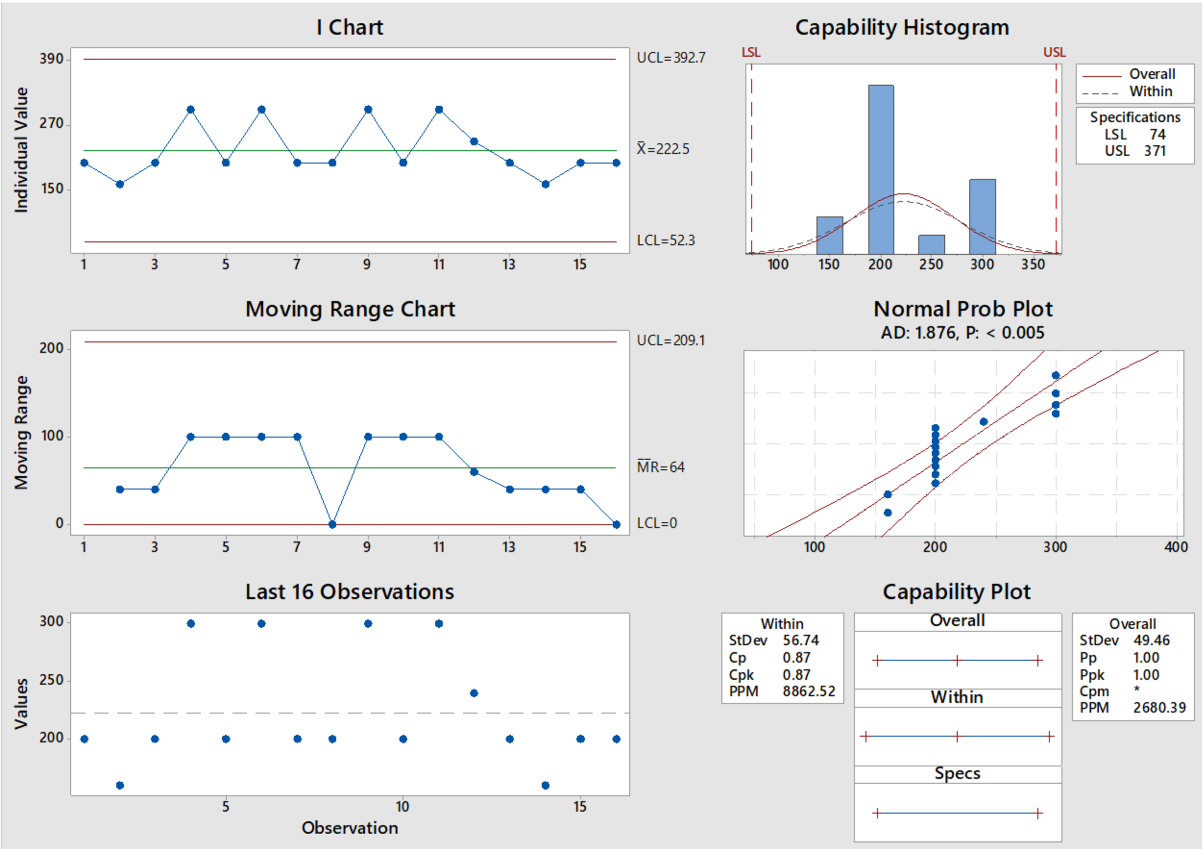


Figure 41: Process Capability Sixpack for Spreading Wet Microalgae Slurry for Sun Drying

7.2.4.2.3.2 Capability Analysis of 'Sun Drying Wet Microalgae' Process

The effectiveness of drying processes can have a large impact on microalgae quality and process efficiency in SPRTC. The average or process mean ($\bar{X}$) is 3550 seconds per pond worth of harvested biomass with a standard deviation of 1791. Table 41 shows that harvested wet biomass were not dried on days 4, 14 and 15. These was due to unfavourable weather – rainy and/or cloudy weather. According to one of the managers in-charge of operations: "*we had to pour back the harvested microalgae into the ponds and hope for a better weather the following day*". The manager also states that "*sometimes we froze the wet algae depending on the space we have in the refrigerator*".

Table 41: Outdoor Sun Drying Wet Biomass in SPRTC Case Organisation

No. of observations (N)	Operators	(X) in seconds	($\bar{X}$)	(X- $\bar{X}$)	(X- $\bar{X}$)^2
1	A	4500.00	3550	950.00	902500
2	A	5000.00	3550	1450.00	2102500
3	A	4000.00	3550	450.00	202500
4	A	-	3550	-3550.00	12602500
5	B	3800.00	3550	250.00	62500
6	B	4400.00	3550	850.00	722500
7	B	4400.00	3550	850.00	722500
8	B	4600.00	3550	1050.00	1102500
9	C	4000.00	3550	450.00	202500
10	C	4600.00	3550	1050.00	1102500
11	C	4400.00	3550	850.00	722500
12	C	4900.00	3550	1350.00	1822500
13	D	4200.00	3550	650.00	422500
14	D	-	3550	-3550.00	12602500
15	D	-	3550	-3550.00	12602500
16	D	4000.00	3550	450.00	202500
		Σ(X) = 56800.00		**Σ(X- $\bar{X}$) = 0.00**	**Σ(X- $\bar{X}$)^2 = 48100000.00**

The data plotted in Figure 42 below shows that not all the observations are within the specified limits and three points come very close to the LCL limits. The fact that three points are outside the specified limits generate a defective Parts per Million (PPM) value of 519630.20 for the observed performance. A result of 0.04 C_{pk} also suggests that sun drying is an ineffective process in SPRTC, which could lead the company into producing defective products. The Figure also shows that the performance of the sun drying process (P_{pk}) is not reasonably capable with a value of 0.03, indicating that the process is not in control. The capability histogram on the upper right side of Figure 42 below also shows that sun drying process in SPRTC is off-centred and exhibits special causes of variation (due to unfavourable weather conditions such as rainy and/or cloudy weather). These findings have great implication on the VoCs and subsequent the CtQs. For example, the 'cost of failure' will increase whenever wet algae fail to dry and begins to grow moulds and bacteria due to unfavourable weather[49]. In the same vein, the overall 'quality' and flavour of the product is also highly influenced by the method of drying since

[49] It is worth noting here that the results show that the drying process is not reliable due to unfavourable weather, but it does not lead to process failure if they pour back harvested biomass into the ponds.

moisture level higher than 8% can lead to low product quality that is susceptible to contamination and lower shelf live.

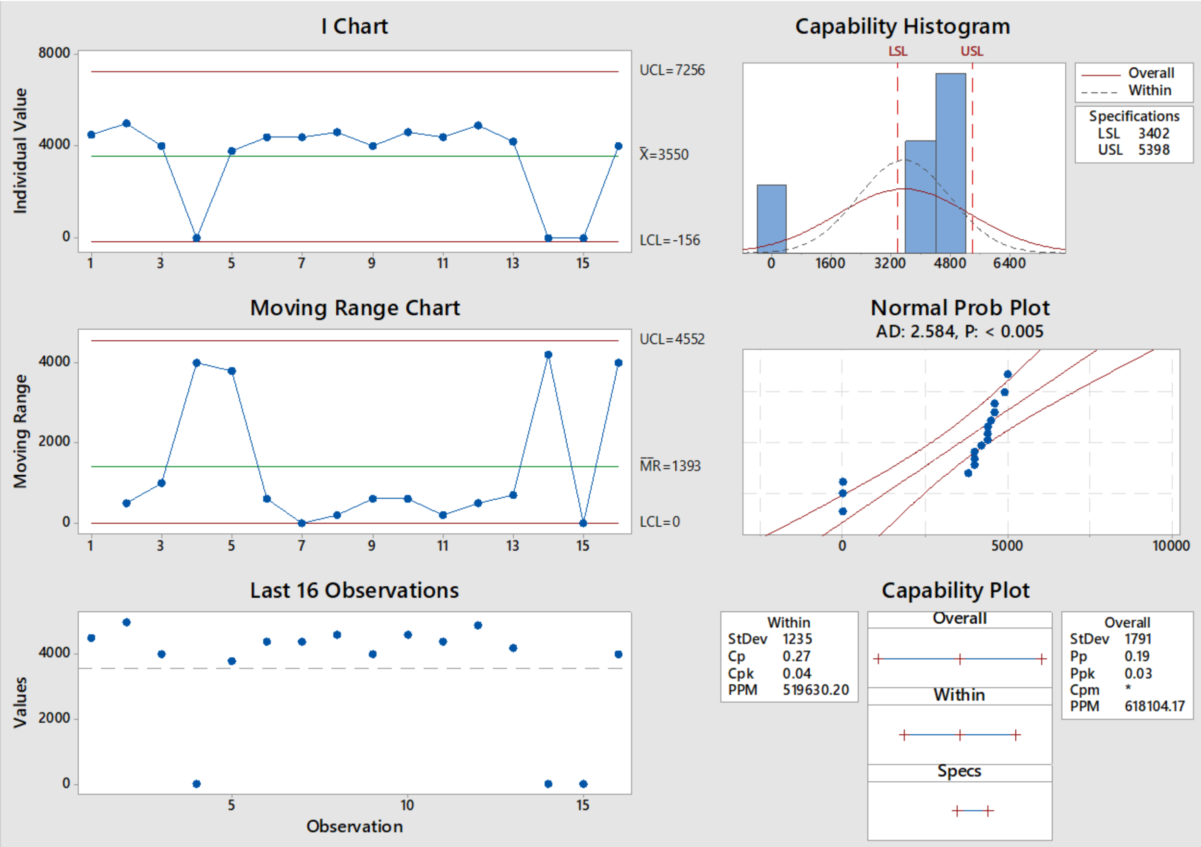


Figure 42: Process Capability Sixpack Report for Sun Drying Wet Microalgae

7.2.4.2.3.3 Capability Analysis of 'Collecting Microalgae Flakes after Sun Drying' Process

Table 42 below presents the data gathered during the process of collecting dry microalgae in SPRTC by four different workers. It shows that this process is highly dependent on the drying process as no collection is done on day 4, 14, and 15 due to failure to sundry the harvested wet algae. However, in the 13 days that collection was possible, the process mean ($\bar{X}$) was 237 seconds per pond worth of harvested biomass with a standard deviation of 52.18.

Table 42: Collecting Dry Microalgae process in SPRTC

No. of observations (N)	Operators	(X) in seconds	($\bar{X}$)	(X- $\bar{X}$)	(X- $\bar{X}$)^2
1	A	200.00	237	-36.92	1363.32
2	A	300.00	237	63.08	3978.70
3	A	240.00	237	3.08	9.47
4	A	-	-	-	-
5	B	200.00	237	-36.92	1363.32
6	B	240.00	237	3.08	9.47
7	B	360.00	237	123.08	15147.92
8	B	200.00	237	-36.92	1363.32
9	C	200.00	237	-36.92	1363.32
10	C	200.00	237	-36.92	1363.32
11	C	200.00	237	-36.92	1363.32
12	C	240.00	237	3.08	9.47
13	D	300.00	237	63.08	3978.70
14	D	-	-	-	-
15	D	-	-	-	-
16	D	200.00	237	-36.92	1363.32
		Σ(X) = 3080.00		**Σ(X- $\bar{X}$) = 0.00**	**Σ(X- $\bar{X}$)^2 = 32676.92**

The C_{pk} values for the 'collecting dry microalgae' process in SPRTC is 0.98, which indicates that the process is operating within 2.5 - 3σ limits. Moreover, it can be observed that all the points in both the MR-chart and i-chart are within the control limits. The i-chart also shows only common/natural cause variation as no points appeared outside the 396.5 UCL and 77.3 LCL limits, in other words, no special cause variation. In addition, a C_p and C_{pk} values of 0.98 further translate into a capability percentage of 99.35 to 99.73% based on Suozzi (1999) scale (see Table 36).

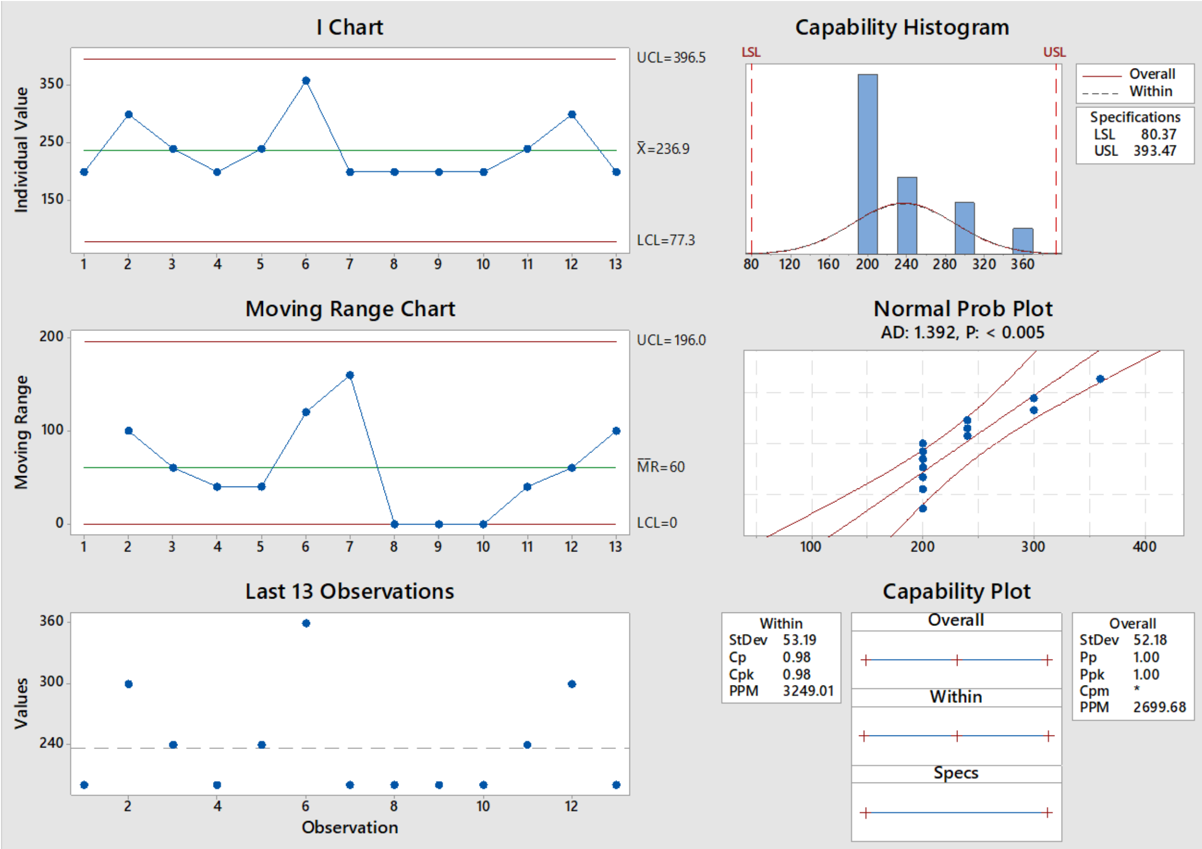


Figure 43: Process Capability Sixpack Report for 'Collecting Dry Microalgae' Process

In the define, measure and analysis phases above, the researcher presented the case organisation's microalgae production processes and procedures and was able to recognize the processes with the highest potential for improvement (e.g. filtration and spreading wet microalgae) and more importantly the one that needs to be changed or modified (i.e. sun drying) using capability sixpack analysis in Minitab. Filtration is slow because there is no mechanism in place to drive the flow of the culture medium through the filter and the workers must rely on gravity while they wait. More importantly, sun drying takes a long amount of time, and drying depends completely on the weather condition. Figure 44 below shows the weights of harvested wet and dry biomass in SPRTC over 90 days period, with days like 8, 9, 15, 37, 44. 45, 46 and so forth (marked by the red circles) showing zero microalgae harvest due to rainfall and/or inability to dry. According to SPRTC technical team, "*sometimes we have to dispose the biomass put out to dry, as it starts to develop mould due to high humidity and/or lack of sun. While in the case of rainy days the entire harvested wet biomass had to be poured back into the ponds or refrigerated*". The implication of poor drying system to the overall production capacity of the case company ranged between 10 kg to 22 kg of wet biomass, which is equivalent to about 1 kg to 2kg of dry mass per day. Accordingly, based on the sample production records over the period of three months, SPRTC lost approximately 1.6 kg of dry mass of *Spirulina* per day from 10 ponds of 18m^2 size each due to poor drying system. More specifically, three days in the month of January (4.8 kg of dry *Spirulina* lost), ten days in February (16kg of dry *Spirulina* lost) and three days in March 2018 (4.8 kg of dry *Spirulina* lost).

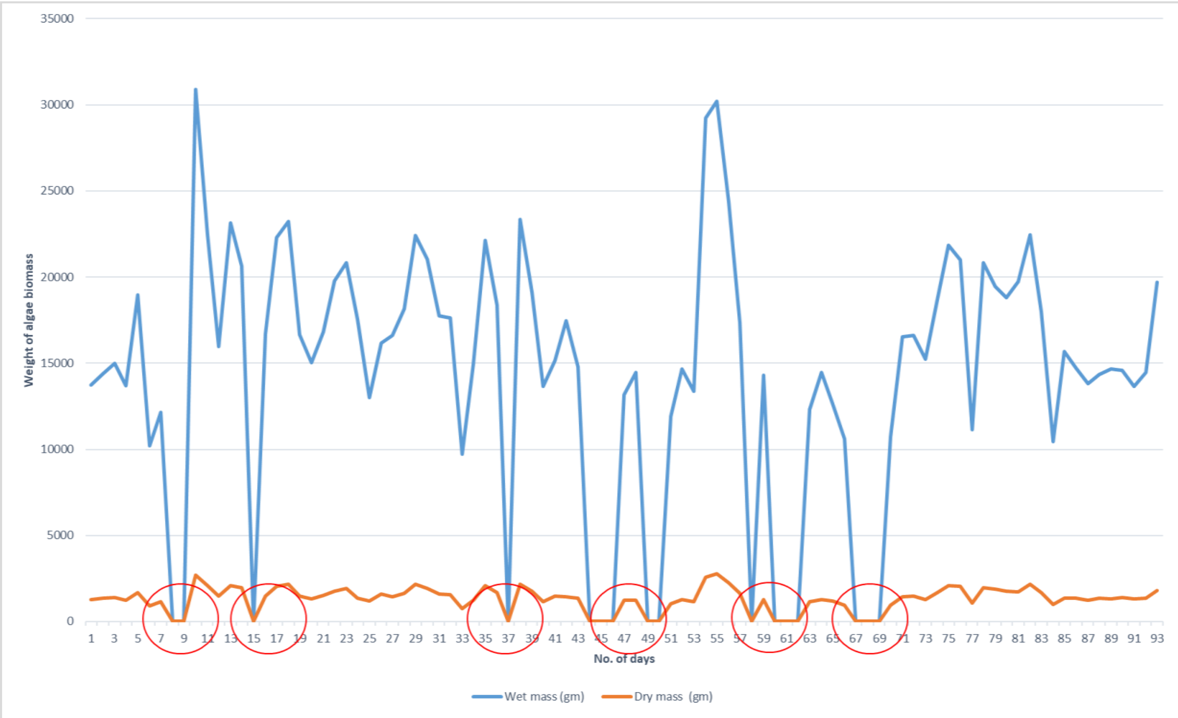


Figure 44: Three Months Sample of Harvested Microalgae Biomass in g from 10 Ponds each of 18m² size

In the measure phase, information was collected about the processes regarding how long different process steps take across four operators or workers. This makes it possible to exclude processes that are capable or capable with some noises e.g. filtration and washing, and focus on the drying process that is having a larger impact on the production or have room for modification/change. In the analysis phase, the harvesting processes that were considered critical to algae cultivation are analysed (from the point of repeatability and stability) using statistical methods such as mean, standard deviation, C_p, C_{pk} and PPM values using capability sixpack analysis.

7.2.4.3 Quality Analysis and Standards at SPRTC

The product quality at SPRTC is carried out on sample of *Spirulina* flakes provided by the case company under their parent organization Antenna Nutritech Foundation to SGS India Pvt ltd. SGS is a "world's leading inspection, verification, testing and certification company, [which is] recognised as the global benchmark for quality and integrity" (SGS Group, 2020). Internal measures currently in place to control contamination and maintain monoculture at SPRTC is presented in Table 31 FMEA analysis. A breakdown of the quality test parameters and methods of testing performed by the SGS on behalf of the case company to measure the nutritional contents of *Spirulina* are presented in Figure 57 through 61 in the Appendix. According to one of the SPRTC manager in charge of production, these tests are undertaken on a quarterly bases or at least twice a year, depending on the number of cultivation cycles for the year in question. The test result indicated that the quality (i.e. protein content) of product with sun drying and manually operated by local SHG (Self Help Group) women still fits with the market requirement. Even, the product resulted from open pond sun dried *Spirulina* biomass is on a par with the available market product by commercial producers like Nutrex Hawaii (60% protein of *Spirulina's* dry weight).

7.2.4.4 "As-is" Cost of production

Cost analysis is a tool that could be used to shed some light into both the process elements that contribute most to the cost of production as well as help to estimate the ultimate cost *Spirulina* biomass at SPRTC case company. Thereby helping stakeholders on where to focus future systems design and research. According to Slade & Bauen (2013), "the limitations of algae production cost assessments […] include data constraints and reliance on parameters extrapolated from lab-scale analyses. The purpose of this cost overview is to provide a consistent procedure for evaluating decisions to help farmers and other livestock agriculture stakeholders in Nigeria make informed choices on whether to invest in open-pond microalgae production, designed not only to offer relatively high-quality feedstuff for animal consumption, but also to help improve animal husbandry. Table 43 below shows the "as is" cost of production at SPRTC case study farm from the year 2012 to 2018.

Table 43: Cost of Producing 1 kg at SPRTC Farm

Year	Cost of producing 1kg of dry Spirulina
2012	£4.80
2013	£5.01
2014	£5.53
2015	£5.69
2016	£5.81
2017	£6.02
2018	£6.18

Figure 45 (page 202) summarised percentage breakdown of the production cost: the farm size, fixed and variable/recurring costs that led to the production cost per kilogram shown in Table 43 above.

Table 44: SPRTC Initial Investment Requirements[50] (SPRTC, 2019)

Plant size	**Small**
Land requirement	0.3 Acre
Production Capacity (10 tanks)	1 Ton
Plant type	Manual
Production area	400 square m
Recurring Cost	**GBP**
Input cost[51]	£1,933.5
Spares and maintenance	£128.9
Fuel charges	£0.0
Consumables	£128.9
Fixed Cost	**GBP**
Salaries and wages	£3,222.5
Interest on Capex @ 12%	£644.5
Depreciation @ 10%	£537.1
Administration expenses	£214.8
Land cost	£3,437.3
Miscellaneous fixed assets	£1,074.1
Certification & preoperative	£859.3
1 X PVC pond	£197.0
Production accessories & Equipment	£656.6
Other expenses	£481.5

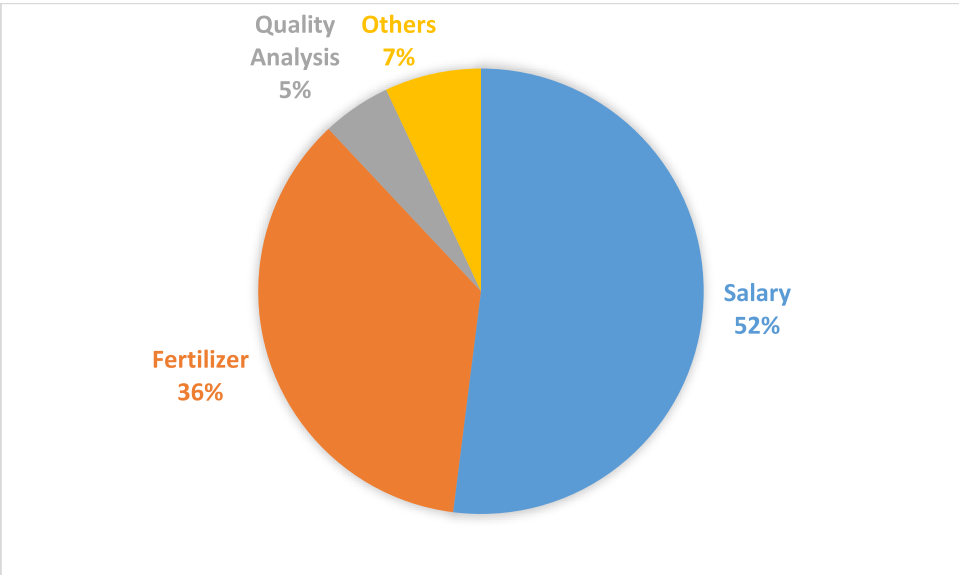


Figure 45: Percentage Breakdown of Production Cost (SPRTC, 2019)

[50] @ 1 Indian Rupee equals 0.011 Pound sterling
[51] Including agitator. vibro sifter, siever, blender, vacuum packing machine, deep freezer, and raw material for inoculums.

The initial investments for setting-up a one tonne microalga ponds according to the case study are presented above. However, these estimates include unit cost of materials not required for growing microalgae for animal used. For instance, the initial investment for the case study farm, includes £130.2 for a stone pulveriser, £157.3 for a hot air oven, £16.2 for an electric sealing machine, £21.7 for a sealing and packaging counter, £10.85 for a 5 kg capacity weighing machine, and £27.1 for a microscope. These are not necessarily needed for a microalga *cum* livestock production systems for animal feed and can easily be deducted from the overall initial input investment cost. Thus, a potential savings of about 19%.

7.2.5 Improving and Controlling Out-of-Control Processes

Following the measure and analysis phase, the Improve Phase is concerned with changing or modifying the analysed processes in the direction of becoming "in control", predictable and able to meet livestock farmers' requirements by generating a set of probable solutions. In this research, the performances were overwhelmingly in control or predictable apart from sun drying, which is unpredictable and out of control. Consequently, the object of this phase is to investigate improvement opportunities for the capable or barely capable processes as well as potential new designs or methods for the out-of-control process. Some of the systematic tools applied by the researcher in this phase includes fishbone diagram (also referred to as cause-and-effect diagram or Ishikawa diagram), and the Failure Modes, and Effects Analysis (FMEA) in the define phase.

7.2.5.1 Fishbone Diagram (Cause and Effect Analysis)

Commonly referred to as "Ishikawa Diagram" because it was invented and incorporated by the Japanese quality control statistician named Kaoru Ishikawa. The fishbone analysis is a tool for examining organisational processes and their effectiveness (Bose, 2012). It is also referred to as a "Cause and Effect Diagram" because it evaluates the root causes and sub-causes of a particular problem (in this case product contamination/defect) and therefore contributes in uncovering other symptoms of a business problem. The fishbone diagram is created with the intention to identify and group the root causes that generate a quality problem as well as causes of other types of problems, which the case company confronts. For the cause-and-effect analysis presented in Figure 46, the problem "contaminated microalgae biomass" an undesirable event with negative impact on feed quality was chosen. The risk assigned to the investigated event will be referred to as "the risk of contaminating microalgae biomass". The frequency of contaminated biomass represents a performance indicator, which can be taken into consideration when analysing the production processes. The main issue that needs to be minimised according to the VoC has been situated on the head of the diagram while the causes are put as the bones. Five main causes – people, process, equipment, environment, and materials, and 28 secondary causes were identified by the researcher based on responses from the case study participants. These are presented in order of relevance in the fishbone diagram below, with the most important causes being situated at the beginning.

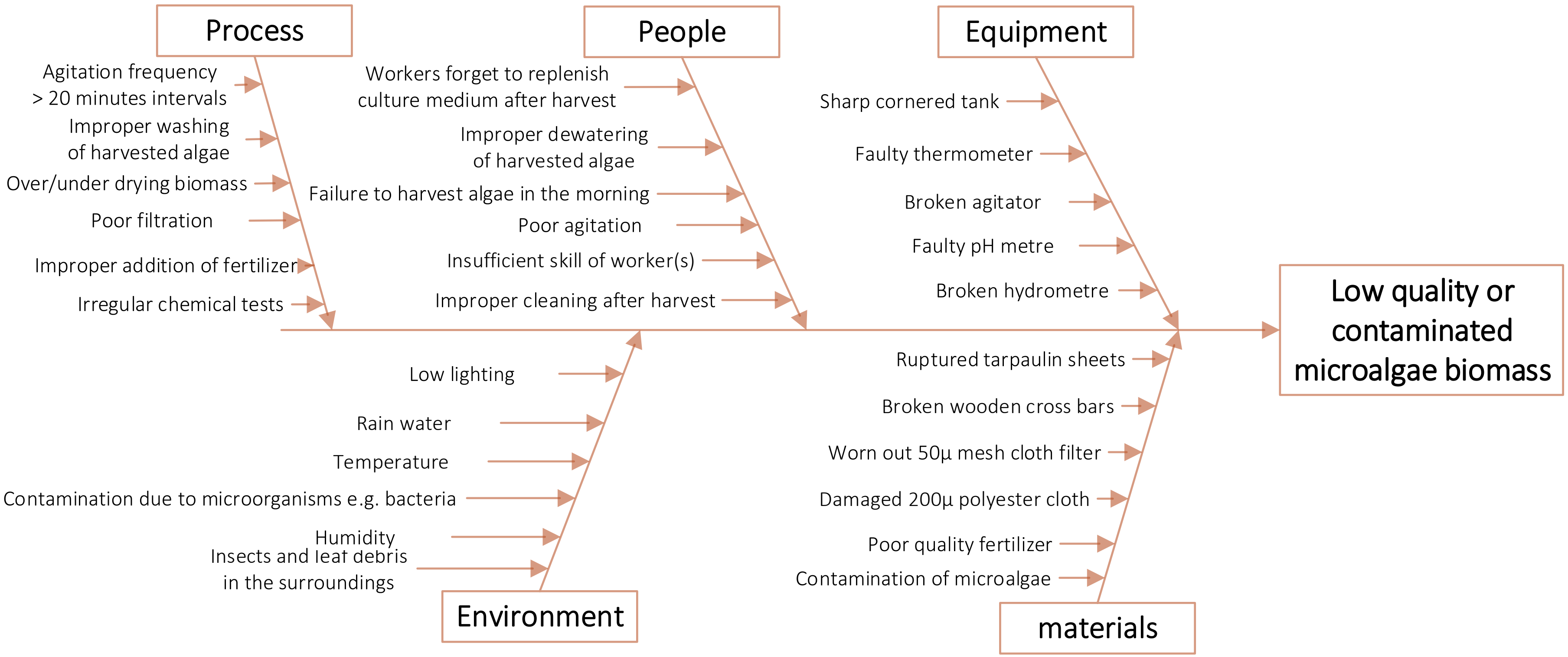


Figure 46: Cause and Effect Diagram

The case study of SPRTC reveals that the major production problem of the microalgae farm is contamination. “Sun drying is by no means a perfect process with problems arising due to potential contamination of the produce, variability in drying times, rain damage and so on” (Weiss & Buchinger, 2012). The case company is a small-scale open-air microalgae producer and its sun drying process involves dewatering wet algae biomass and hand spreading it on polyethylene plastic sheets to dry under direct sun light. Like most production companies, this process is carried out by people and involves the use of different items in the fishbone diagram such as materials and equipment. Moreover, these entirely takes place in the environmental setup of the company and it is carried out by the management in-charge of production (people). Both the case company’s technical team and the analysis phase above revealed that the major problem in SPRTC microalgae culture system is ensuring a smooth system of drying wet biomass. If this can be fulfilled, then there is high possibility that small-scale livestock farmers in Nigeria could adopt this production system. The FMEA analysis in the define phase examines the potential root causes identified in the fishbone diagram by looking into the effects, likeliness of occurrence and the current control measure(s) in place in the case company.

7.2.5.2 Identified areas of focus for improvements

After performing the FMEA analysis using information collected from the case study participants, improvement opportunities are explored from the literature to identify and examine as elaborative suggestions as possible. Unfortunately, these suggestions could not be tested in the case company; however, the purpose is to obtain suggestions for open pond microalgae culture system that could improve process stability, predictability and reduce product defects. Based on the RPN ratings of the operational procedures, only two processes have relatively high RPN and thus stand out for improvement. They are scaling-up mother culture and drying of biomass.

7.2.5.2.1 Suggestions for Improving Scaling-up Mother Culture Process

The improvements suggestions presented in the literature for the scaling-up single inoculation of microalgae cells until the population reaches its near maximum density to be transferred into larger ponds are presented and discussed here. While some researchers focused on the filtration of culture medium or using drugs to control contaminants (Borowitzka, 2005; Li, *et al*., 2006), others are concerned with changing the cultivation environmental condition to annihilate them (Morales, *et al*., 1993; Ismaiel, *et al*., 2016).

7.2.5.2.1.1 Filtration and Chemical Control Measures

Owning to the microscopic nature of *Spirulina* cells, filtration can be to a certain extent an effective method of removing biological pollutants such as copepods and rotifers. According to Borowitzka (2005), filtration during harvesting as well as in culture netting could help in controlling biological contaminants. However, although larger adult rotifers can be easily controlled through filtration using mesh silk screens, their eggs and developing young could pass through the filter. Wang *et al*., (2013) suggest microalgae culture medium should be continuously filtered every three to four days to thoroughly clear the larger biological contaminants. In the same vein, the use of chemicals to kill biological contaminants in algae culture has also been explored in the literature. For instance, both Snell and Hoff (1987), and Wang & Yi (1997) found several pesticides (e.g. *Trichlorphon, Buprofezin, Decamethrin* and *Tralocythrin*) that could be used to annihilate common harmful zooplankton suspensions on microalgae culture. Moreover, studies have shown that 10mg of quinine could be used to kill ciliates with relatively less damage on the algae cells, which is one of the criticisms of using chemical additives to control biological pollutants as they may also damage the desirable algae (Moreno-Garrido & Canavate, 2001). Although, chemical additives are one of the suggestions for controlling contamination due to biological pollutants, the screening of pesticides that do not damage the target culture is important.

7.2.5.2.1.2 Changes to the production environment Measures

In addition to photosynthesis, the temperature and light in the culture environment also influence the rate of growth of biological pollutants (Huntley & Lopez, 1992). According to Morales *et al.*, (1993), the feeding intensity of some biological pollutants increases in the dark (or night), suggesting that adjusting the light cycle in the algae farm to an optimum range in favour of the native microalga could reduce contamination due to copepods. Moreover, adjusting the pH of the culture medium is another method of eliminating biological contaminants. For example, monoculture of *Spirulina* can be attained by raising the pH of the medium above 10.5. Conversely, by reducing the culture medium pH to 3.0 one could annihilate flagellate. However, “the pH level of the medium [also] affects the growth of [*Spirulina*], [whose] […] optimum pH for growth was recorded at pH 9.0” (Ismaiel, *et al*., 2016). A pH of 3.0 could cause significant reduction in growth rate, and therefore, these pH levels is assumed to cause stress according to the literature.

Salinity drops above 20% (w/v) NaCl can also be used to control ciliate and amoeba dominance in *Dunalialla* ponds (Wang, *et al*., 2013). Taken together it can be suggested that maintaining a high pH is important for maintaining monoculture especially in case of *Spirulina*, however, in line with Becker (1994), employing a pH drop to 3.0 for one to two hours daily can help control rotifers. However, these methods will require farmers to have detailed knowledge of the adaptive range to environmental factors of both the contaminants and the target microalga.

7.2.5.2.2 Suggestions for Improving/Modifying Microalgae Drying Process

Parikh (2014) defined drying as "the vaporization and removal of water or other liquids from a solution, suspension, or other solid-liquid mixture to form a dry solid". Drying harvested *Spirulina* biomass from a moisture content of about 80% wet basis to the recommended moisture content of <10% is challenging. Several studies have been conducted aiming to fulfil the knowledge gap in the drying mechanism of microalgae, probing into the reasons for long drying times and subsequent drying cost (Hosseinizand, *et al.*, 2017; Biz, *et al*., 2019; Bheda, *et al*., 2018) (Biz, *et al*., 2019). In 2017, Hosseinizand *et al*. study the drying mechanism of microalgae and the optimum drying temperature to preserve quality characteristics. The authors found that "the dominant mechanism in *Chlorella* [microalgae] drying is diffusion, which is attributed to the collapse of microalgal cells structure with increased drying temperature". Therefore, "microalgae should be dried at an optimum medium (60–80°C) temperature to evaporate entrapped moisture in the cells". Freeze, sun, and oven drying have been extensively evaluated in the literature as plausible methods for drying microalgae (Zepka, *et al*., 2008; Viswanathan, *et al*., 2012; Biz, *et al*., 2019). Except for spray drying, all the aforementioned drying techniques requires a preliminary step of harvesting and dewatering, which represents between 20 – 35% of the production cost of the biomass (Gudin & Thepenier, 1986).

7.2.5.2.2.1 Spray Drying

Spray drying is a fast, continuous, scalable and reproducible process of producing dry powders from a wet material by atomisation in a hot drying medium typically air (Sosnik & Seremeta, 2015). See Figure 47. Drying in spray dryers is essentially a time saving operation that is specially appreciated for drying heat sensitive materials such as microalgae. Drying algae dispersion straight from the cultivation tank in the case company through this technique could minimise some of the issues that make the drying process out of control or unpredictable. Yet, spray dryers may cause disruption of the microalgae cells especially when the cell membranes that accumulates water and lipid behaves like a rigid skin in the drying chamber (Sadek, *et al*., 2015), which could make the end product to appear hollow and very porous (Mujumdar, 2006). Besides, spray dryer is expensive to install and not energy efficient due to high amount of heat lost as well as "loss of product in the walls of the drying chamber and the low capacity of the cyclone to separate fine particles" (Sosnik & Seremeta, 2015). For these reasons, other techniques such as vacuum tray drying, and innovative solar conduction drying are examined further as more suitable drying improvement options for this research.

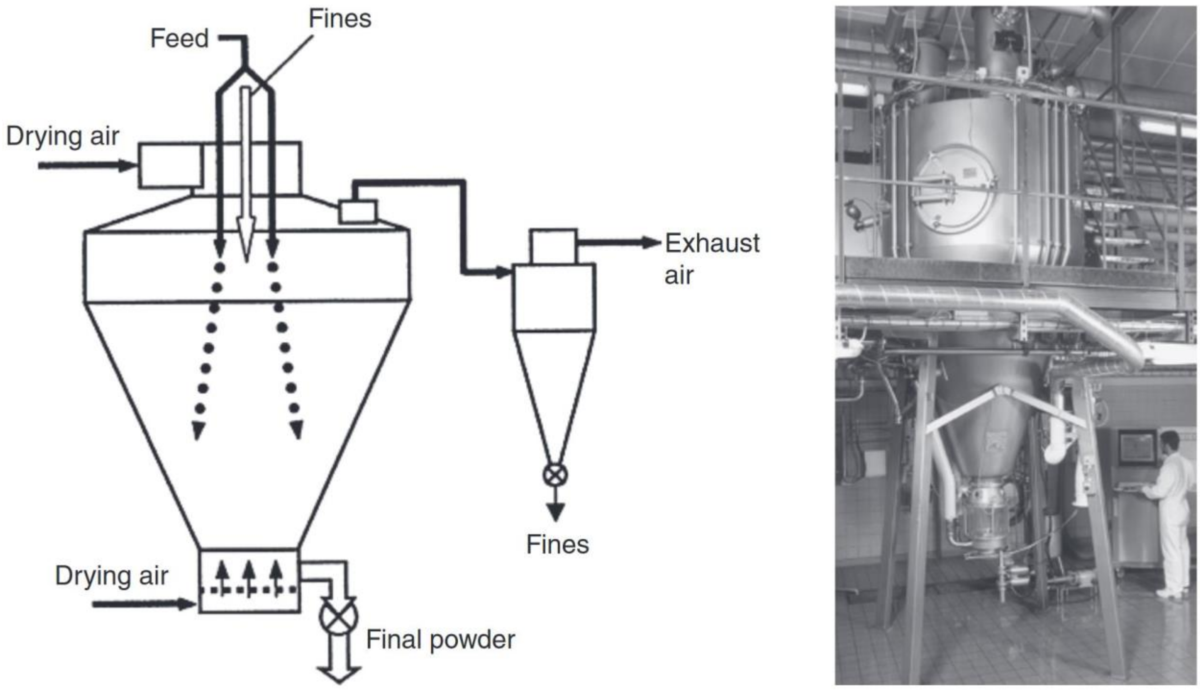


Figure 47: Schematic of two-stage spray dryer (Left Hand Side) & Pilot scale integrated fluidized bed spray dryer (Right Hand Side) (Anandharamakrishnan & Padma, 2015).

7.2.5.2.2.2 Vacuum Tray Drying

Tray dryer passes hot air over the surface of wet algae biomass (or any wet solid) that is spread on trays arranged in racks. According to Parikh (2014), this type of dryers has low initial cost and are highly versatile for drying almost any material, excluding dusty solids that are better suited for spray drying. In vacuum tray drying (Figure 48), there are no changes to molecular structure of the material during the drying process, most likely due to the low temperature (50 – 60^{o}C) of the technique. When microalga is dried at lower temperatures, its quality is even better, which is one of the unique selling points of vacuum drying. Contrast to sun drying where microalgae is immersed directly into open hot air under the sun and is dried by convection, vacuum tray dryers are an indirect heat dryer in the sense that the heating media usually hot gas is transferred to the wet material through the dryer's heated surface by conduction (Mujumdar, 2000). Although, heat transfer rates by conduction are low, because contact between the tray bottom and its supporting shelf is rarely continuous or uniform, the shelf above the material also foster drying by radiation. Drying time are usually between 12 – 48 hours (Parikh, 2014), which despite reducing dust losses could create dying bottleneck as harvest is undertaken daily in the case company. Thus, this technique is suitable for small batch drying of wet materials. According to Mujumdar (2000), for production rates under 200 t/year (such as the case company 30000 – 50000g/month), shelf dryers could be considered economical, however, batch identification need to be maintained. In Nigeria, vacuum dryers are common within the food drying and smoking industry. At the time of this report, vacuum dryers are relatively expensive in Nigeria (approximately £2000) compared to solar conduction dryers that can be built by farmers themselves using readily available materials.

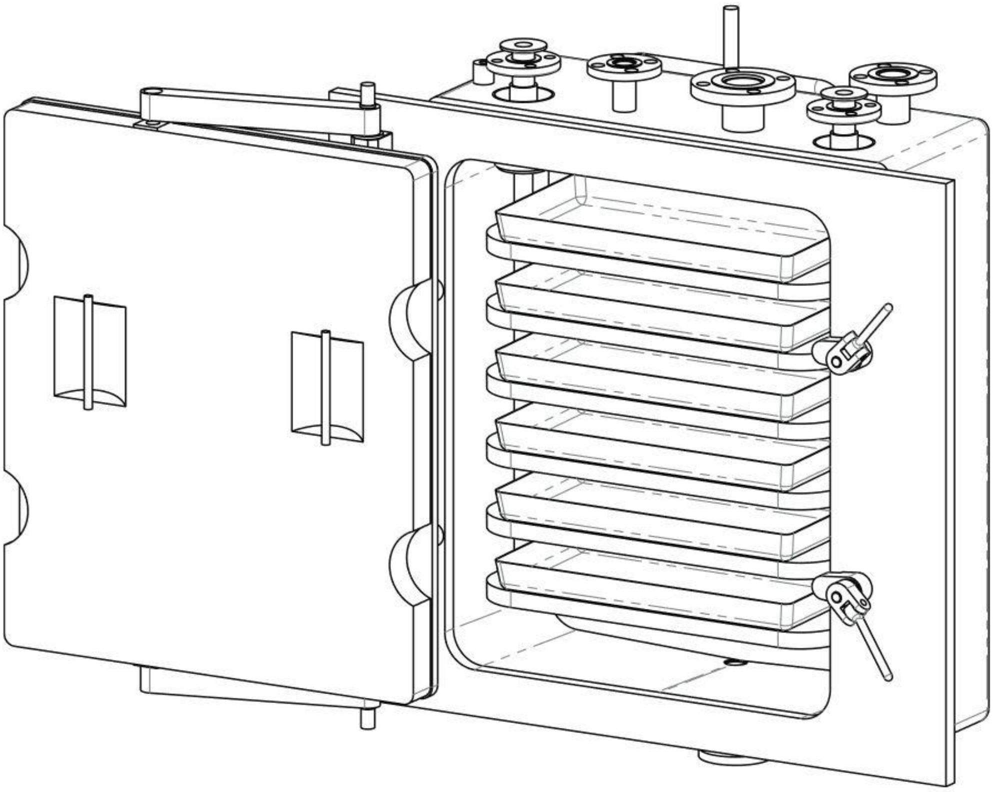


Figure 48: A Vacuum Tray Dryer (PSL, 2016).

7.2.5.2.2.3 Solar Conduction Dryer (SCD)

In Nigeria, open sun drying, and preservation of agricultural produce is a widespread, effective, and economical technique, especially among fish farmers. However, as found in the measure and analysis phase of this research, external parameters such as temperature, moisture contents and drying airflow rate cannot be controlled. Thus, resulting in longer drying time that could lead to contamination and degradation of biomass quality by windblown debris, insects etc. (Kumar, *et al*., 2016). An innovative solar conduction dryer "comprise [of] a radiation absorbing heat conducting surface, and a convection channel formed by a radiation controlling cover over the conducting surface" (Michael, *et al*., 2010). Solar drying is distinct from direct sun drying in that it utilises equipment(s) to collect the sun radiation to harness energy for drying application. It offers desirable biomass quality with less impact from the environment. Moreover, in this method, the moisture in the wet material is removed by sun-heated air with temperature ranging between 50 and 60^{o}C (Subedi & Bhattarai, 2017). Thermolabile products such as microalgae and other sensitive food products like cardamom and coffee that requires constant temperature while drying necessitates preparation and processing not easily available to local farmers at an affordable cost. Fortunately, most of the existing solar dryer designs are suitable for small-scale industrial production (as in the case organisation) or family use for drying various crops.

In Nigeria, local farmers continue to dry crops by traditional open sun drying techniques, despite the various solar dryers available in the country (Itodo, *et al*., 2002). Eke (2014) asserts that several materials such as wood, metal cement and mud are available, affordable and could easily to be worked on by rural farmers to build solar collector in Nigeria. The author also found that solar dryers "savings in drying time over the open sun drying for wood, cement, mud and metal solar conduction dryers were 131.25%, 131.25%, 136.17% and 192.11% respectively" with system drying efficiencies of "7.38%, 19.56%, 20.25%, 20.91% and 27.24% […] for open sun, wood, cement, mud and metal in that order". In the same vein, Itodo *et al*. (2002) achieved a 12% and 10% collector and system drying efficiencies respectively using an indirect passive dryer with rock bed. However, One of the major problem facing crop farmers in relation to food drying is that "most crops are harvested when the outdoor air conditions is not suitable for natural air drying and crops have relatively short time of spoilage unless the moisture is removed" (Aliyu, *et al*., 2013). Itodo & Fulani (2004) added an air-preheated unit to a passive solar dryer to improve the collection, system and pickup efficiencies. The authors achieved a sun-drying rate of 1.6kg/day, the collection, system and pickup efficiencies were 85%, 7% and 14% respectively under the climate of central Nigeria. The authors also indicate that one solar drying technology is not sufficient for all the geographical zones in Nigeria because of the variability in solar parameters, which makes it important to consider the location where the drying operation is done for optimum performance. For example, in Northern Nigeria preheated air unit might not be necessary due to high temperature and longer dry seasons compared to the Southern part of the country where rainy season last from March to November.

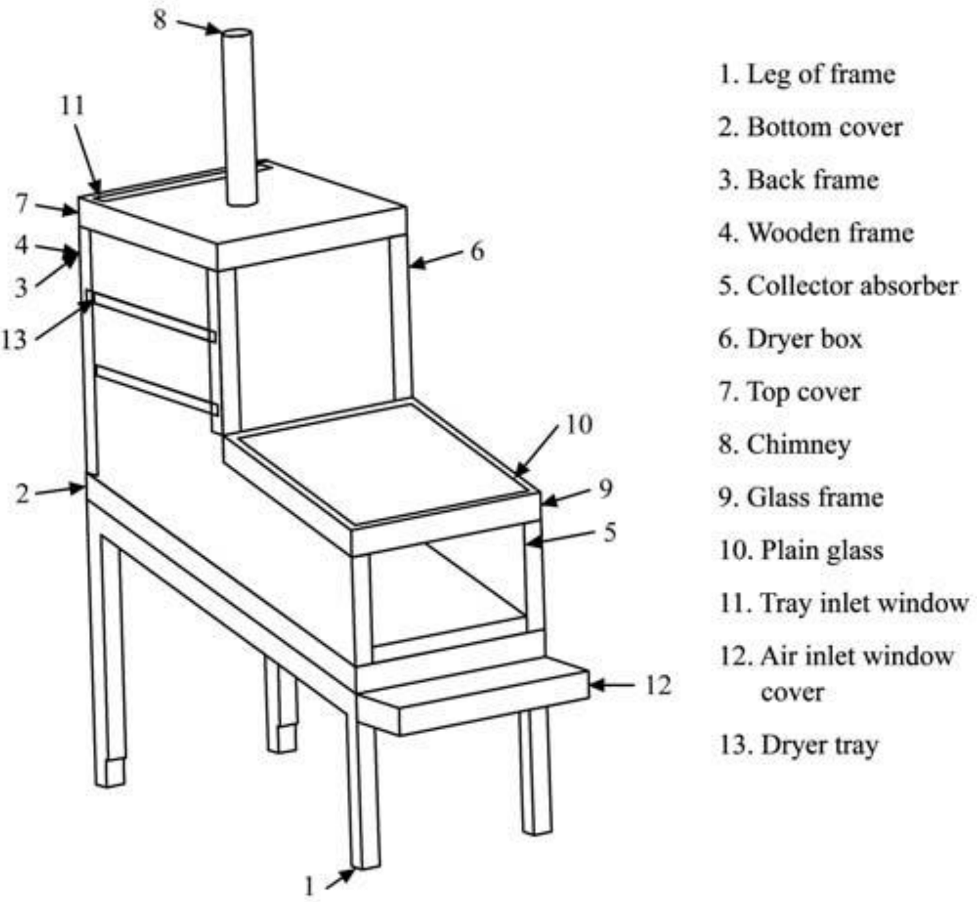


Figure 49: Schematic Diagram of a Typical Nigerian Solar Dryer Model (Aliyu, *et al.*, 2013).

As shown in Figure 49, the dryer is made up of a chimney for passing moisture and heated air into the atmosphere. A glass window that allows radiation from the sun as well as an inlet and outlet window for the dryer tray. It also has a tray absorber for spreading wet materials within the main box. The frame of the dryer as well as the walls could be made from wood, metal or even clay to save cost. The walls are wrapped with insulating materials for collecting radiation from the sun. Finally, the frame can also be constructed from metal, wood or clay. When made from clay or cement, the dryer is constructed in area free from shades (See Figure 50 below). Likewise, moveable ones made from either wood or metal are placed under direct sun. Wet materials such as tomatoes or wet algae slurry is spread on the dryer try. "Sun radiation falling on the glass is being absorbed by the collector plate painted black and transmitted into the drying chamber through the inlet window by natural air blowing" (Aliyu, *et al*., 2013).

Figure 50: Solar dryer with cement thermal solar collector (Eke, 2014).

The duration of drying, moisture level and temperature generated by metal, wood, cement, mud dryers and open sun drying are shown in Table 45 below. Although mud or clay dryers are the most affordable option, they dry crops twice as fast as cement and wood dryers. It can also be observed that metal solar dryers exhibit higher performance form the four types of dryers under examination.

Table 45: Dryers' performances while drying tomato and the dryers' production cost (Eke, 2014).

	Metal Dryer	**Wood Dryer**	**Cement Dryer**	**Mud Dryer**	**Open Sun Drying**
Average temperature generated by solar collector units of these dryers during the drying test, °C	42.43	40.46	40.76	41.08	30.00
Average temperature generated by solar drying chambers of these dryers during the drying test, °C	46.62	42.52	43.10	44.08	30.00
Initial tomato moisture content-Wet basis, %	90.00	90.00	90.00	90.00	90.00
Final tomato moisture content- Wet basis, %	4.00	4.00	4.00	4.00	4.00
Total drying time, hr	76.00	96.00	96.00	94.00	222.00
Production cost, ₦ (2014)	15000.00	8860.00	10470.00	5000.00	0.00
Production cost equivalent in GBP (2019)[52]	32.46	19.17	22.65	10.82	0.00

Overall, solar dryers made from readily available local materials offers the most suitable improvement/modification options for both the case company as well as small-scale livestock farmers in Nigeria. A review of the literature for these dryers revealed that savings in drying time over the existing open sun-drying method as in the case study company can be achieved. The drying chamber temperature solar dryers could range between 50 – 60°C from natural sun radiation and can be optimised for use in cloudy weather by adding preheated-air unit. Studies have also shown that solar energy in Nigeria can be harness and utilised to dry wet materials such as microalgae slurry during

[52] Researcher's

cloudy weather (Itodo, *et al.*, 2002; Itodo & Fulani, 2004; Eke, 2014; Musembi, *et al.*, 2016). The technique can offer faster drying process, better product quality and >50% time saving than open-air sun drying. The time saving advantage of solar dryers can easily be improved by adding solar powered fan at the air inlet (Eke, 2014) or through integrated solar and biomass cabinet dryer (Okoroigwe, *et al.*, 2013)). Furthermore, "using combined solar and biomass [cabinet] dryers have the potential to increase the productivity and resultant economic viability of small and medium-scale enterprises producing and processing agricultural produce in developing countries" (Okoroigwe, *et al.*, 2013).

7.2.5.3 Conceptual Design of an Algae Cum Livestock Production System

Figure 51 below illustrates a conceptual microalga cum livestock production system designed by the researcher. The system shows how microalgae could be cultivated using livestock waste. However, this type of system needs to be researched further, especially with regards to the different ways the liquid fertilizers from the animal waste effluent can be sterilised and sustainable ways to dry the biomass etc. Based on the results of this research, the latter, could be improved using locally constructed solar dryer. See Figure 49 & 50 above.

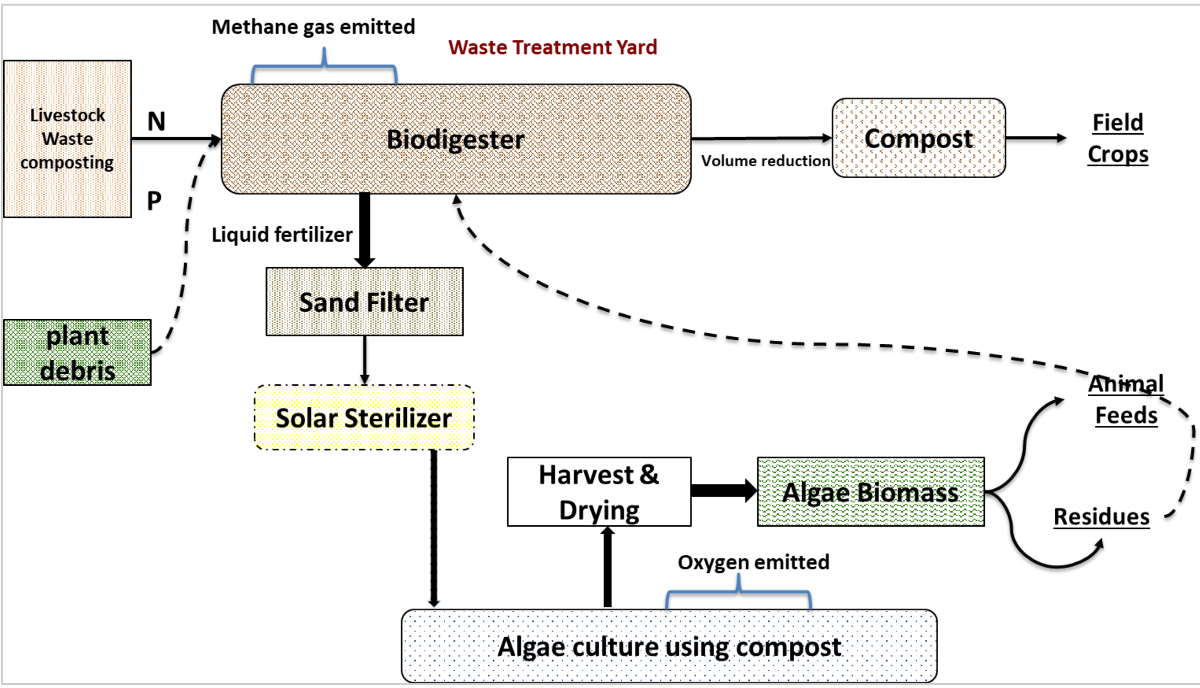


Figure 51: A Conceptual Microalgae cum livestock production system (Source: The Research)

7.3 Transferability of Results Consideration

Transferability is "the degree to which the results of [a] […] research can be transferred to other contexts or settings with other respondents" (Korstjens & Moser, 2018). In this study, the researcher facilitates the transferability judgment by potential animal farmers in Nigeria through extensive description of the case study environment in India as well as comparing some of the important parameters of culture, which has great impact on the overall yield of microalgae biomass, such as tank design and scale, light, temperature, nutrients, weather, human resource requirements between SHG operators in India and smallholders in Nigeria.

Temperature is an important parameter for cultivating microalgae and has immense impact on the overall yield as it directly influences the biochemical processes such as photosynthesis within the cell factory of the microalgae (Khan, *et al*., 2018). It is one of the determining factors in microalgae growth and production. With an optimum temperature range of 20 to 30 °C (Singh & Singh, 2015), the countries to cultivate microalgae (in an open-air systems) are relatively confined to the regions between the Tropic of Cancer and Tropic of Capricorn (see Figure 52 below).

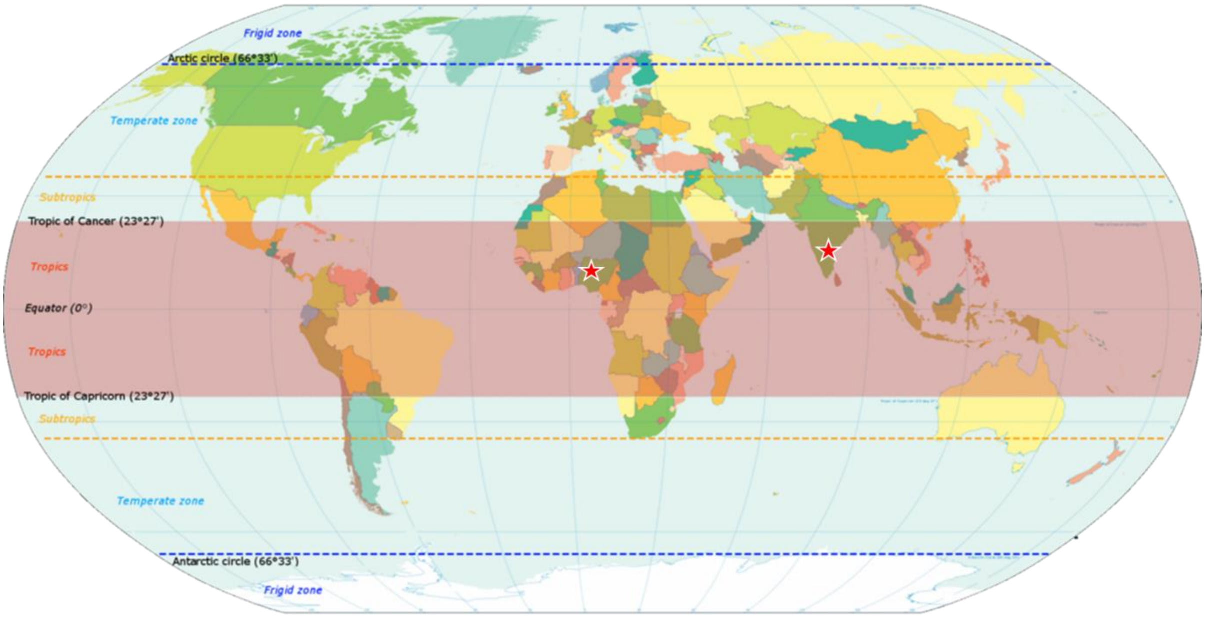


Figure 52: Countries between the Tropic of Cancer and Tropic of Capricorn[53]

As long as the other parameters such as light intensity, nutrients, pH, salinity etc. are met, the cultivating environment in India is very similar to that of Nigeria. Furthermore, similar strain of microalgae (*Spirulina*) could be transferred from India to Nigeria since temperature is one of the key characteristics of selecting what strain of microalgae to grow (Borowitzka, 2013). Figure 53 below shows the temperature comparison between India and Nigeria through the seasons.

[53] Stars indicated the regions under consideration for this research

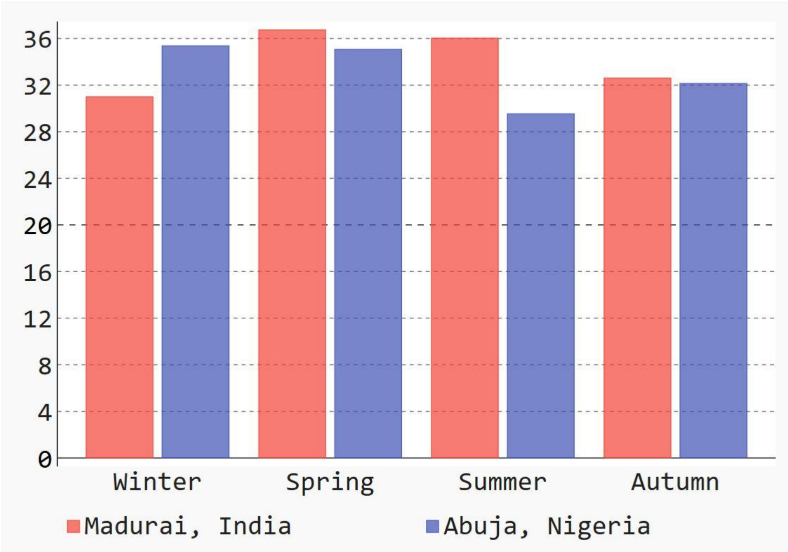


Figure 53: Average daytime temperatures for Abuja, Nigeria vs Madurai, India (in °C) (WMO, 2020).

According to the World Meteorological Organization, the average temperature in Madurai India where the case study company is located and central Nigeria (Abuja) are 34.1 °C and 33.0 °C respectively (WMO, 2020). This implies that both regions maintain temperatures close to the optimum temperature stipulated in the literature for growing various strains of microalgae (i.e. between 27 and 31 °C depending on the source) (Kitaya, *et al.*, 2005).

Water requirement is also vital for growing *Spirulina*, and although microalgae can grow in various kinds of alkaline waters, it requires Sodium bicarbonate, Magnesium sulphate, Potassium nitrate, citric acid, common salt, urea, Calcium chloride, Iron sulphate and Ammonium sulphate to grow. According to Data Africa, "from 1990 to 2015, Nigeria had average annual rainfall of 1,197mm across a total cropland area of 41.35M ha" (Data Africa, 2015). In the same vein, India's average annual rainfall ranged between 300 to 650mm, with the case study region of Madurai averaging around 840mm (Climate-Data, 2020). Suggesting that the availability of water in Nigeria could support similar culture medium requirement in terms of water supply. Other facilities required such as harvesting basin and dryer for instance are readily available in Nigeria and other developing countries and not confined to India. Figure 54 below summarises in a bar-chart the average rainfall for the regions under investigation with Nigeria having more than twice the amount of rainfall during the summer.

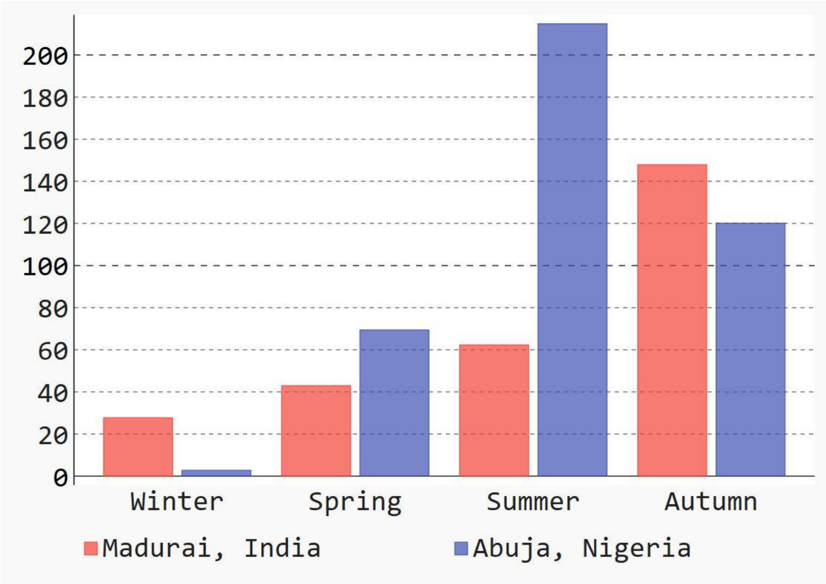


Figure 54: Average rainfall for Abuja, Nigeria vs Madurai, India (in mm) (WMO, 2020).

The majority of the microalgae in developing countries are produced in open ponds, made of either basin lined with thick polyethylene plastic or polished cement. The former although much more common due to their relative cost effectiveness in the short run (as polyethylene material) is prone to wear and tear in the long run. Similar polyethylene plastic ponds are readily available in Nigeria, especially among the fish farming communities.

Chapter Eight: Discussion, Conclusion & Recommendations

8 Introduction

This chapter discusses some of the key findings from the previous chapters. The overall discussion and implications to the livestock industry in Nigeria are presented in two separate sections. The first section of this chapter discusses the findings in relation to the challenges and prospects of the Nigerian livestock and aquaculture industry as well as the potential role that microalgae could play in reducing them. The second section presents the key findings from the case study microalgae farm and the potential improvement or modification techniques that livestock farmers in Nigeria could adopt while considering to integrate microalgae culture with their livestock farming. This is then followed by conclusion and recommendations.

8.1 Study 1: Understanding the Feed Market and Market Analysis

8.1.1 Discussion and Implications

In this section, the major findings of the market primary research are discussed. Local livestock and aquaculture farmers in Nigeria are engaged to capture, articulate and prioritise feed user's requirements in Nigeria. The analysis of the semi-structured questionnaires gathered from the respondents of this research identified; the amount of feedstuff used, farmers criteria for selecting feeds, feed brands market share, perceived benefits of different feed ingredients, and farmer's familiarity and interest in growing their own feed material (i.e. microalgae) for animal feed formulation. Three ingredients commonly used in formulating feeds namely crop residues, vitamins and minerals premix, as well as cereal grains (such as maize, corn and sorghum) were observed as the most common materials utilised by farmers. This is because low-income communities control the livestock industry in Nigeria who cannot afford the relatively expensive fishmeal, as well as materials for which humans and animals compete for, as food such as soybean meal and/or groundnut meal to feed their animals. In addition, the majority of the livestock farmers (flagged by 77.9%) do not have access to credit or loans and therefore rely on informal sources of credit such as family savings and/or fellow farmers. Consequently, local feeds are typically deficient in dietary amino acids - the building blocks of proteins, lipids and essential fatty acids. These findings support previous research that reported that low quality feed materials such as crop residues and roughages are commonly used among low income farmers actively engaged in livestock production in Nigeria (Abowei & Ekubo, 2011; Udo & Umoren, 2011), which is increasing animal mortatlities, low productivity and low return on investment (Udo & Umanah, 2017). In the literature, both convetional plant-based sources of protein and lipids like groundnut cake, soybean meal etc. as well as unconventional sources such as blood meal, tadpole meal, house fly larvae meal, single cell protein including algae, fungi and bacteria have been suggested (Memon, *et al*., 2002; Sogbesan & Ugwumba, 2008; Selvakumar, *et al*., 2013; Abowei & Ekubo, 2011). Granted, groundnuts and soybeans are less expensive to cultivate and are currently produced by local farmers in Nigeria, however, they are feedstocks for which humans compete with animals (FAO, 1992). Moreover, whereas blood meal is considered unethical by most Nigerians due to their religions and/or beliefs (Fisher, 1968; Green, 2011), tadpole meal contains alkaloid toxins that need to be investigated further prior to commercialisation (Tran, 2015). Subsequently, this research focuses on the single cell protein-microalgae, specifically the microalga *Spirulina*, which can be use as alternative to conventional protein and lipids sources in feed. The use of microalgae for animal feed supplementation or as feed ingredients is auspicious as an alternative to the aforementioned staple foodstuff, thereby mitigating the current food-feed competition in Nigeria and contributing towards sustainable agriculture.

This research consequently found that despite the fact that current price of microalgae feedstock is about twice that of fishmeal and about five times that of conventional plant-based protein sources, it is one of the few plant-based protein source that is on a par with fishmeal in connection to crude protein and lipids contents. Protein and lipids are also considered by farmers as the most vital nutritional constituents in feeds as well as a key indicators of feed quality. Moreover, the cost of buying imported feeds with adequate levels of the aforementioned nutritional requirements is extremely high to the point where return on investment is almost impossible when/if farmers choose to use foreign brands throughout the farming cycle. For instance, the feed brands with the biggest market share especially in the non-ruminants subsectors are Coppens, Skretting and Topfeeds. Both Coppens and Skretting are foreign brands perceived by livestock and aquaculture farmers as having high quality due to high protein content, while Topfeed is a high-end local brand praised for it high crude protein content.

Additionally, according to the results of the survey conducted for this study, local livestock farmers are unfamiliar with microalgae, however, the majority of them (flagged by 83.5%) are interested in learning and undertaking training on how to grow microalgae. Unfortunately, the level of education and literacy skills among Nigerian livestock and aquacuture farmers is very low. Thus, farmers capability to induldge in cultivating new feedstuff as well as adopting integrated microalgae *cum* livestock prodcution system is limited. In the same vein, as mentioned earlier lack of capital due to limited access to credits and loans could also affect local farmers ability to adopt microalgae culture system with their animal production. Commenting on farmers limited access to bank loans in Nigeria, Kamunga *et al*. (2008) assert that the requirements set by private credit and loans agencies like commercial banks in Nigeria are such that repayment is expected to begin one to two months after the loan, which is not favourable for livestock farmers who require a minimum of three feedlot cycles to begin earning money for repayments. Public loans from government sources are also inaccessible to individual farmers except through cooperative societies that most farmers are not members of because of the society's weak financial strength and poor management, which has led to fraud and financial malpractice and limited loans and savings for their members.

Taken together, the conceptualisation of a low cost microalgae *cum* livestock production system for Nigerian farmers to adopt could improve the quality of on-farm feed formulation for non-ruminats, as well as serve as a protein and lipids supplements for ruminants. The implication of these is that farmers perception that only imported high-cost foreign feedstuff can promote animal growth at a rate in which profit can be achieved could be proven wrong. Unfortunately, the present cost of producing microalgae in photobioreactors or open-ponds for human consumption is extremely high for local farmers to adopt directly. It is therefore important to design a microalgae culture system that focuses on cutting production cost, whilst ensuring quality as stipulated by animal farmers (i.e. voice of the customer). Thus, this research (i.e. in study 2) employed a process improvement methodology - lean six sigma, which is designed to eliminate production bottlenecks, remove waste and reduce cost (i.e. cost of failure) to provide a better response to farmers' feed needs.

8.2 Study 2: Microalgae Production Process Analysis

This section discusses the key findings of the case study analysis, which aimed at achieving the fourth and fifth research objective[54]. The results of the case study analysis indicate that, the majority of the input materials (Xs) required for cultivating microalgae in an open-air system can be sourced locally in Nigeria or created using readily available materials. For example, it was found that any non-toxic watertight open container that can withstand damage by oxidisation and/or other chemical reactions could be used to cultivate microalgae if sharp angles are avoided.

In addition, the DMAIC cycle applied to the case company (SPRTC microalgae production farm), demonstrates that:

- The sun drying process after harvesting microalgae biomass is the only "off-centred" process that exhibits special causes of variation like unfavourable weather conditions due to rainy and cloudy weather. This implies that, sun-drying method although cheap has associated risks with regards to wet algae growing moulds and bacteria due to rainy or cloudy weather. Thus, cost

[54] To develop a conceptual framework for measuring process variation in open pond microalgae farm(s) based on lean 6-sigma DMAIC model, and to apply the developed conceptual lean 6 sigma's DMAIC framework in an open-pond microalgae farm to identify non-value adding activities based on animal farmer's feed requirements.

of failure due to waste from inability to dry harvested biomass is high. Consequently, small-scale livestock farmers could adopt open-air microalgae cultivation system as in the case organisation for producing microalgae by modifying the drying process from open-sun drying to solar drying using homemade thermal solar collector, a widely used and readily available device in Nigeria.

- Microalgae culture contamination is more likely to occur during the scaling-up process of the inoculate when microalgae cell population is low as it is been introduced into a larger pond from the small-scale mother culture (usually in test-tube or buckets). The implication of this is that other algae species like chlorella as well as bacteria and protozoans could infest the culture and destroy the *Spirulina* inoculum monoculture.
- The medium composition can be diluted from the standard Zarrouk's medium composition in order to reduce cost of nutrients depending on the water supply. This is because some water sources such as animal wastewater and well-water already contain some of the required nutrients such as sodium, sulphate, chloride, iron, and manganese. According to Delrue *et al*. (2017), Zarrouk's medium "could be diluted up to five times without impacting the [microalgae] biomass productivity up to 21 days after inoculation". Similarly, according to Rajasekaran *et al*. (2016), "modified Zarrouk's medium, devoid of A5 micronutrients [such as H3BO3, MnCl2.4H2O, ZnSO4.4H2O, Na2MoO4, CuSO4.5H2O] and with replacement of potassium nitrate in place of sodium nitrate, is better for the growth performance of [microalgae] *Spirulina*, in terms of specific growth rate, mean daily division rate, biomass, and chlorophyll-A".

8.3 Conclusion

Both the existing supply of microalgae-based feedstock and the current need for commodity livestock and aquaculture feeds and feed materials in Nigeria faces some challenges. While the former is constrained by lack of affordable mass culture facilities that could enable heterotrophic and photobioreactors closed culture systems, the latter is challenged by high cost and persistent lack of high-quality feeds, which accounts for 40–60% of the operational cost in aquaculture and about 60-80% of the total production cost in intensive and semi-intensive poultry farming. Nevertheless, significant benefits are expected for the livestock and aquaculture sectors in Nigeria through investment in low-cost microalgae biotechnology in the form of an integrated animal *cum* open pond *Spirulina* production systems for greater availability of high protein feedstuff. The present research found that the poultry sub-sector offers the most appropriate market segment to target for potential microalgae production. Poultry feeding trials results present in the literature also indicates that layer chickens respond very well to dietary *Spirulina* and could be used to reduce both plasma and yolk cholesterol significantly. Thus, the poultry feed market segment could benefit significantly from microalgae feedstock. Moreover, the poultry sub-sector is well established compared to ruminants or aquaculture. It is made up of 40% commercial and 60% local production systems, accounting for about 9-10% of the Nigerian agricultural GDP.

According to the survey results, the majority of the respondents are unfamiliar with microalgae, which might create unrealistic expectations for the feedstock or the proposed integrated farming practice. In the same vein, the result of this study indicates that the majority of livestock farmers in Nigeria have no formal training or education in connection to farming practices. This is not a desirable outcome as the potential to utilise new feeds or feed materials, as well as make farming decisions to adopt new farming practices that involves microalgae cultivation could be challenged by low literacy rate.

Several studies in the literature tend to concentrate on using of industrial co-products from microalgae in animal feed to minimise cost of algae-based feed material compared to fishmeal and other plant-based protein sources like soybean meal and groundnut meal. For instance, Draganovic (2013) asserts that by integrating industrial algal co-products into feeds, the prices of feed could be reduced while providing revenue streams for the biofuel and nutraceuticals involved in commercial microalgae production. In this study, the researcher investigates a functioning low cost microalgae farm that produce *Spirulina* for human consumption using lean six sigma's DMAIC model to map out the production processes and assess their repeatability/predictability, stability (in terms of low defects rates) and areas that are non-value adding based on the requirements and needs of animal farmers in Nigeria. It was found that the majority of the input materials (Xs) required for cultivating microalgae in an open-air system can be sourced locally in Nigeria or created using readily available materials. These suggest that open-pond microalgae culture for food could be adopted by livestock farmers in Nigeria to produce algae-based feedstuff. However, there are a number of challenges that need to be considered[55].

One of the most important production challenge identified in the case study was contamination due to biological pollutants that makes it difficult to maintain monoculture. This is followed by the challenge of sun drying with challenges arising due to potential contamination of the culture, unpredictability in drying times, and rain damage. In the case study analysis undertaken for this research, the sun drying process involves dewatering wet algae biomass and hand spreading it on polyethylene plastic sheets to dry under direct sun light. This activity is carried out by the farm operators made up of local community members with little or no formal education. The process was

[55] Research question No. 4: Can existing open-pond microalgae cultivation system for food be adopted and/or modified for on-farm feed production in Nigeria?

found to be unpredictable and difficult to maintain over a continuous drying cycle. A review of the literature on dryers revealed that savings in drying time over the existing open sun-drying method in the case study company can be achieved using solar dryers. The drying chamber temperature of a solar dryers could range between 50 – 60°C from natural sun radiation and can be optimised for use in cloudy weather by adding preheated-air unit. Studies have also shown that solar energy in Nigeria can be harness and utilised to dry wet materials like microalgae slurry during cloudy weather. The technique can offer a faster and more stable drying process, less defect rates and >50% time saving than open-air sun drying. The time saving advantage of solar dryers could easily be improved by adding solar powered fan at the air inlet or through integrated solar and biomass cabinet dryer systems.

8.4 Research Contribution

The primary and secondary findings from this research contribute to the current literature in microalgae commercialisation. First, the investigation of the Nigerian livestock and aquaculture macro-environment[56] suggests that the semi-intensive ruminants' industry is constrained by seasonality of feedstuff while the intensive non-ruminants' industry is challenged by high cost of feeds and/or feed materials. Moreover, it was found that the livestock subsector is threatened by diseases that reduce productivity, despite vaccination attempts by the government. Consequently, farmers are prone to using low quality livestock medications and vaccines to treat their animals. In the same vein, this research also found that lack of capital and inadequate labour force limits the Nigerian livestock subsector through low productivity and ability to meet the market demand. A key contribution to knowledge by this research has been exploring the ways to integrate microalgae culture with animal farming to mitigate the aforementioned challenges – no previous research has investigated this in Nigeria.

The DMAIC-based conceptual framework for implementing lean six sigma shown in Figure 24 (page 156) is another major contribution of this research. It demonstrates the detailed process map as well as the relevant areas of an open pond microalgae culture system and how the different phases of the DMAIC cycle could be utilised to improve and optimise the production processes and desings. The framework also shows the different steps to be taken along each phase of the DMAIC cycle across the microalgae production processes.

Another contribution from this research is the end-to-end Failure Mode and Effects Analysis (FMEA) (Table 31, page 164-167). It gives a structure appraoch to exploring potential causes of failures within the production processes of an open pond microalgae farm. The table presents the ways in which processes and/or designs can fail such as sharp angles on the corners of ponds, invasion by other

[56] Research Question No. 1: What are the current constraints militating against feed production in Nigeria?

microorganisms, shortage of light, and high moisture contents in dried algae. It also offers the ways by which these failures could lead to waste, such as obstruction of culture agitation due to sharp corners in pond, or invasion by other microalgae could lead to competition for culture nutrients, etc.

Another research contribution formt this research is the conceptual microalgae *cum* livestock production system (Figure 51, page 214) that offers a high-level design for integrating livestock farming with algae culture based on both the VoCs and the case study analysis. However, as mentioned earlier further reaserch is needed to investigate how animal waste effluent could be sterilised for used as liquid fertilizers in the culture medium of microalgae.

Primary data is collected from livestock and aquaculture farmers in Nigeria to gather the voice of the customer or prioritised list of features required from animal feeds products. Little or no studies have evaluated livestock farmers' requirements/expectations from feeds in Nigeria, as a guard for making strategic decisions for developing feed products or designing potentially sustainable farming system that will improve animal productivity in the country. In addition, a case study analysis is conducted using animal farmers prioritised list of feed features (or VoC) to analyse a microalgae farm (using lean six sigma) in order to investigate potential improvement or modification opportunities within the case organisation's value chain. This approach of modifying existing microalgae production system for food to suit the animal industry is also a new contribution to knowledge both in microalgae and agricultural technology.

The present study also makes several noteworthy contributions as to which animal subsector should be targeted for the introduction of microalgae farming in Nigeria. The research found that the poultry subsector in Nigeria (with aquaculture being a close second) is the most suitable segment for the introduction of microalgae either as a product for poultry feed formulation or as an integrated farming system for farmers to adopt in order to grow their own feedstock. This is because the poultry segment in the country is estimated to exceed 150 million birds of which approximately 40% are being commercially produced, thus, highly accessible. While the ruminants' subsector is predominantly subsistence farming operations and aquaculture is divided between highly competitive inland fisheries and industrial trawl fishery. In the same vein, the poultry industry in Nigeria is not challenged by imports, which makes the segments extremely profitable for feed producers. However, about 21% of the total poultry products have been attributed to undocumented imports. In the same vein, the aquaculture industry in Nigeria is potentially profitable for prospective microalgae feedstock producers, as its responsible for about 10% of the country's total agricultural GDP. On the other hand, rural families under subsistence operation mostly involved in ruminant's farming, makes the sub-sector neither profitable nor accessible to feed producers. The primary data analysis conducted for this research support this segmentation target. The case study analysis in particular indicates that although microalgae can be cultivated using local materials coupled with some trainings, the initial investment cost per open-air pond is estimated at about £344.61 or ₦160,336.14. This suggests that ruminants' farmers who rely on traditional farming practices such as feeding livestock crop residues might not be able to invest in microalgae cultivation, although they might be interested in using algae-based supplements or concentrates for cattle fattening. Fortunately, the significant number of poultry and aquaculture farmers practice intensive farming operations and consequently more susceptible to invest in microalgae production to feed their animals.

8.5 Limitations and Recommendations for further research

This research is focused on the animal farming sector in Nigeria, which has a well-developed and diversified animal production industry that consist of livestock (such as goats, cattle, sheep, pigs, donkeys, horses, giant rats, rabbits and guinea pigs), poultry (such as chickens, turkeys, geese, ducks, and guinea fowls), and aquaculture (such as catfish and Tilapia fish) resources. Although the study was able to demonstrate that the poultry and aquaculture subsectors in Nigeria present better opportunities for potential integrated animal *cum* microalgae production and that existing open-pond microalgae cultivation system for human food can be adopted for feed production with minor modifications that could reduce cost. It has certain limitations, which has evolved many questions in need of further investigation:

- Further research is needed to better understand the health and economic implications of including the on-farm animal wastewater as culture media for microalgae cultivation as compared to this research suggestion to use diluted Zarrouk's medium. In this connection, the researcher has proposed a conceptual microalga *cum* livestock production system (see Figure 51 in page 214) based on the literature and the findings of the present research. However, the proposed system requires further investigation into wastewater treatment methods especially regarding the pathogens in animal wastes and how best to treat them as well as odour and colour removal from animal wastewater.
- In-depth exploration into the different characteristics of various animal effluent in Nigeria to investigate the potential of microalgae culture in animal waste management. Further research might compare, for instance, the benefits of using harvested microalgae biomass as feedstock for producing plant fertilizer in order to improve mineral composition and soil water holding capacity as opposed to direct irrigation using raw livestock wastewater as fertilizer
- Research to develop methods and carryout a cost–benefit analysis of farmer's involvement in microalgae *cum* livestock farming system would be beneficial. Although methodologically

challenging, it might be very valuable to embark on some longer-term research that sought to measure the impact of microalgae *cum* livestock production on such key performance indicators of animal and crop production like quality and price of feeds, feed conversion ratio, digestibility and soil fertility (some of these have been covered in this research).

- To establish scientific evidence and to gain a better understanding of how algae can best be utilised in the previously suggested poultry and aqua-feed target market in Nigeria, a great number of well-designed animal feeding trials are required to assess microalgae as sources of proteins and lipids in place of fishmeal and/or cereal grains. Nonetheless, it seems even now from the literature review that microalga could play an important role in the effort to improve on-farm feed formulation and supplementation.
- There is also a need to further validate the output from the conceptual framework developed for this research in a real-life environment through Impact Case Study (ICS).

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10 Appendix

CONSENT FORM

Case Study Working Title: Application of Lean Six Sigma (LSS) DMAIC (Define–Measure–Analyse–Improve–Control) Methodology to Reduce Defects in the Cultivation Process of an Open Pond Microalgae Farm in a Developing Country.

Research Description

The goal of this research study is to investigate the animal feed market needs in a developing country as the bases for implementing LSS's DMAIC continuous improvement methodology in an open pond small to medium size microalgae production system. The case study is concerned with increasing product quality and reducing defects in the production processes of a microalgae farm. The DMAIC framework/cycle will be followed to identify and resolve the underlying problem(s) in minimizing process variation and improving yield. This project will explore how an open pond microalgae manufacturing system for food can utilise a systematic LSS methodology to improve and/or modify their processes for animal feed production.

I have read and understand the description above of all the arrangements as well as the implications of using all the collected data. Based on the content of this form, I hereby give my free consent for surveys, interview, photographs and recordings if needed and for Mr. Aminu Bature to obtain information from our company records and on-going production processes.

I have the right to decline to sign this consent form without any ramification. I will not receive any payments from the use of shared data collected for this case study now and/or in the future.

By signing this document:

- I accept that photos of production sides and the information gathered can be published professionally or be used to build a case study.
- I accept that all the materials shared with the researcher (Aminu Bature) such as photo(s) and records can be published in the PhD thesis of Mr. Aminu Bature and subsequent publications. I therefore recognise that the materials can be seen by the public.
- I consent that the information that will be used to write the case study story can also be used with other photographs, drawings and recordings.
- I understand that the company name will be mentioned/used with this consent.
- I agree to take part in the project. Taking part in the project will include being interviewed, recorded and/or completing survey questionnaires.
- I understand that I can withdraw my consent any time before any publication and/or thesis submission. Nevertheless, once the gathered data has been submitted to be published, I can no longer retract this consent.
- I understand that the data I provide will be retained for research purposes at Birmingham City university.

Figure 55: SPRTC Case Study Letter of Consent Pg.1

Consent

I, undersigned D Selvendran, consent that Mr. Aminu Bature PhD student Birmingham City University, United Kingdom, can use the information collected for the case study entitled: "Application of Lean Six Sigma (LSS) DMAIC (Define–Measure–Analyse–Improve–Control) Methodology to Reduce Defects in the Cultivation Process of an Open Pond Microalgae Farm in a Developing Country" for his PhD thesis and subsequent publications.

Signature of Participant...... [redacted]

Company/Organisation Name...*Spirulina Nutritech Foundation*

Declaration of the person responsible to obtain the consent

I, **Aminu Bature**, confirm that I have described this form to the participants and provide answers to all their questions on the matter and have clearly identified that he/she can withdraw their consent any time. Thus, I will make certain that the objectives of this research will be pursued, and the privacy respected.

Signature: [redacted]

Date: 19/08/2018

Figure 56: SPRTC Case Study Letter of Consent Pg.2

SGS

Test Report

SAMPLE NOT DRAWN BY SGS INDIA PVT. LTD.

Print Date : 30/10/2019
JOE No : CG19-018465

Sample / Report No : CG19-018465.001
ULR No : TC500619000014226F

Report Control No : CGR0001114295

Sample described by customer as : SPIRULINA FLAKES

Customer Name	: ANTENNA NUTRITECH
Customer Address	: NO 45/20, 120 FEET ROAD
	: SWAMY VIVIKANANDHA NAGAR
Postal Code	: 625007
State	: Tamil Nadu
Country	: INDIA
Sample Type	: SPIRULINA FLAKES
Received	: 24/10/2019
Sample Qty. Recd.	: 100 GMS
Batch no.	: SNF-Q319
Mfg Date	: OCT-2019
Exp Date	: SEP-2022
Test Start	: 24/10/2019
Test End Date	: 30/10/2019
Group	: **Food & Agricultural products** : **Others**

Test/Parameter	Method	Result	Unit
DISCIPLINE: BIOLOGICAL			
Total plate count	ISO 4833 -1: 2013	4300	cfu/g
Escherichia coli	ISO 16649 (Part 2) : 2001	<10	cfu/g
Staphylococcus aureus	ISO 6888 (Part 1) : 1999 (Amendment 1:2003)	<10	cfu/g
Enterobacteriaceae	ISO 21528-2-2017	<10	cfu/g
Clostridium perfringens	ISO 7937 : 2004	<10	cfu/g

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Kavita SP
Authorized Signatory

****End of Report****

Page 1 of 1

SGS India Pvt. Ltd. Multi Laboratory, 28 B/1 (SP), 28 B/2 (SP), IInd Main Road, Opposite to State Bank of India, Ambattur Industrial Estate, Chennai - 600 058. Tel: 91-44-66081600
Regd & Corp. Off : SGS House, 4B, A.S. Marg, Vikhroli (West), Mumbai-400083. Tel : (022) 25798421 to 28 Fax : (022) 25798431 to 35 www.sgs.com

Figure 57: SPRTC Case Study Company Quality Chemical Test Result 2019, Results Exp Date SEP-2022

SGS

Test Report

SAMPLE NOT DRAWN BY SGS INDIA PVT. LTD.

Print Date : 18/09/2018
JOE No : CG18-016933

Sample / Report No : CG18-016933.001

Report Control No : CGR0000936797

Sample described by customer as : SPIRULINA FLAKES

Customer Name	: ANTENNA NUTRITECH
Customer Address	: 45/20, 120 FEET ROAD,
	: SWAMY VIVEKANANDHA NAGAR,
City	: MADURAI
Postal Code	: 625007
State	: TAMILNADU
Country	: INDIA
Sample Type	: SPIRULINA FLAKES
Received	: 10/09/2018
Sample Qty. Recd.	: 100G
Batch No.	: SNF-Q218
Mfg Date	: AUGUST 2018
Exp Date	: JULY 2021
Test Start	: 10/09/2018
Test End Date	: 18/09/2018

Test/Parameter	Method	Result	Unit
Total plate count	ISO 4833 - Part 1 2013	100	cfu/g
Escherichia coli	ISO 16649 (Part 2) : 2001	<10	cfu/g
Staphylococcus aureus	ISO 6888 (Part 1) : 1999 (Amendment 1:2003)	<10	cfu/g
Enterobacteriaceae	ISO 21528-2-2017	<10	cfu/g

Per pro SGS India Private Ltd

A Vijayalakshmi
Authorized Signatory

****End of Report****

Page 1 of 1

Figure 58: SPRTC Case Study Company Quality Chemical Test Result 2018, Results Exp Date July 2021

SGS

Test Report

SAMPLE NOT DRAWN BY SGS INDIA PVT. LTD.

Print Date : 19/04/2016

Report No : CG16-007964.001 **JOE No** : CG16-007964

Report Control No : CGR0000534801

Sample described by customer as : SPIRULINA FLAKES

Customer Name : ANTENNA NUTRITECH FOUNDATION
Customer Address : NO.1, GANESH COMPLEX, 120 FEET ROAD,
: SURVEYOUR COLONY,
City : MADURAI
Postal Code : 625007
State : TAMIL NADU
Country : INDIA
Sample Type : SPIRULINA FLAKES
Received : 09/04/2016
Sample Qty. Recd. : 100g
Batch No. : ANF-P 0416
Mfg Date : APRIL 2016
Expiry Date : MARCH 2019
Mark on sample : SAMPLE 1
Test Start : 09/04/2016
Test End Date : 19/04/2016

Test/Parameter	Method	Result	Unit
Crude protein	AOAC 2001.11	60.67	g /100 g
Total Carbohydrates (by difference)	By Difference (Ref. AOAC 986.25)	22.96	g /100 g
Fat	AOAC 922.06	4.92	g /100 g
Energy	Nutritive value of indian food (ICMR)	378.8	kcal/100g
Moisture	IS 4684 : 1975	4.75	g /100 g
Total Ash	IS 4684 : 1975	6.70	g /100 g
Iron (as Fe)	SO-IN-MUL-TE-063-by ICPOES	652.84	mg/kg
Zinc (as Zn)	SO-IN-MUL-TE-063-by ICPOES	79.440	mg/kg
Crude fibre	AOAC 962.09	0.12	g /100 g
Carotene	AOAC 970.64	195.67	mg/100g
Phycocyanin	SO-CHML-CTS-C01-QU-046	12.29	g /100 g
Saturated Fatty Acids	IS0 5508 :1990 & 5509 : 2000	2.21	g /100 g
Mono Unsaturated Fatty Acids	IS0 5508 :1990 & 5509 : 2000	0.97	g /100 g
Poly Unsaturated Fatty Acids	IS0 5508 :1990 & 5509 : 2000	1.73	g /100 g
Trans Fatty Acids	IS0 5508 :1990 & 5509 : 2000	<0.01	g /100 g

Figure 59: Case Study Product Content Quality Test Result 2016, Results Exp Date March-2019 Pg.1

SGS

Test Report

SAMPLE NOT DRAWN BY SGS INDIA PVT. LTD.

Print Date : 19/04/2016

Report No : CG16-007964.001

JOE No : CG16-007964

Report Control No : CGR0000534801

Per pro SGS India Private Ltd

K Kumar
Authorized Signatory

Per pro SGS India Private Ltd

M. Shanmugam
Authorized Signatory

****End of Report****

Figure 60: Case Study Product Content Quality Test Result 2016, Results Exp Date March-2019 Pg.2

Test Report

SGS

SAMPLE NOT DRAWN BY SGS INDIA PVT. LTD.

Print Date : 10/02/2015

Report No : CG15-001986.001

JOE No : CG15-001986

Report Control No : CGR0000312883

Sample described by customer as : SPIRULINA FLAKES

Customer Name	:	ANTENNA NUTRITECH FOUNDATION
Customer Address	:	NO.1, GANESH COMPLEX, 120 FEET ROAD,
	:	SURVEYOUR COLONY,
City	:	MADURAI
Postal Code	:	625007
State	:	TAMIL NADU
Country	:	INDIA
Sample Type	:	SPIRULINA FLAKES
Received	:	03/02/2015
Sample Qty. Recd.	:	250g
Batch No.	:	ANF-P 0215
Mfg Date	:	FEB 2015
Expiry Date	:	JAN 2018
Test Start	:	03/02/2015
Test End Date	:	10/02/2015

Test/Parameter	Method	Result	Unit
Energy	Nutritive value of indian food (ICMR)	374.3	kcal/100g
Total carbohydrates (by difference)	By Difference (Ref. AOAC 986.25)	14.56	g /100 g
Chlorophyll	AOAC 942.04	1.31	g /100 g
Phycocyanin	SO-CHML-CTS-C01-QU-046	13.95	g /100 g
Carotene	AOAC 970.64	0.20	g /100 g
Total ash	IS 7874 (Part 1) : 1975	7.66	g /100 g
Crude fibre	IS 7874 (Part 1) : 1975	2.02	g /100 g
Moisture	IS 7874 (Part 1) : 1975	4.71	g /100 g
Sodium (as Na)	SO-CHML-CTS-C-01-QU-063-by ICPOES	0.98	g /100 g
Iron (as Fe)	SO-CHML-CTS-C-01-QU-063-by ICPOES	76.26	mg/100g
Zinc (as Zn)	SO-CHML-CTS-C-01-QU-063-by ICPOES	16.67	mg/100g
Crude protein	AOAC 2001.11	68.31	g /100 g
Vitamin B12	By Ridascreen ELISA kit	3.65	µg/100g
Fat	AOAC 922.06	4.76	g /100 g

Page 1 of 2

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Figure 61: Case Study Product Quality Chemical Test Result 2015

Table 46: FMEA Questionnaire (Severity Ranking)

		Criteria for ranking severity	Effect	Rank
		Failure occurs without warning	Deadly	10
		Failure occurs with warning	Hazardous	9
		Product inoperable, with loss of function	Very Serious	8
		Product operable, but with loss of performance	Serious	7
		Product operable, but with loss of comfort	Moderate	6
		Product operable, with low effect on performance	Low	5
		Noticeable effect by most customers	Very Low	4
		Noticeable effect by average customers	Minor	3
		Noticeable effect by discriminating customers	Very Minor	2
		No effect	None	1
s/n	**Questions**			
1	How severe is the effect of having sharp angles of container in your open pond tank to the microalgae culture?			
2	How severe is the effect of not having all the essential nutrients to grow microalgae to your Spirulina culture?			
3	How severe is the effect of other microorganisms invading your microalgae mother culture?			
4	How severe is the effect of low light penetration and self-shading to your open pond culture?			
5	How severe is the effect of contamination due to having a pH less than 9.5?			
6	How severe is the effect of depletion and faded or yellowish culture with foam?			
7	How severe is the effect of having a high depth of culture leading to agitation difficulties and reduced light penetration?			
8	How severe is the effect of contamination on harvested microalgae due to poor filtration?			
9	How severe is the effect of high moisture content in harvest due to under-drying?			

10	How severe is the effect of having low essential nutrient contents due to over-drying of harvested algae?			

Table 47: FMEA Questionnaire (Causes of Failure Ratings)

			Occurrence	**Failure Rate**	**Criteria**	**Rank**
			Very High	>1 in 2	Failure is almost inevitable	10
				1 in 3		9
			High	1 in 8	Repeated failures	8
				1 in 20		7
			Moderate	1 in 80	Occasional Failures	6
				1 in 400		5
				1 in 2000		4
			Low	1 in 15000	Relatively few failures	3
				1 in 150000		2
			Remote	<1 in 1500000	Failure is unlikely	1
s/n	**Potential causes of failure**	**Questions (rate from 1 to 10 only: 1 been very remote/low and 10 been very high)**				
1	Spirulina culture in zero corners will be stagnated and leads to have more bacterial growth contaminants, which will affect the growth of spirulina and quality of its product.	What are the chances of this happening in your algae farm?				
2	1. Improper addition of Fertilizers 2. Poor quality of fertilizers 3. Depth imbalance	What are the chances of these happening in your algae farm?				

3	1. Bacterial /Protozoans will be increased when there are more dust / dead particles present 2. Chlorella invasion through water and/or air	What are the chances of these happening in your algae farm?				
4	1. Reduced photosynthesis, and growth during cloudy / monsoon season / culture depth is more	What are the chances of this happening in your algae farm?				
5	1. Depth imbalance due to rainwater addition / evaporation loss 2. Improper addition of fertilizers	What are the chances of these happening in your algae farm?				
6	1. Culture nutrient dilution due to rainwater addition 2. Improper addition of fertilizers. 3. Irregular chemical test to analyse culture nutrient balance	What are the chances of these happening in your algae farm?				
7	1. lack of regular harvest of microalgae and/or irregular agitation of the culture medium	What are the chances of this happening in your algae farm?				
8	1. Spirulina wet mass will contain small and minute dust particles that leads to have poor quality of product.	What are the chances of this happening in your algae farm?				
9	1. Flakes with more moisture will attract bacteria to grow and affects the quality & shelf life of the dried product.	What are the chances of this happening in your algae farm?				
10	1. Colour of the product will be faded. 2. Reduce the vitamin and pigment levels	What are the chances of these happening in your algae farm?				

Table 48: FMEA Questionnaire (Control Measures)

				Chances of detection of failure mode	**Rank**
				No known controls available	10
				Very remote chance of detection	9
				Remote chances of detection	8
				Very low chances of detection	7
				Low chances of detection	6
				Moderate chances of detection	5
				Moderately high chances of detection	4
				High chances of detection	3
				Very high chances of detection	2
				Almost certain to detect	1
s/n	**Potential causes of failure**	**Current control measure(s)**	**Questions**		
1	1. Microalgae (Spirulina) culture in zero corners will be stagnated and leads to have more bacterial growth contaminants, which will affect the growth of spirulina and quality of its product.	1. Fold and place the tarpaulin sheet gently in the corners in such a way that water cannot stagnate there.	What are the chances of failure detection using this control measure(s), in your microalgae farm?		
2	1. Improper addition of Fertilizers 2. Poor quality of fertilizers 3. Depth imbalance	1. Regular monitoring of fertilizer addition 2. Buy good brand / supplier fertilizers 3. Proper depth maintenance	What are the chances of failure detection using this control measure(s), in your microalgae farm?		
3	1. Bacterial /Protozoans will be increased when there are more dust / dead particles	1. Regular cleaning of settled dusts 2. Use fresh bore well water and grow your mother culture in	What are the chances of failure detection using this control measure(s),		

	present 2. Chlorella invasion through water and/or air	hygienic place to avoid air borne contaminants.	in your microalgae farm?		
4	1. Reduced photosynthesis, and growth during cloudy / monsoon season / culture depth is more	1. Increase the frequency of agitation 2. Covering the tank with transparent polythene sheet during monsoon season to allow light through.	What are the chances of failure detection using this control measure(s), in your microalgae farm?		
5	1. Depth imbalance due to rainwater addition / evaporation loss 2. Improper addition of fertilizers	1. Excess diluted medium to be discarded and replace the fertilizers to balance. Add water to compensate the evaporation loss daily. 2. Regular monitoring of fertilizer addition can correct it.	What are the chances of failure detection using this control measure(s), in your microalgae farm?		
6	1. Culture nutrient dilution due to rainwater addition 2. Improper addition of fertilizers. 3. Irregular chemical test to analyse culture nutrient balance	1. Diluted culture medium are discarded and the fertilizers replaced to balance concentration. 2. Regular monitoring of fertilizer addition can correct it. 3. Routine chemical test by SGS India pvt Ltd.	What are the chances of failure detection using this control measure(s), in your microalgae farm?		
7	1. lack of regular harvest of microalgae and/or irregular agitation of the culture medium	1. Increase the frequency of agitation 2. Routine cultivation of biomass from 9 out of 10 ponds every morning (the 1 pond unharvested will be harvested the following cycle to avoid over harvesting and high population density)	What are the chances of failure detection using this control measure(s), in your microalgae farm?		

8	1. Spirulina wet mass will contain small and minute dust particles that leads to have poor quality of product.	1. Pre filter cloth should be placed to avoid mixing of dusts 2. Washing of slurry with fresh water helps removing of tiny dusts.	What are the chances of failure detection using this control measure(s), in your microalgae farm?		
9	1. Flakes with more moisture will attract bacteria to grow and affects the quality & shelf life of the dried product.	1. Do not mix the moist flakes with well-dried ones. 2. We use hot air oven to reduce the moisture level of dried products and to maintain even moisture in flakes (55 degree Celsius – 1hour)	What are the chances of failure detection using this control measure(s), in your microalgae farm?		
10	1. Colour of the product will be faded. 2. Reduce the vitamin and pigment levels	1. Monitor the drying duration according to the climatic conditions	What are the chances of failure detection using this control measure(s), in your microalgae farm?		

Table 49: Interview questions and the exemplary quotes from Case Study Participants and Company Records

Themes explored	Questions asked	Exemplary Quotes: Failure modes and control measures	Exemplary Codes
1) Site selection and tank design	"I would like to hear your thoughts on the design of your open pond tanks. How do you select the construction site and what material, and shape is your pond and why?"	*"The first and foremost aspect to be considered for microalgae cultivation is a flat site with adequate sunlight (i.e. free from shade) and sufficient water supply throughout the year. The site should have easy access to the nearby settlement(s). It should be free from pollution from industrial, drainage systems etc. Moreover, the site should have access to electricity and work force."* *"Any non-toxic, non-corrodible and waterproof open container can be used to culture microalgae. Its shape is unimportant under the circumstances, however we used D-ended shaped tanks to avoid sharp angle (especially right angles) that could lead to culture contamination due to stagnation, and to make cleaning and agitation easier. Moreover, although microalgae can be grown in permanent concrete tanks, we used transferable tanks made from tarpaulin. We fold and place the tarpaulin sheet gently in the corners in such a way that the culture medium cannot stagnate"*	-Flat terrain -Adequate sunlight -Sufficient water supply -Pollution free -Access to electricity -Container material -Shape of container -Transferability of tank
2) Culture colouration and smell/odour	"In connection to changes in culture colouration and smell, could you give me an idea of what these indicate(s) and the trouble shooting measures you presently use to troubleshoot and/or reduce/prevent these?"	*"Faded colour of the culture can be due a number of factors and sometime mean different things depending on the pH. For example, faded colour at a pH>10.5 is usually because of CO_2 or Bicarbonate deficiency. While, faded colour at a pH<10.5 indicates Nitrogen deficiency in the medium. In the same vein, when the culture turns yellowish, lysis has occurred and with foam – the cell walls have ruptured expelling polysaccharides on to the medium. Moreover, when the osmotic medium shock is severe, the culture can turn milky colour. When fermentation odour is perceived from the culture, it is usually due to heavy bacterial load in the medium."* *"To reduce and/or prevent these we shade the culture to reduce dust, leaves and other debris from falling into the open tanks. Lower the pH with CO_2 and add Nitrogen and Potassium (fertilizer). Poor quality fertilizers are avoided. Moreover, we remove clumps and settled dust and*	- pH imbalance -Culture colouration -CO_2, & N deficiencies -Lysis -Culture S smell/odour -High-quality fertilizer -Agitation -See-through cover -Culture depth

		Increased agitation of the culture to; keep the polysaccharides afloat; help the filaments to avoid been trapped in the polysaccharides."	
3) Culture density and Clumping	"Can you describe some of the potential causes and/or signs of poor culture density and clumping as well as the correction measures you used in your algae farm?"	*"When the culture becomes viscous, it usually a sign that the density is affected by sudden stress, vegetative reproduction, and/or extra metabolites from normal growth. We control this by partly replacing the culture and medium with fresh mother culture and medium respectively"* *"Regarding clumping, if the water contains more than 100mg/lt of calcium and 300mg/lt of magnesium, precipitations of carbonate or phosphate can entangle the filaments and cause clumping at the bottom. The most frequent causes of clumping we found includes the production of exo-polysaccharides (EPS), excess amount of bicarbonates in the medium, Nitrogen and Sulphur deficiencies. To control clumping we usually prevent the accumulation of microalgae masses by frequent agitation."*	-Culture viscosity -Excess CO_2 -N & S deficiencies -Mother culture replacement -Medium replacement -Frequent agitation
4) Contamination of microalgae culture	"Can you tell me about some of the contaminants you have come across in your open pond microalgae culture, and how you currently troubleshoot and controlled them?"	*"Many varieties of bacteria are commonly found. Their growth is inevitable and sometimes even useful in scavenging dead algae and other accumulates. Bacteria also helps in breaking down the tissues of other accumulations, which provides nutrients in the medium for further microalgae generation. However, since most of them grow within the pH range of 4.0 to 7.6 and very few can tolerate a maximum pH over 10.0, we operate our microalgae culture at pH from 9.5 to 10.5, which eliminates most pathogens."* *"Protozoa are also found in the culture most likely from our water sources and/or windblown particles. It is a necessary part of the culture and add fixed nitrogen to the medium. Moreover, in dry algae, there are 74 varieties of amoeba, but only Entamoeba histolytica is pathogenic to man. Amoeba, like the other protozoan died at 40^{o}C. Regular cleaning of settled dust and the used of fresh well-water also helps"* *"Sometime our culture can be invaded by rotifers despite the high salinity of the medium. They are a rich source of carbon dioxide to microalgae. We control rotifers by adding urea of 0.01g/lt to 0.02g/lt for two to three days."*	-Bacteria -Other algae (Chlorella) -Protozoa -Amoeba (Entamoeba histolytica) -Dust -Rotifers -Viruses -Higher pH range (10.5) -Regular cleaning of dust -Fresh well water -High salinity against rotifer

		"Viruses are usually destroyed by oxidation, when they pass into our microalgae culture medium they are attacked by the high oxygen tension in the water, which is produced by the photosynthesis. In our dried microalgae product, the majority of the viruses are inactivated in about 20 minutes at 50-60^{o}C." *"Finally, contaminations by other algae such as Chlorella and the Diatom Navicula are frequent at the early stages of the culture. However, if the inoculum used to seed the tank is healthy, then invasion by other green algae and diatoms is minimal. We tend to maintain a good growth mono-algal culture in this farm and thus do not face serious difficulty from contaminating organisms."*	-High temperature & oxygen tension against viruses -Healthy inoculum to prevent invasion by other algae
5) Effect(s) of light	"Reduced light penetration and self-shading are common when cultivating microalgae in an open tank like yours. In your experience what are some of the effects of these and what control measure(s) do you practice to improve these?"	*"As you may already know microalgae transform water and CO_2 into plant material with the help of light. Reduced light penetration can be due to two rhythms of light. The first is during agitation in the tank containing the culture, when algae cells move between full light radiation and complete darkness depending on where they located during the turbulent flow of the mixing process. The second light cycle is during the day between sunrise and sunset (the desired duration of sunshine is 10 hours for every 24 hours). We come to realised that growing algae at a culture depth of between 12 cm can lead to self-shading unless the culture is diluted. Hence we used a culture depth of 20cm in our 6X3 metre open tanks to get optimum light and temperature."* *"We also try to increase agitation to improve the turbulence flow during the day especially when our cell concentration in the tank is high."*	-Agitation -Day/night cycle -Self-shading -Photosynthesis
6) pH control	"The pH of the culture medium plays an important role in avoiding contamination. What in your experience is/are the common causes of pH shift below or above the optimum range of 9.5- 10.5?	*"We maintain a pH between 9.5 – 10.5 in order to avoid contamination by bacterial and other algae. Although it is uncommon in our farm for the pH to falls below 9.0, upward shifts in the pH however is quite common because of improper addition of nutrients and/or rainwater. This has led to $CaCO_2$ precipitation followed by microalgae sedimentation and flocculation, which can lead to bacterial growth and affect product quality. In some cases, we had to replace the entire culture."*	-pH range (9.5 – 10.5) -$CaCO_2$ precipitation due to upward shift in pH -Microalgae sedimentation and flocculation -Bacterial contamination

	Moreover, what control measure do you employ to reduce defects and comply with quality guidelines?”		
7) Harvesting and filtration	“What in your experience are some of the issues that occur during the harvesting processes in your microalgae farm and what control measure(s) do you have in place to eliminate and/or minimize this?”	*“The harvest efficiency is contingent on the trichome size and the mesh size of the filters used. However, smaller mesh size on the fibre cloth reduces the culture flow rate during the filtration process. One of the issues that might arise is that an operator may try to pour the culture on to the filter with a higher force, which can damage the algae cell. Moreover, Wet microalgae biomass may contain small dust particles that after harvest, which can affect product quality.”* *“To control these, we ensure that a pre-filter cloth is placed on the filtration set-up to prevent dust from getting into the culture. Moreover, we wash the slurry with fresh water to further remove tiny dust impurities.”*	-Trichome size & filter mesh size -Pouring pressure of culture through filter -Pre-filter cloth to prevent large particles in harvest -Splashing of slurry with clean water after filtration
8) Drying	“In you experience what are some of the effects of over and under drying of wet microalgae. Moreover, what control measure(s) do you currently have in place to prevent these from occurring?”	*“Proper and fast drying is important in the production of high-quality microalgae. As you may notice our operation here is small with limited budget and thus we use sun drying. Some of the shortcomings and possible issues that we usually face from this method is the loss of heat sensitive pigments, nutrients and enzymes. On the other hand, during monsoons and rainy seasons, algae flake with moisture in them can easily grow bacteria, which reduced the quality and shelf-life of our product.”* *“We prevent this from happening by refrigerating the wet during days with low sunshine and/or rainy days. We also ensure that partially dried algae are not mixed with dried ones. To ensure that the moisture content in finish product does not exceed 3-4% (recommended optimal moisture level), we use hot air oven (at 55^{o}C for 1 hour) to reduce the moisture level.”*	-Proper and fast drying -Sun trying is more economical -Loss of heat sensitive pigments, nutrients and enzymes

School of Engineering and the Built Environment

Birmingham City University

City Centre Campus

Millennium Point

Birmingham B4 7XG

United Kingdom

CONSENT FORM

Title of Research Project:

An investigation into the feasibility and potential benefits of integrating microalgae culture with livestock farming in Nigeria

Name and Position of Researcher:

Aminu Bature, PhD student Faculty of Computing, Engineering and the Built Environment, Birmingham City University.

1. I confirm that I have read/being read to and understood the information sheet for the above research and have had the opportunity to ask questions **(Y/N).**
2. I understand that my participation is voluntary and that I am free to withdraw at any time without giving a reason **(Y/N).**
3. I agree to take part in the study **(Y/N).**
4. I agree to the interview being recorded **(Y/N).**
5. I agree to the use of anonymised quotes in thesis report and publications **(Y/N)**.

Name of participant/respondent:	Date:	Signature:
Aminu Bature (Researcher)	Date:	Signature:

Table 50: Preliminary interview responses with farmers in Nigeria

Participant number	Gender	Age	Do you have any fish farming training?	Years of animal farming experience	Are you a member of any cooperative society?	Do you have access to credit? If yes, please state the source	Do you own the fish farm enterprise?	Do you formulate your own feed? If Yes, how do you formulate the feed?	If NO, how often do you purchase feed?	What brand(s) of feed do you buy and why?	Which of the following factors have impact on your decision to buy feed?	How do you define quality in feed?	What factors do you consider when deciding which brand of feed to buy?	Have you never heared of the term microalgae?
1	M	25	No	7	No	No	No	I use foreign brand feeds like Coppens or Skrettings when the animals (fish and poultry) are still young (for the first 4 months) because imported feeds demonstrate better growth (probably because the local brands marketed nutritional contents are not always correct!), and then switch to our own locally produced feeds when the animals are bigger	We buy feed on a weekly bases, however, this depends on the number of fishes.	Coppens and Skretting	Cost/price of feeds (medium), Quality of feed (High), Availability (Low), Logistics (Low)	Quality feed to me is the one that foster growth	The price of feed and the quality are the most important facotrs for me. We do not have scarcity issues here and in relation to logistics I am willing to drive long distance to obtained a good quality feed for my farm	No
2	M	20	Yes, I was trained locally here in the farms	5	No	No	No	No	Depends of the age and amount of fish in the pound. For fingerlings I will say once a month/bimonthly. And for older fish on a weekly bases.	0	Cost/price of feeds (Low), Quality of feed (High), Availability (Low), Logistics (High)	Poor quality feed is the one that does not make the fish grow eventhough you feed them a lot. Good quality feed promote quick growth and does not need to be over applied	The first thing I will consider is the quality of the feed, followed by the how expensive it is. We normally have all the brands available at the fish market.	No
3	M	27	I grew up in a family of farmers, rearing sheeps, goats, cattle chickens et cetra. and very naturally we added fish farm to the farming and I learned all I know through experience and not through any specific training	4	No	No	I am renting the land and the pond, so NO	No	I purchase feed based on demand. As the healthier the fish the more they eat.	Bluecrown, Skretting, Coppens and Vitafeeds	Cost/price of feeds (Low), Quality of feed (High), Availability (Low), Logistics (Low)	Better performance in terms of growth rate compared to other feeds is to me a quality feed	The price and the quality are the most important factors I consider, followed by logistics. Everything else is negligible	No
4	M	56	Yes, I have a masters degree in fishery	30	No	No	Yes, and I am also a consultant/care taker of the farm	Its hard to make any sort of profit if i do not formulate my own feeds. However, the growth rate of the animal is not as good compared to branded commercial feeds. We have cases in this community (Abuja) were after selling the livestock, the farmers find it hard to break-even the amount of money they invested in feedstuff	Depends on the quantity.	I usually used a locally produced foreign feed brand. Such as Bluecrown, Vitafeeds because there is no import charges on them which makes them less expensive. Coppens is the best brand in my opinion, however it is too expensive.	Quality and price are the equaly important (both rated high). All other factors are insignificant to me.	I look at what the feed is made of (that is, the content and the ingredients breakdown). Personally I feel that all the feeds brands in the market are not completely poor in terms of nutrition. However, I always starts my fish with the expensive foreign brands and later on switch to local brands.	High protein content	No
5	F	55	No	25	No	No	Yes	Yes, if am not too busy. I use ingredients such as salt, corn, blood meal, crayfish, palm oil, soya bean and groundnut cake. Mix them up in the right propotion and grind them	It depends on the amount and age of the livestock I have in the farm. However, adult animals eat more feed. This is true for both my poultry and fish farms. It is one of the biggest challenge that we face here, as most of us make feed estimations based on early stage of the stock consumption rate only to find that adult animals consume more	in the first 1-2 months I used skretting (foreign brand) and after that I switch to local brands such as Vitafeed	The feed is too expensive. Sometimes I end up not making profit. Cost (high), Logistic (high), Availability (low), and quality (medium).	Protein content determines the quality of feed to me.	Most of us in Nigeria assume that foreign products are better. This is due to bad experience from locally formlated feed brands. I always consider high protein as the main selection criteria however, due to local brands been unreliable, I also consider foreign brands	No
6	M	18	No	4	No	No	No I look after the production process and manage the farm.	I do not personally formulate feed, but we have a local person here that does it for us for a price	Depends on the quantity of feed you bought for stocking. 10 bags of feed can last 3 weeks on average	I only buy foreign feed brands such as Coppen	Quality is the most important factor because it is of no use to me if I have to feed my fish double the amount of feed needed for a longer period of time to achieve result that I could get within a short period using good quality feeds. This is followed by the distance i need to travel to buy the feed (as transportation cost need to be considered) and lastly the cost (i believe that low cost feeds have poor quality and low groth performance)	Fast growth rate	I look at the quality of the product in terms of how fast the fish are growing when fed with a particular brand of feed. Followed by price of the feed, and then the disstance I need to travel to purchase it, and finally the sustainability of the brand in terms of been available in the market	No
7	M	26	No	1	No	No	No	No	I purchased feed every 2 weeks.	Topfeed	Quality of feed has the biggest impact on my fish farm. Price of feed is not too much of a factor to me as I do not own this farm I only managege for my employer. Moreover distance to market and or logistics is also not a factor that I give much interest as feed are delivered to me here in the farm by the farm owner.	Quality feed is the feed that makes the fish grow very fast.	Quality will be the first thing I will consider. I will also not buy any feed that is the lowest price in the market. I am not worried about sustainability of the brand as I select feed based on their quality and will switch to a different brand (of the same or close quality) if the one i am currently using become scarce or discountinued.	No

8	F	28	No	6	No	No	Yes	No	Weekly	Bluecrown	Quality of feed has high impart, followed by price. As far as logistics and supplies of feed are concern not too impactful.	Quality is high protein content that can help build the body of the animal. Protein sources are the most difficult ingrediant (both in terms of availability and price) to attain when formulating my own on-farm feed. Other feed materials are easy to find locally and are not expensive. local feed manufacturers may say that their product contained 42% crude protein, however, out of this only 20% is actually real protein from fishmeal.	Simply consider the quality of the ingredients such as fishmeal/proteins.	No
9	F	32	No	2.5	No	No	No, but I owned a fish feed business were I sell to farmers	No, I only used/sell branded fish feeds	Bimonthly on an average	Coppens, Skretting and Aller Aqua	The most important factor to me is the quality followed by cost in terms of profits	Quality to me is been able to achieve a good fish growth at a reasonable period of time	The price of feed, and transportation cost	No
10	F	25	Yes, I have a BSc in Animal Science	5	Yes, FITA (Fishfeed and Fisheries Traders Association)	No	No, this is a family owned business	No, eventhough I know how to formulate my own feed, I chose not to because it is not economical, unless you are formulating in large scale. Hence, We need access to more high quality foreign feed brands in our area. We need access to more high-quality foreign feed brands in our area. *But why do you need this?* "Because I only use imported feeds. […] local brands and/or farm-compounded feeds require the use a lot of feeds in order to achieve the same growth rate as when I use Coppens or Skrettings (both imported feeds)".	I am also in the feed selling business so I do not have specific rate at which a buy feeds for the fishes in production. So, I used feed as much as my fishes require.	I used both local brands e.g. Aqua Special, Aquamax and foreign brands such as Skrettings and Coppens	The most impactful factor is quality. I do not mind travelling long distance to buy reliable quality feed, regardless of the cost and/or price. Another factor that influence my business is how to source the fingerlings and juveniles fishes that are of good health. Moreover, sometimes we have scarcity of these fingerlings and juveniles fishes.	Quality feed to me is that which meets the protein requirement of the fish at any giving stage.	I look at the composition of the feed in terms of crude protein content. Then the logistics in terms of proximity to market and cost	No
11	F	29	No	7	FITA	Yes, I used to have access to Bank loan, but I do not anymore	No, I am managing it for my husband	No, but we hatch our own fingerlings	Every 3 to 4 days	Topfeed, Aller Aqua, Skrettings and Vitafeed	Quality and price of feed are the most impactful factors. If the quality is good and the price is fair then return on investment is expected. Another major factor in my opinion is the lack of start-up and sustainance capital, because it is hard to get loans as there is always the risk of the fishes not meeting the expected outcome after culture. We also have issues with quality fish breeds.	Quality equals protein contents, because fingerlings require a lot of protein to grow	The protein contents and the price	No
12	M	30	No	10	FITA	No	No	No	Twice a week	Coppens, Skretting	High quality	Protein contents	Protein contents	No, but I know "Damsa kuka" i.e. Spirogyra or water silk
13	M	32	No	1	No	No	No	No	Weekly	Skretting	Cost/price of feeds (High), Quality of feed (High), Availability (Low), Logistics (Low). **Another factor that have great impact on our aquaculture is lack of electricity**	Quality of feed to me how fast the fishes grow in relation to the feed that they are fed. They should also be healthier and the fish should consume the feeds when fed as sometimes the fish does not even eats the feed.	I always go for quality feeds, although they are more expensive I realised that the final result is worth it.	No
14	F	36	No, I learned from experience assisting other farmers	12	FITA	No	No	Yes, I used corn, fish meal, antibiotics and other ingredients mix them up	Weekly	Tope feed, Bluecrown, Coppens	Cost/price of feeds (Medium), Quality of feed (High), Availability (Low), Logistics (Low). **Another factor is financial challenges as we do not hae access to funds**	The protein contents is what I used to determine quality of feeds.		No
15	F	34	Yes, I have attended training seminers	7	FITA	Yes, but I do not use any credit	Yes	No	Weekly	Bluecrown, Topfeed	Quality (High), Price (High). **Price of feed is a major challenge to the farmers as it is difficult to gain return on investment when the input cost for feeds is to high**	High quality to me is determine by the protein content	The protein contents and the price	No

16	M	40	Yes, Training seminers	12	FITA	No	Yes	No	Bimonthly	Coppens	The main factor to me is **logistics challenges**. The imported feeds with **high quality** come through Lagos ports and the transport charges from lagos to other part of the country raises **the price,** which have high impact on the farmers as they cannot afford expensive products.	Protein	Price	No
17	M	37	Yes	13	FCFNL (Fisheries Cooperative Fedeartion of Nigeria Ltd.) and FITA (Fishfeed and Fisheries Traders Association)	No	Yes	Yes	Weekly	Coppens	Quality (High), Price (Medium), Availability (Low). **Another challenging factor is the cost of feed is high. Moreover, our clients that buy the fish from us do not buy at a reasonable price as they are unionized.**	High protein contents	The quality of the feed	No
18	M	36	No	15	FITA	No	Yes	Yes	Weekly	Coppens	Quality (high), Cost (Medium). **Another factor that impact the business is that some of the ingredients (such as fishmeal) needed for formulation are not available locally and therefore need to be imported. This raises the overall cost of production due to the drop of the Nigerian currency value. Moreover, we also face shortage of electricity, which stops us from using our local milling machines as well.**	High protein contents	Quality	No
19	M	44	Yes	10	FITA	No	Yes	Yes, I used locally available ingredients such as groundnut cake, fishmeal, soya beans, bone meal, maize, lysine, methionine and other additives, grind them and pellet.	3 times a week	Coppens at the begining, Topfeed and Bluecrown	Quality feed (refered to as imported feeds) is very impactful at the earier stages when the you have fingerlings. However, as soon as the fishes reaches juvenile stage I believe price becomes more impactful and that's when I switched to cheaper brands (refered to as local feed brands). **Other major factor impacting my fish farming is water management, lack of funds and finally lack of knowledge**	Quality feed is one that have a reasonable feeding to growth rate. Which means that the feed has a high level of protein	Protein contents and price	No
20	M	32	No	4	No	No	Yes	No	Weekly	Foreign brands e.g. Skretting/Coppens for fingerlings and local brands e.g. Topfeed/Aller Aqua for older fishes	Cost/price of feeds (Medium), Quality of feed (High), Availability (Low), Logistics (Low). **Another major factor affecting my fish farming is the problem of pond space/land area and water. As when the fish have enough swimming space they grow faster than if they are in a tight pond**	Quality feed to me means that when used the fish grows faster	I consider the feed with the best fish-growth performance (quality brand) for fingerlings and for more mature feeds I will consider local/less expensive feeds	No
21	M	42	No	3	No	No	Yes	Yes, for more mature fishes	Bimonthly	Coppens at the beginning for fingerlings and then Aller Aqua or Multi Feed	Quality of feed (High), Cost/price of feeds (Medium), Availability (Low), Logistics (Low). **Other major relevant factors include lack of funding and the sales rate is low as the market is not reliable.**	Quality feed equals fast growth to me	Quality	No
22	M	35	No	4	International Institute of Tropical Agriculture (IITA)	No	Yes	Yes	Weekly	Aller Aqua because its cheaper	Quality of feed (Medium), Cost/price of feeds (High), Availability (Low), Logistics (Low). **Another factor affecting my fish farming business is theft**	Quality feed should have the right amount of nutrients and minerals	Price of the feed	Yes, Spirogyra
23	M	41	No	4	No	No	Yes	No	Weekly	Coppens	Quality of feed (High), Cost/price of feeds (High), Availability (Low), Logistics (Low). **Lack of startup funds**	Quality equals high protein and other nutrients content	Protein content	No
24	M	44	No	5	No	No	Yes	Yes, I mix ingredients such as soya beans cake, groundnut cake, salt, lysine and methionine, cassava flour/corn	NA	NA	Cost (High), Quality (Medium)	the amount of nutrient present in the feed that help the animal grow at a reasonable rate incomparison to the amount of feed.	Price and quality of ingredients	No
25	M	29	No	4	No	No	Yes	No	Weekly	Skretting	High quality, Medium Price, Availability (Low impact), and Logistics (High impact)	quality to me depends on the overall nutritional value that the feed has in relation to growth performance	Quality and transportation cost are the criteria I use when considering which feed to purchase	No

26	M	25	No	1	No	No	Yes	No	Weekly	Coppens	Quality of feed (High), Cost/price of feeds (Low), Availability (Medium), Logistics (Low). Another challenging factor for me is lack of security and theft	Quality feed contains the appropriate nutriens that helps the fish to grow	The quality of the ingredients	Yes, blue green algae
27	M	33	No	6	No	No	Yes	No	Weekly	Coppens	Quality of feed (High), Cost/price of feeds (Low), Availability (Low), Logistics (Low)	quality feed means faster growth	Quality of ingredients especially the protein content	Yes
28	M	35	Yes, those organized by feed manufacturers such as Multifeed and Coppens	10	FITA	No	Yes	No	Weekly	Coppens, Topfeed, Vitafeed and Bluecrown	Quality of feed (High), Cost/price of feeds (Medium), Availability (Low), Logistics (Low)	Fast growth rate	Quality	No
29	M	25	No	7	No	No	No	No	Monthly	Skrettings, Coppens, and Vitafeed	Quality of feed (High), Cost/price of feeds (Medium), Availability (Medium), Logistics (High)	Quality feed is the feed that foster better performance in terms of growth and the overall health of the fish.	Quality and price are the 2 determining factors for me	No
30	M	20	No	5	No	No	No	No	Bimonthly	Coppens, Skretting	Quality of feed (High), Cost/price of feeds (Low), Availability (Medium), Logistics (Low)	Fast growth rate	Quality and price are the 2 determining factors for me	No
31	M	27	No	4	No	No	No	No	Weekly	Coppens, Bluecrown, Skrettings and Topfeed	Quality of feed (High), Cost/price of feeds (Low), Availability (Medium), Logistics (Low)	Fast growth rate	Quality of the feed	No

Table 51: Market Survey Questionnaire

1	Which geographical zone do you belong to?	1. North Central	2. North West	3. North East	4. South East	5. South West	6. South-South
2	What is your Gender?	1. Male	2. Female	3. Prefer not to say			
3	What age (years) range do you belong to?	1. Less than 18					
		2. 18-24					
		3. 25-34					
		4. 35-44					
		5. 45-54					
		6. 55 and over					
		7. Prefer not to say					
4	Which of the following animal farming sector do you belong to?	1. Fish farming					
		2. Poultry					
		3. Ruminants e.g. Cattles, Sheep, Goats etc.					
		4. Pigs					
		5. Others (please specify)					
5	How many animals do you have in your farm?	1. 1 to 30 2. 31 to 60 3. 61 to 90 4. 91 and above					
6	Do you have any animal farming training?	1. Yes	2. No				
7	How many years have you been involve in animal farming?	1. Less than 1 year					
		2. 1 to 5 years					
		3. 6 to 10 years					

		4. 11 to 20 years					
		5. 21 years or more					
8	Are you a member of any cooperative society?	1. Yes	2. No				
9	Do you have access to credit?	1. Yes	2. No				
10	If YES, please specify the source	1. Bank loans					
		2. State government					
		3. Cooperative societies					
		3. Others (please specify)					
11	Do you own this animal farming enterprise?	1. Yes	2. No				
12	Do you formulate your own animal feed?	1. Yes	2. No				
13	If YES, do you use any of the following ingredients? Select all that apply.	1. Fishmeal					
		2. Groundnut cake					
		3. Maize					
		4. Blood meal					
		5. Soybean meal					
		6. Vitamin/ mineral premix					
		7. Crop residue					
14	If NO, how often do you purchase feed?	1. Biweekly					
		2. Weekly					
		3. Monthly					

		4. Bimonthly					
		5. Others (please specify)					
15	How do you purchase your feed?	1. Retail	2. Credit				
16	When the need to buy feed becomes necessary, which of the following types of feeds do you prefer to buy?	1. Any locally available feed or feed materials					
		2. Any FOREIGN branded feed					
		3. Topfeeds					
		4. Bluecrown					
		5. Aller-Aqua					
		6. Aqualis					
		7. Aquamax					
		8. Aqua Special					
		9. Skretting					
		10. Coppens					
17	How influential are the following factors in relation to what feed or feed materials you buy?	1. Product price					
		2. Product quality					
		3. Product availability					
		4. Convenience					
		5. product warranties					
		6. Others (please specify)					
18	How beneficial do you consider the following feed nutritional contents when deciding which feed to buy?	1. Crude protein	1. Very beneficial	2. beneficial	3. Neutral	4. Somewhat beneficial	5. Not beneficial

		2. Fat	Very important	Important	Neutral	Low important	Not important
		3. Crude fibre	Very important	Important	Neutral	Low important	Not important
		4. Ash	Very important	Important	Neutral	Low important	Not important
		5. NFE	Very important	Important	Neutral	Low important	Not important
19	Which of the following best describe quality animal feed to you?	1. Optimum/high protein content					
		2. Improve the animal immunity and overall health					
		3. animal grow faster with minimum feed input (i.e. high conversion rate)					
		4. Balanced nutritional contents					
20	Do you supplement your farm animals?	1. Yes	2. No				
21	If Yes, what type of supplement do you use?	1. Crop residue/Roughage					
		2. Concentrate (straights/blends/compounds)					
		3. Improved fodder crops					
		4. Vitamins					
22	If No, would you be interested in using supplements in your animal diet?	1. Yes	2. No				

23	Are you familiar with microalgae (blue-green algae)?	1. Yes	2. No				
24	Would you be interested in growing your own plant-based high protein feedstock to supplement your animals?	1. Yes	2. No				
25	If Yes, are you willing to undergo training in order to learn how to grow your own high protein feed supplement?	1. Yes	2. No				
26	Is there period(s) when you experience feed shortages in your area?	1. Yes	2. No				
27	If Yes, what time of the year?	1. January to March					
		2. April to June					
		3. July to September					
		4. October to December					

CEBE Faculty Academic Ethics Committee

BIRMINGHAM CITY University

STAGE ONE ETHICAL REVIEW FORM

This form needs to be completed by **everyone** undertaking research (including staff studying in other Faculties or at other institutions). It must be completed **before** the project starts, and be submitted with a copy of the research project proposal. It will be used by the module coordinator (in the case of student projects)/ Faculty Academic Ethics Committee (in the case of staff/postgraduate research students projects) to identify whether a fuller application for ethical approval needs to be submitted or whether the research can proceed without this."

Name: AMINU BATURE

Student/Staff ID Number: S10522708

School/Course: Research to PhD (Planning) (Faculty of Computing, Engineering and the Built Environment)

Please circle the capacity in which you are completing this form:
Undergraduate Taught
Postgraduate Taught
Postgraduate Research ✓
Staff – Non-funded Research
Staff – Funded Research

1. Potential physical or psychological harm, discomfort or stress

(a) Is there a significant foreseeable potential for psychological harm or stress? YES/NO
(b) Is there a significant foreseeable potential for physical harm or discomfort? YES/NO
(c) Is there a significant foreseeable risk to the researcher? YES/NO

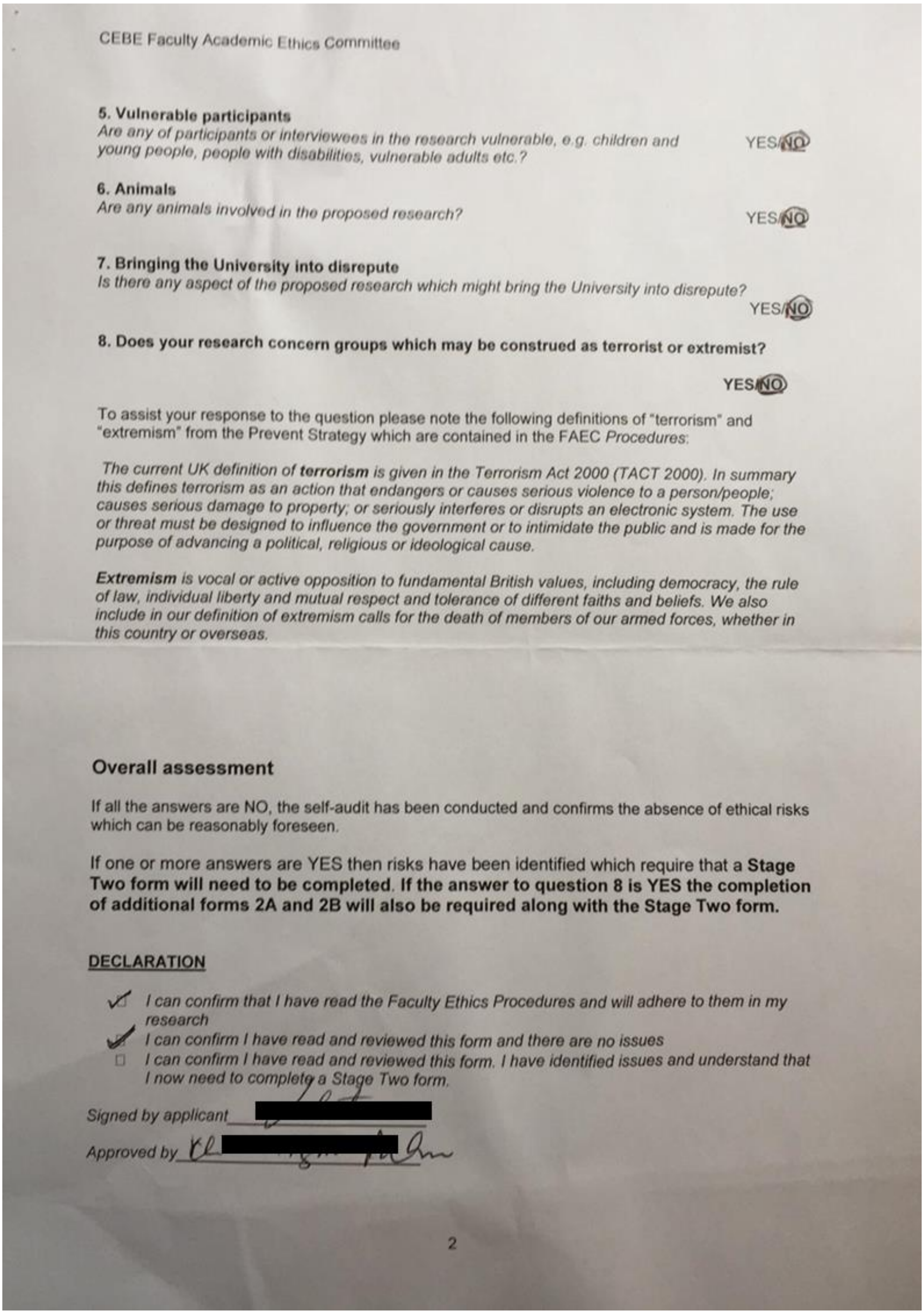
2. Protection of research subject confidentiality
*Are there any issues of **confidentiality** which are **not** adequately addressed by the following actions:*
(a) Non-attribution of individual responses;
(b) Individuals and organisations to be anonymised in publications and presentations, or to give consent to be named;
(c) Specific agreements with respondents regarding any feedback to collaborators and relating to any publications.
YES/NO

3. Data protection and consent
*Are there any issues of **data handling** and **informed consent** which are not dealt with by established procedures? This would entail ensuring:*
(a) Compliance with the Data Protection Act with reference to safe/secure storage of data and its management on completion of the project.
(b) That respondents have giving consent regarding the collection of personal data by completing a Consent Form (please attach form)
(c) That there are no special issues arising concerning confidentiality/informed consent.
YES/NO
(d) Is there any difficulty providing your participants with a participant information sheet?
YES/NO

4. Moral issues and Researcher/Institutional Conflicts of Interest
Are there any special moral issues and/or conflicts of interest identified? YES/NO
(a) An example of conflict of interest would be the researcher compromising research objectivity or independence in return for financial or non-financial benefit for him/herself or for a relative or friend.
(b) Particular moral issues or concerns could arise, for example, where the purposes of research are concealed, where respondents are unable to provide informed consent, or where research findings would impinge negatively/differentially upon the interests of participants.

1

Figure 62: Birmingham City University Ethical Review Form Pg.1



CEBE Faculty Academic Ethics Committee

5. Vulnerable participants
Are any of participants or interviewees in the research vulnerable, e.g. children and young people, people with disabilities, vulnerable adults etc.? YES/NO

6. Animals
Are any animals involved in the proposed research? YES/NO

7. Bringing the University into disrepute
Is there any aspect of the proposed research which might bring the University into disrepute? YES/NO

8. Does your research concern groups which may be construed as terrorist or extremist?

YES/NO

To assist your response to the question please note the following definitions of "terrorism" and "extremism" from the Prevent Strategy which are contained in the FAEC *Procedures*:

The current UK definition of ***terrorism*** *is given in the Terrorism Act 2000 (TACT 2000). In summary this defines terrorism as an action that endangers or causes serious violence to a person/people; causes serious damage to property; or seriously interferes or disrupts an electronic system. The use or threat must be designed to influence the government or to intimidate the public and is made for the purpose of advancing a political, religious or ideological cause.*

Extremism *is vocal or active opposition to fundamental British values, including democracy, the rule of law, individual liberty and mutual respect and tolerance of different faiths and beliefs. We also include in our definition of extremism calls for the death of members of our armed forces, whether in this country or overseas.*

Overall assessment

If all the answers are NO, the self-audit has been conducted and confirms the absence of ethical risks which can be reasonably foreseen.

If one or more answers are YES then risks have been identified which require that a **Stage Two form will need to be completed. If the answer to question 8 is YES the completion of additional forms 2A and 2B will also be required along with the Stage Two form.**

DECLARATION

- ☑ *I can confirm that I have read the Faculty Ethics Procedures and will adhere to them in my research*
- ☑ *I can confirm I have read and reviewed this form and there are no issues*
- ☐ *I can confirm I have read and reviewed this form. I have identified issues and understand that I now need to complete a Stage Two form.*

Signed by applicant [redacted]

Approved by [redacted]

2

Figure 63: Birmingham City University Ethical Review Form Pg.2

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