2016

Evaluation of physiochemical properties and applications of grain flour

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Recommended Citation

Ozoh, Chinwendu Felicia, "Evaluation of physiochemical properties and applications of grain flour" (2016). *Graduate Theses and Dissertations*. 15040.
http://lib.dr.iastate.edu/etd/15040

Evaluation of physicochemical properties and applications of grain flour

by

Chinwendu F. Ozoh

A thesis submitted to the graduate faculty

in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Major: Agricultural and Biosystems Engineering

Program of Study Committee:
Kurt A. Rosentrater
Thomas Brumm
Stephanie Clark

Iowa State University

Ames, Iowa

2016

DEDICATION

I dedicate this thesis to the memory of my parents and my family for their unending support, understanding and encouragement.

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NOMENCLATURE

CD	Celiac disease
d.b.	Dry basis
EIA	Environmental Impact Assessment
GF	Gluten-free
LCA	Life cycle Assessment
in.	inches
MC	Moisture Content
TEA	Techno-economic Analysis
w.b.	Wet basis

ACKNOWLEDGEMENTS

I would like to thank my major professor, Dr. Kurt Rosentrater, and my committee members, Dr. Thomas Brumm, and Dr. Stephanie Clark, for their support, and guidance throughout the course of this study.

I would like to show my gratitude to the members of my lab group, my friends and everyone who supported me in any respect during the completion of my project.

ABSTRACT

In recent years, there has been a growing demand for alternative protein sources in the US. Grains are important in the food industry and they are staple foods around the world. Grains are good energy sources and some grains have very high protein content (e.g., amaranth). There has also been high demand for fish because fish are a very good source of protein. Improving methods of fish farming and processing of grains is beneficial to meeting these high demands for protein. For this thesis, three studies were investigated. They focused cost effectiveness, sustainability, and meeting the high demand of alternative food products.

For the first study, a techno-economic analysis and life cycle assessment of extruded aquafeed were evaluated by developing a model for five production rates (10ton/y, 100ton/y, 250ton/y, 500ton/y, and 1000ton/y). The study was carried out to optimize cost and environmental performance in the production of aquaculture feed for small-scale producers. The results showed that unit cost of producing extruded aquafeed decreased as the production output increased.

The second study focused on amaranth milling with three different mills (burr mill, roller mill, and nutrimill) with three corrugations (0.002 in., 0.005 in. and 0.010 in.) and three moisture levels (10%, 20%, and 24%) for the grain. The results revealed that the 10% moisture content and the fine setting for the nutrimill had the finest mean particle distribution. These findings will be relevant when incorporating amaranth flour into gluten-free food products.

Lastly, the third study focused on meeting the needs of individuals with gluten intolerance. GF bread was formulated from amaranth and rice flour with the goal of improving sensory properties, nutritive value, and reducing cost of GF bread. Bread flour was used as control, while rice and amaranth flour were used at different combination ratios. Results show that consumer panelists consistently preferred the control to other treatments for all attributes tested but a bread with 18.7% rice flour had acceptable properties.

Meeting the needs for alternative protein sources is challenging but these studies highlight that there are effective solutions which can be capitalized on by researchers in the food industry.

CHAPTER ONE

INTRODUCTION AND LITERATURE REVIEW

1.1 Introduction

Grains are important in the food industry, as they are the base for most staple foods around the world. Apart from the importance of the high starch content of grains which is a vital energy source, they provide dietary fiber, nutritious protein, and lipids rich in essential fatty acids. Grains are also good sources of obtaining essential micronutrients such as vitamins, minerals, antioxidants and phytochemicals (Dewettinck et al., 2008); whole grains provide significant dietary amounts of B vitamins, particularly thiamine, pyridoxine, niacin and riboflavin (Bock, 2000). According to FAO (2015), the world grain production in the year 2015 is now forecast at 2.53 trillion tons; this forecast is 2.6 million tons less than the last foreseen and 33.9 million tons below the 2014 record. There are different types of grains within the true cereal grains which are from the botanical family *Poaceae.* These grains include wheat, oats, rice, corn, barley, sorghum, rye, and millet. They are grown primarily for the harvesting of mature grains, which are processed into staple food for human and feed for livestock. Wheat accounts for approximately 33% of grains produced in the world while rice accounts for 25% (Trabelsi et al., 1999). Grains are also processed into various products such as starch, malt, biofuel (alcohol) and sweetener. The physical properties have to be measured on a regular basis to determine optimum condition for processing (Trabelsi et al., 1999). Most grains are fed to livestock, as feed and they often consume the whole grain products.

Feed grains are processed mostly to improve digestibility in livestock and remove contaminants to ensure highest feed quality.

1.2 Grain Processing

Physical properties of grains are important parameters often used to determine the quality and optimum conditions for processing and safe storage of grain. Grain hardness is a fundamental physical property of cereal because it reflects the milling quality of the grain, and can be related to the texture of a cooked food product (Lin, 1997). Grain processing is essential for both human food and animal feed production. For bread and other baked goods, grains are milled, and the flour is subjected to treatment with water and heat. Commercial cereals may be extruded, puffed, flaked, or altered to improve product quality. Grain processing is required as a prior condition for manufacturing attractive and palatable food products. On the contrary, grain processing may result in an increase or decrease in the levels of bioactive compounds in grains (Slavin et al., 2001).

The core objective of the dry-milling process is to make cereals more desirable as food. Milling is referred to as size reduction. Prior to milling of the endosperm for flour, the bran and germ, which are enriched with fat and protein, are separated from the starchy endosperm. Since fat oxidizes when exposed, which could result to poor shelf life, separation process before final milling helps prolong the shelf life of the flour (Hoseney, 1994). Size reduction aids further processing of food products; it increases the surface area of the products. The required particle size after milling varies for different grains. For instance, the endosperm must remain in whole pieces from rice and barley; a fine flour is demanded from wheat; and a high yield of large flaking grits is desirable from com (Hoseney, 1994). Dry milled grains are used in different areas of the food industry. For instance, corn grits are used for breakfast cereals and brewing, corn meal for dry mixes in pancakes or corn bread, and flour from different grains for baked food products, binders, breading and batters for processed or frozen meat products (Lin, 1997). One major disadvantage of milling is the decrease in nutritive value of the flour (Hegedüs et al., 1985). Though, the flour can be fortified after milling (Preedy et al., 2011).

Extrusion cooking is a widely used processing technique in the food industry. It is suitable for producing pasta (Marti et al., 2010), though formulating gluten-free (GF) pasta is a challenge (Marti and Pagani, 2013). Amerayo et al., (2011) reported the effects of extrusion cooking on pasta quality. Studies have adapted extrusion cooking for formulating GF pasta. Marti et al. (2010) reported extrusion of pasta using brown and milled rice, though using brown rice for extruded pasta was a challenge (Silva et al., 2016).

1.3 Gluten-free Food Products

Celiac disease is a digestive disorder which damages the villi, tiny hair-like projections in the small intestine that absorb nutrients, due to an immunological reaction to gluten (King, 2006). It has led to higher demand for gluten-free products as persons with celiac disease have to abstain from food products containing gluten.

Various grains have been used in different studies to improve the nutritional benefits of GF food products. These grains include chestnut flour (Demirkesen et al. 2010), tiger nut flour (Demirkesen et al. 2013), carob germ flour (Tsatsaragkou et al. 2013), amaranth and oat composition (inglett et al., 2015), quinoa (Rothschild et al., 2015), and legume flours (Gularte et al. 2012; Miñarro et al. 2012), especially the grains with high dietary fiber, vitamin and mineral contents. Studies have been carried out on different GF food products, including spaghetti (Bastos et al., 2016), sugar-snap cookies (Mancebo et al., 2015), and cake (Rothschild et al., 2015). The physical, chemical, sensory, and rheological properties of various GF food products have been investigated in recent studies. Ziobro et al. (2016) evaluated the effects of protein isolates on starch based GF bread quality. Decrease in bread volume was reported as the composition of proteins increased; bread structure was influenced by replacement of gum with protein. However, positive results were reported for crumb color and consumer acceptance.

The shelf life of GF food products is shorter than gluten-containing food products. According to Ozkoc and Seyhun, (2015) the shorter shelf life of GF food products may be as a result of the relatively high amount of starch in GF formulation.

1.4 Techno-economic Analysis

Although studies have been conducted to assess TEA on grain storage and refining of food waste to useful chemicals or livestock feed composition, to my knowledge, nothing has been published on TEA and LCA of GF food products. “Techno-economic analysis (TEA) can be defined as a tool used to evaluate the potential costs and profits based on assumed equipment and facility characters and costs” (Petter and Tyner, 2014). TEA is a useful tool used in various industries for evaluation of mobile broadband services (Frias and Pérez, 2012), biofuel production (Kazi et al., 2010; Vlysidis et al., 2011) and other biological systems. Utilization of TEA can enable merging of engineering design, technical information, costs and profits. It can provide support for long-term business strategic decisions and also for on-going operations (Knoll, 2012), decisions of system improvements can be inferred from the tool. To conduct TEA, system boundaries and flowcharts are required, realistic assumptions are necessary and major technical and economic parameters must be identified. Based on the model, capital and operating costs are calculated, and profits are calculated to evaluate the economic potential of the system. According to Wallace (2011), from preliminary design to final commercial launch, TEA can be conducted with different levels of rigor. Sensitivity analysis can be adapted in TEA to test various results when changing process and parameters in the flow diagram. Optimizing specific elements can be achieved through sensitivity analysis (Wallace, 2011; Knoll, 2012). Lam et al., (2014) studied TEA of bakery waste, while Han et al., (2015) reported TEA for conversion of food waste into hydrogen. Suleiman et al., (2014) reported TEA for grain storage facility.

1.5 Life Cycle Assessment

There are different developed methods used when evaluating environmental impacts during product manufacture and service process. Life Cycle Assessment (LCA), Environmental Impact Assessment (EIA), Material Flow Analysis (MFA), Environmental Risk Assessment (ERA), Strategic Environmental Assessment (SEA), Ecological Footprint, and Cost-Benefit Analysis (CBA), are tools that can be employed when assessing environmental impact (Finnveden et al., 2009). LCA is a tool used to evaluate the environmental burden during product manufacture or service or product’s activity throughout its life cycle (Roy et al., 2009). The variables of concern would be the unit environmental impact (Du et al., 2010). A well rounded LCA contains four stages, namely: goal and scope definition, life cycle inventory analysis (LCI), life-cycle impact assessment (LCIA), and the interpretation phase.

The goal and scope stage comprises of the reason and purpose of the LCA study, the system boundaries, and the functional unit will be defined at this stage (Finnveden et al., 2009). The functional unit can be quantitatively calculated to express effectively the function of a product or service (Finnveden et al., 2009). In the LCI stage, the inputs and outputs, within the chosen system boundary, are determined and quantified. Interpretation helps the user understand LCA results at the goal definition stage so that conclusions can be drawn and suggestions for further study or improvement on the already existing system to be made (ISO, 2006).

1.6 Thesis Organization

This thesis follows the format for journals where manuscripts will be submitted. Each chapter in this thesis is self-contained; they include introduction, materials and methods, results and discussion, conclusion, references, figures, and tables.

Chapter one (this chapter) is a broad introduction to this project and literature review. Chapter two includes the hypothesis and objectives of the three studies carried out in this project. Chapter three, titled “Techno-economic analysis and life cycle assessment of extruded aquafeed”, is a research paper modified from a manuscript submitted to ASABE 2015 conference. Chapter four, titled “Characterization of thermophysical and rheological changes during amaranth grain milling” and Chapter five, titled “Evaluation of Rheological, physicochemical, and sensory properties of rice and amaranth flour based GF bread”, are research papers modified from a manuscript to be submitted to ASABE 2016 conference. Chapter six draws a general conclusion from this project and also includes suggestions for future work.

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CHAPTER TWO

OBJECTIVES AND HYPOTHESES

In this project, each study had two main objectives and each objective has its null hypothesis (Ho) and alternative hypothesis (Ha).

The objectives for techno-economic analysis and life cycle assessment of extruded aquafeed were:

To optimize cost in the production of aquaculture feed for small-scale producers using TEA and LCA for production rates of 10 ton/y, 100 ton/y, 250 ton/y, 500 ton/y and 1000 ton/y.

- (Ho) There would be no difference in the unit cost of production as the production rate increases from 10 ton/y to 1000 ton/y.
- (Ha) There would be decrease in the unit cost of production as the production rate increases from 10 ton/y to 1000 ton/y)

To evaluate environmental performance in the production of aquaculture feed for small-scale producers using TEA and LCA for production rates of 10 ton/y, 100 ton/y, 250 ton/y, 500 ton/y and 1000 ton/y.

- (Ho) There will be no difference in the unit CO_2 emission across all production output.
- (Ha) There will be differences in the unit CO_2 emission across all production outputs.

The objectives for characterization of thermophysical and rheological changes during amaranth grain milling were:

To evaluate characteristics of amaranth grain using different mills at various moisture content.

- (Ho) There would be no difference in the mean particle size of amaranth flour at 10% MC for roller mill, burr mill, and nutrimill.
- (Ha) There would be differences in the mean particle size of amaranth flour at 10% MC for roller mill, burr mill, and nutrimill.

To evaluate physical properties (color, bulk density, thermal properties, moisture content, angle of repose) and quality of amaranth flour from different mills and moisture content (burr mill, roller mill, and nutrimill).

- (Ho) There would be no difference in the colorimeter reading for amaranth flour at 20% MC for nutrimill and roller mill.
- (Ha) There would be difference in the colorimeter reading for amaranth flour at 20% MC for nutrimill and roller mill.

The objectives for evaluation of rheological, physicochemical, and sensory properties of rice and amaranth flour based GF bread were:

To formulate GF bread from amaranth and rice flour, which would be fortified to meet the required nutritional need obtained from a regular wheat bread.

- (Ho) There would be no difference in the physical test between control and GF bread made with 18.7% rice flour.
- (Ha) There would be difference in the physical test between control and GF bread made with 18.7% rice flour.

To conduct consumer test panel on GF bread from amaranth and rice flour with wheat bread

- (Ho) There would be no difference in the attribute acceptance from consumers for GF bread samples and control in this study.
- (Ha) There would be difference in the attribute acceptance from consumers for GF bread samples and control in this study.

CHAPTER THREE

TECHNOECONOMIC ANALYSIS (TEA) AND LIFE CYCLE ASSESSMENT (LCA) OF EXTRUDED AQUAFEED

Abstract

The increasing world population has led to higher demand for protein source. Fish is an excellent source of protein for humans; hence, the need for more farmed fish. The aquaculture industry has been recognized as the fastest growing food production system globally, with a 10% increase in production every year. It is also one of the sustainable and reliable growth market for manufactured fish feed. This study was carried out to optimize cost and environmental performance in the production of aquaculture feed for small-scale producers. Techno-economic analysis (TEA) and Life-cycle assessment (LCA) were tools for the analysis. In this study, the cost assessment and environmental assessment were analyzed for the production of fish meal diet; using single screw extruder for five different production output (10 ton/y, 100 ton/y, 250 ton/y, 500 ton/y, 1000 ton/y) in three states in the US (Iowa, Ohio and Indiana). The location used for producing fish feed will influence the total CO_2 emitted annually. Since the CO_2 emission was calculated using electricity generation and gas production, CO_2 emission will vary in different states because the source of electricity for most states in the US differ. Aquatic feed producers can use this tool to evaluate their annual cost, energy consumption, and CO_2 emissions in the course of producing fish feed.

Keywords: Aquaculture feed, TEA, LCA, Extrusion

3.1 Introduction

Aquaculture is an intensely expanding sector of agriculture. This expansion is resulting from the increase in demand for fish. As the human population continues to expand beyond 6 billion, it is expected that humans would rely on farmed fish as an important source of protein. The worldwide decline of ocean fisheries stocks has resulted in an increasing demand for farmed fish; which has provided momentum for rapid growth in fish farming or aquaculture (Naylor et al., 2000). The market for manufactured feeds is growing rapidly (Riaz, 1997), this would enable fish farmers to meet the growing market for farmed fish.

Lapere (2010) reported that the global decline in fish catch coupled with the increasing demand for fish made the prospect of aquaculture sectors very bright. Global aquaculture production attained another all-time high of 90.4 million tons (live weight equivalent) in 2012 (US$144.4 billion), including 66.6 million tons of food fish and 23.8 million tons of aquatic algae, with estimates for 2013 of 70.5 million and 26.1 million tons respectively (FAO, 2014). Historically, the aquaculture industry has relied on fish meal and fish oil as the primary sources of protein and essential fatty acids for fish diets. Fish feed manufacturing is considered as a reliable and sustainable industry in feed production (Rosentrater et al., 2009a; Drew et al., 2007). Studies have been carried out to substitute fishmeal in fish diet with distiller dried grains (DDGS), soy meal, oilseed meal. Rosentrater et al., (2009a and 2009b) evaluated the effect of substituting fish feed on extrusion parameters.

Extrusion technology is commonly used to produce fish feeds, since physical properties, such as water stability, durability, hardness, oil absorption capacity and buoyancy control, are usually improved compared to steam pelleted diets (Sørensen et al., 2009). Extrusion processing helps with the improvement in the nutritional and physical properties of the fish feeds (Davis and Arnold, 1995; Cheng et al., 2003).

Extrusion processing is an adaptable process in the food industry, it requires relatively low energy to function effectively (Dziezak, 1989). Studies have reported that extrusion technology has been accepted in aquafeed feed production because it is cost effective and potential improvement of extruded feed. Extrusion is a controllable process. The barrel temperature, cook time, moisture content and degree of physical damage on the feedstock can be influenced in one unit operation. When extrusion process is handled properly, a very high-quality product can be produced (Riaz, 2007; Davis and Arnold, 1995). Extrusion cooking is defined as a high-temperature-short-time (HTST) cooking process, which involves the cooking of ingredients in the extruder barrel, with a combination of high pressure, heat, and friction. The extruded materials exit through a die. The die is designed to produce highly expanded, low-density products with unique physical and chemical characteristics (Robinson, 1991; Pansawat et al., 2008). During the extrusion process, heat and shear force facilitates hydration of starches and proteins. Both classified as structure-forming materials, starch and protein are turned into a melt where droplets of water are entrapped (Guy, 2001; Sørensen et al., 2009). Bjiirckt and Asp (1983) reported that there are beneficial and undesirable effects of extrusion cooking on nutritional value of food products. The beneficial effects include the destruction of anti-nutritional factors and gelatinization of starch. The undesirable effect happens from the reactions between protein and sugars which reduce the nutritional value of the protein. One of the critical factors that should be considered during extrusion cooking is optimum processing. Since, over or under processing will reduce the nutritional value of the output (Riaz, 2007).

Extrusion is categorized according to screw types; single screw and twin screw extruders. Single screw extruders are an attractive option for many applications due to low capital investment, low manufacturing cost, low maintenance, simplicity in design, and straightforward operation (Kim and Kwon, 1996). A typical single screw extruder comprises of three main zones: feed metering, compression zone, and a die for shaping (Previdi et al., 2006). It relies on drag flow to move the material down the barrel and develops pressure at the die (Kelly et al., 2006). Material enters from the feeder and moves in a channel toward the die when a screw rotates inside the barrel (Kim and Kwon, 1996).

The twin-screw extruders are classified according to the direction of screw rotation as either counter-rotating or co-rotating (Ayadi et al., 2011). Twin-screw extruders can process materials with different moisture contents and different viscosities (Hsieh et al., 1990). The feed rates of twin-screw extruders are independent of screw speed and are not influenced by pressure flow caused by restriction at the die (Altomare and Ghossi, 1986).

When manufacturing fish feed, twin-screw extruder is often preferred over single screw extruder. This is because the twin-screw extruder can handle wet, oily or sticky ingredients, and viscous materials with different levels of composition over a broad range of particle sizes (Cheng et al., 2003; Chevanan et al., 2007). The twin-screw extruder can also produce floating feeds, which helps prevent feed waste and easy to handle fish feed. Aquaculture farmers often prefer floating fish feeds to sinking feeds (Cheng and Wang, 1999). It is typical of fish to eat only floating feed. In this study, techno-economic analysis (TEA) and life cycle assessment (LCA) were used to optimize cost and environmental performance in the production of aquaculture feed for small-scale producers.

3.2 Materials and Methods

3.2.1 Functional Unit

The functional unit for both TEA and LCA was 1ton of fish feed. Environment impacts and economic feasibility of this study were evaluated based on 1ton of fish feed production.

3.2.2. Techno-Economic Analysis

Techno-economic analysis (TEA) can be defined as a systematic analysis used to assess the economic feasibility aimed to recognize opportunities and threats of projects, taking into account the capital, fixed costs, and variable cost (operational) (Simba et al., 2012), as well as benefits. Fixed and annual operating costs are critical parameters in TEA and are critical factors for cost estimation, project evaluation, and process optimization (Marouli and Maroulis, 2005). The TEA in this study was conducted using an Excel spreadsheet (MS-Excel) to determine the cost of extrusion processing for aquatic feeds. This economic cost analysis calculation was divided into capital, fixed, and variable costs.

3.2.2.1 Capital Costs

In this study, the capital cost considered was the cost of purchasing the equipment for aquafeed production. It was assumed that the building was already in place. The cost of the equipment was obtained from three Chinese manufacturing companies (Jnsunward

Machinery Co. Ltd, Zhengzhou Taizy Trading Co., Ltd, and Xinxiang hengfu machinery Co., Ltd).

3.2.2.2 Fixed Costs

Fixed cost is independent of production rates (Pearlson, 2011). Fixed costs are those costs associated with depreciation, insurance, interest, overhead, and taxes. Depreciation was calculated using the straight-line method over the estimated service life of the assets. Depreciation is a non-cash deduction that occurs in the financial (profit and loss) report. Different equipment in feed production depreciates at various rates, and there are different methods of calculating depreciation. In this study, depreciation was calculated using the straight-line method over the estimated life services of the assets equation (1) for simplicity.

$$\text{Straight line depreciation (\$)} = A * (PP - SV) / \text{estimated useful life} \quad (1)$$

A is the assets, PP is the purchased price, and SV is the salvage value

Insurance was calculated by multiplying 0.00462 with the sum of initial equipment costs and building cost (Davis et al., 2011). Interest costs were related to capital investments. 5% interest rate was used in this study. The costs of interest were determined using equation (2).

$$\text{Interest (\$/y)} = \left(\frac{I}{100}\right) * (Initial\ equipment\ costs + building\ cost) \quad (2)$$

I = interest rate (5%)

Overhead cost was calculated by multiplying the production rate by 0.16 (Rosentrater, 2013). Taxes were calculated as 0.35% of the total capital costs, cost of miscellaneous and repairs were accounted for as $4.25 for each ton of fish feed produced (Rosentrater, 2013).

3.2.2.3 Variable Costs

Variable cost for fish feed production included the costs associated with labor, utilities, ingredients, maintenance and repair, and other cost required by the facility for daily operation (Suleiman et al., 2014). Feed ingredients costs were determined based on different suppliers' prices of materials per metric ton. A complete list of ingredients used in this study is shown in Table 3.1. The maintenance costs were determined as 3% of the capital investment. Other variable costs are shown in Table 3.2. The cost of labor was calculated based on the estimated number of workers, total annual operational hours and estimated wages per hour. The utilities considered in this study were natural gas (propane), electricity and water. Electricity cost is necessary in feed manufacturing; it includes costs for lighting and powering equipment such as extruder, mill, mixer, blender, dryer, and conveyor. The drying machines considered in this model used natural gas.

3.2.2.4. Total Costs

Total cost refers to the total expenses incurred in the production of a particular set of output. It comprises of the sum of capital, fixed, and variable costs. The unit total cost was obtained by dividing the total cost by the production output.

3.2.3. Life-Cycle Assessment

Life-Cycle Assessment (LCA) is defined as a tool for evaluating environmental effects of a product, process, or identifying and quantifying energy, material used, and waste released into the environment; it is known as a 'from cradle to grave analysis' (Roy et al., 2009; Walker et al., 2011; Hospido et al., 2003). LCA is a recognized procedure for assessing Greenhouse gas emissions of different products from ethanol production to food production to grain storage (Feng et al., 2008). The main goal of LCA is to improve production, assess environmental performance indicators, help decision-making and market claims (Tillamn, 2000). The system boundary of this study is shown in Figure 3.1 and the fish feed production location considered in this study are States of Iowa, Ohio and Indiana. CO_2 emissions from electricity and natural gas generation from these states were used for modeling LCA for this study. The average CO_2 emission from electricity generation for each state was calculated by dividing total CO_2 emitted each year by the total electricity generated in the same year from 2010-2013 using data from EIA (2014). The CO_2 emission for propane was obtained from LCA published data (Morawicki, 2012). The total electricity required for each production rate was multiplied by the yearly estimated hours of operation and the CO_2 emitted for generating electricity to obtain the total CO_2 emitted for each production rate, this same procedure was used to derive the CO_2 emission from propane. The sum of CO_2 emitted from electricity and propane for each scenario was reported as the total CO_2 emission for each production rate.

3.2.4. Assumptions made for Fish Feed Production

TEA and LCA for fish feed production were modeled using different assumptions. Firstly, it was assumed that the production building for all scenarios were already in place. Table 3.1 shows some of the assumptions used for fish feed production in this study. The labor cost was assumed to be 12 $/hour (Xie, 2015). For production of 10ton/y, the production time was calculated based on the production output of the production line (20 kg/hour). It was assumed that 200 hours will be required to produce 10 tons of fish feed while 2000 hours was the assumed production time for other fish feed production outputs (Suleiman et al., 2014).

3.3 Results and Discussion

3.3.1. Techno-economic Analysis (TEA)

3.3.1.1. Capital Costs

The annualized capital cost decreased as the output increased, 2513.43 $/ton, 263.76 $/ton, 158.25 $/ton, 80.68 $/ton and 47.79 $/ton for the production output of 10ton/y, 100 ton/y, 250 ton/y, 500 ton/y and 1000 ton/y respectively as shown in Figure 3.2. This trend was the same as obtained by Suleiman et al., (2014), there was increase in the capital cost as the production rate increased. The capacity required to produce more, increases as rate of production increases. Capital costs are the most important cost in plant establishment and construction; they are the initial investment cost put into the plant (Suleiman et al., 2014).

3.3.1.2. Fixed Costs

The fixed costs calculated in this study were 2830.2$/ton, 297.0$/ton, 178.19 $/ton, 90.84 $/ton and 53.81 $/ton for the production output of 10 ton/y, 100 ton/y, 250 ton/y, 500 ton/y and 1000ton/y respectively, as shown in figure 3.3. Since assets cost increases with an increase in capital investment, depreciation values were expected to increase as production rate increases. Insurance costs are proportional to the production rate, as rate increased from 10 tons/y to 1000 tons/y, insurance also increased from 108.52 $ to 206.34 $. Interest costs were related to capital investments. Like other fixed costs, overhead, and taxes increased as production capacity increased. The total annualized fixed cost decreased as production rate increased as shown in Figure 3.3. This result is similar to that obtained by Suleiman et al., (2014).

3.3.1.3. Variable Costs

The unit variable costs calculated were 1293.99 \$/ton, 1496.93 \$/ton, 601.36 \$/ton, 302.84 \$/ton, and 318.67 \$/ton for the production output of 10 ton/y, 100 ton/y, 250 ton/y, 500 ton/y, and 1000 ton/y respectively as shown in Figure 3.4. Variable costs had the greatest impact on the total operational cost in al scenarios. It was 31.38%, 83.46%, 77.14%, 76.92%, and 85.56% for 10 ton/y, 100 ton/y, 250 ton/y, 500 ton/y, and 1000 ton/y, respectively. This same trend was observed by Suleiman et al. (2014). As expected, the annual costs of feed ingredients increased as production rate increased. The total annualized cost of labor for production of 1ton of fish feed was 86.49 \$. The results showed that the costs of utilities increased as the production rate increased. The cost of ingredients, labor, maintenance, utilities, and other facility costs increases as the production rate increased. This should explain why the percentage of variable cost to total cost is 85.56% for the 1000 ton/y production rate compared with other production rates in this study.

3.3.1.4. Annual Total Costs

The unit total costs per year were 4124.19 \$/ton, 1793.56 \$/ton, 779.56 \$/ton, 393.69 \$/ton, and 372.47 \$/ton for the production output of 10 ton/y, 100 ton/y, 250 ton/y, 500 ton/y, and 1000 ton/y, respectively. The production rate of 10 ton/y was modeled with the effective production time of all equipment, this explains the increase in the unit total cost for the 100ton/y. The unit total costs of production decreased as the production rate increased, as shown in Figure 3.5. According to Marouli and Maroulis (2005) increasing size of production plant is key to reducing production cost. The unit cost of production decreased as the production rate increases. Suleiman et al., (2014) had similar trend as the production output of extruded aquafeed increased.

3.3.2. Life-Cycle Assessment

The kg CO_2 emitted per MW-h of electricity generated for states of Iowa, Indiana and Ohio were 1.04, 0.87, and 0.78 respectively. Propane production emits 1.52 kg CO_2 per liter (EIA, 2002). The unit CO_2 emitted as determined by LCA for each state is show in figure 3.6, figure 3.7 and figure 3.8. Increase in CO_2 emission was observed as the rate of production increased. Figure 3.9 compares the unit CO_2 emitted in the three states. Iowa tended to have higher CO_2 emission compared to states of Ohio and Indiana, this could be because the state of Iowa generated more electricity from coal in the years evaluated in this study (2010 to 2013). Iowa has been generating electricity from renewable energy sources (wind energy) recently, which implies that they would have less CO_2 emission compared to previous years. CO_2 emission from electricity generation from coal is 1.022g/kWh (Spath and Mann, 1999).

3.4. Conclusion

Declination of world fish capture has provided an open market for aquatic feeds and various opportunities for the aquaculture sectors. The LCA spotted increase in CO_2 emission as the required output increased because there was an increase in energy consumption. The location of production has key role in CO_2 emission as well, since most states use different electricity sources. The annual cost of operation increases as the expected output increased, but the unit cost decreased with increase in production. The system boundary for this study was restricted, therefore the need for further work on TEA and LCA of aquafeed production with broader system boundary.

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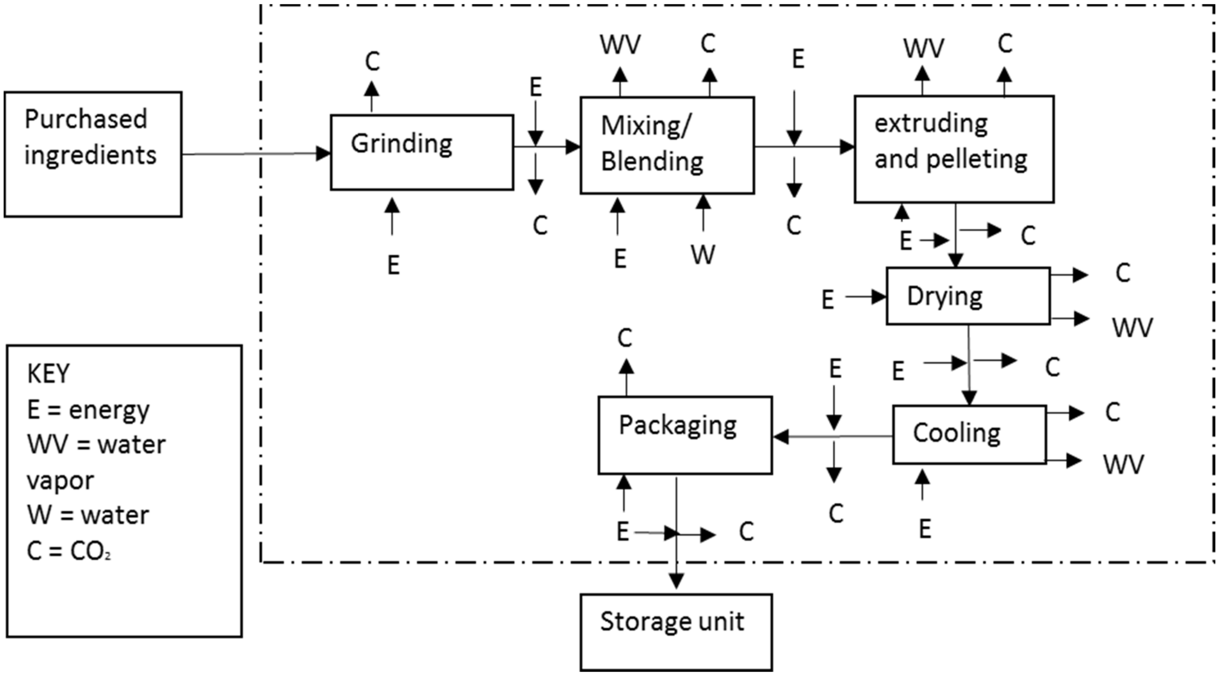

Figure 3.1. System boundary of LCA for fish feed production

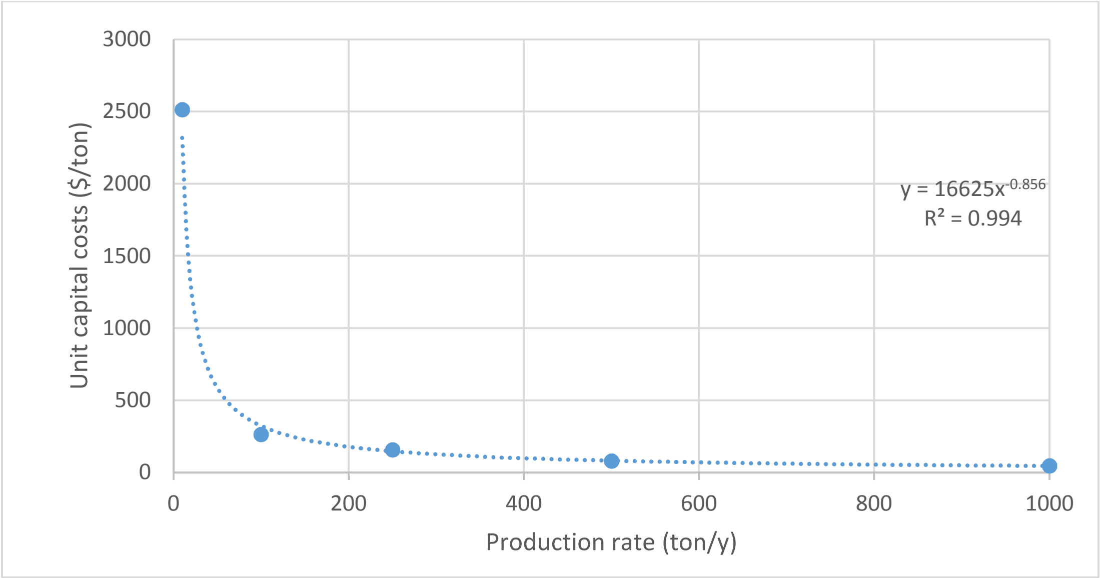

Figure 3.2. Annualized unit costs as determined by TEA for fish feed production

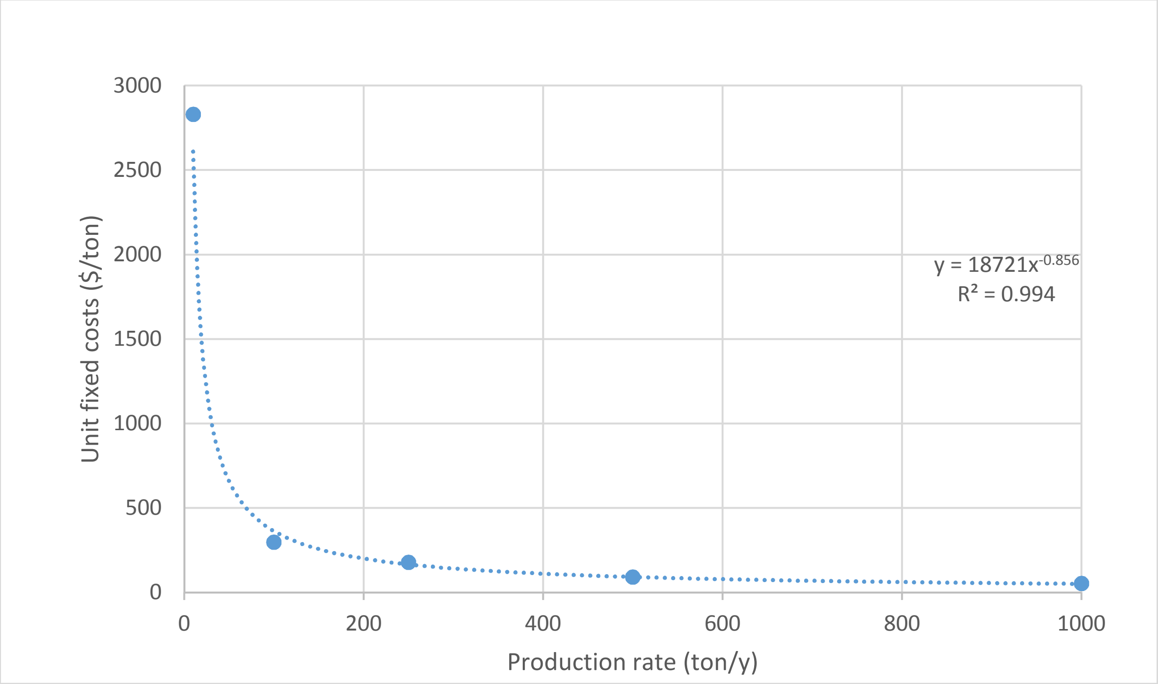

Figure 3.3. Annualized unit fixed costs as determined by TEA for fish feed production

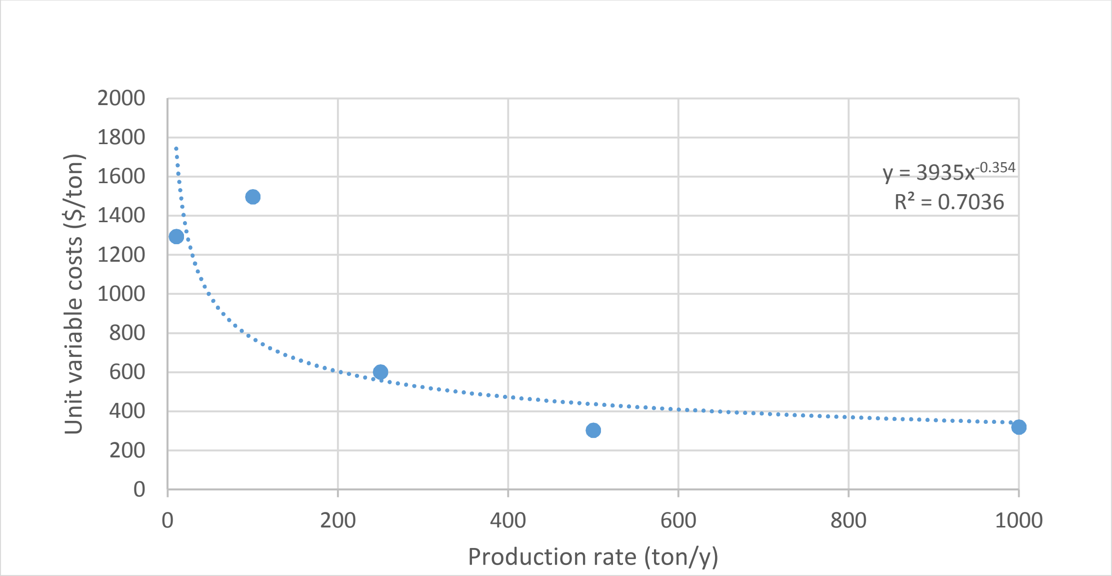

Figure 3.4. Annualized unit variable costs as determined by TEA for fish feed production

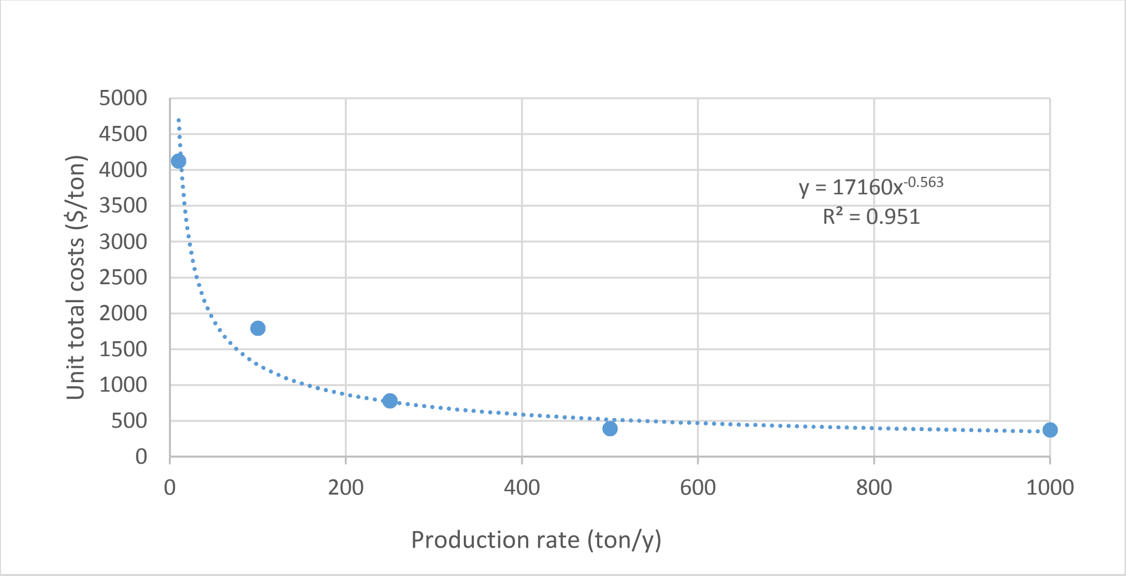

Figure 3.5. Annualized unit total costs as determined by TEA for fish feed production

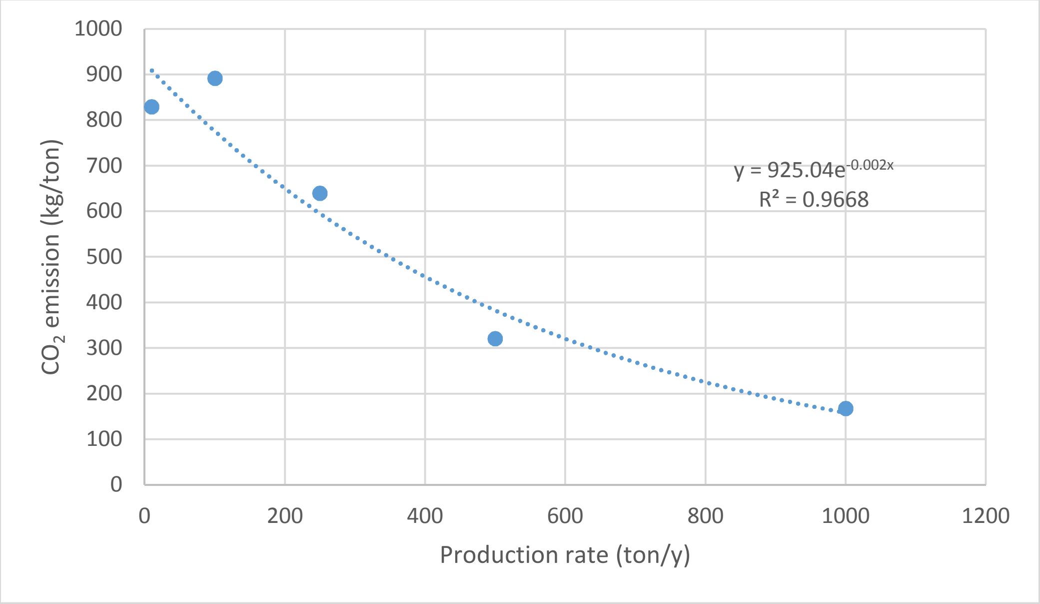

Figure 3.6. Annualized unit CO_2 emission as determined by LCA for fish feed production in the State of Iowa

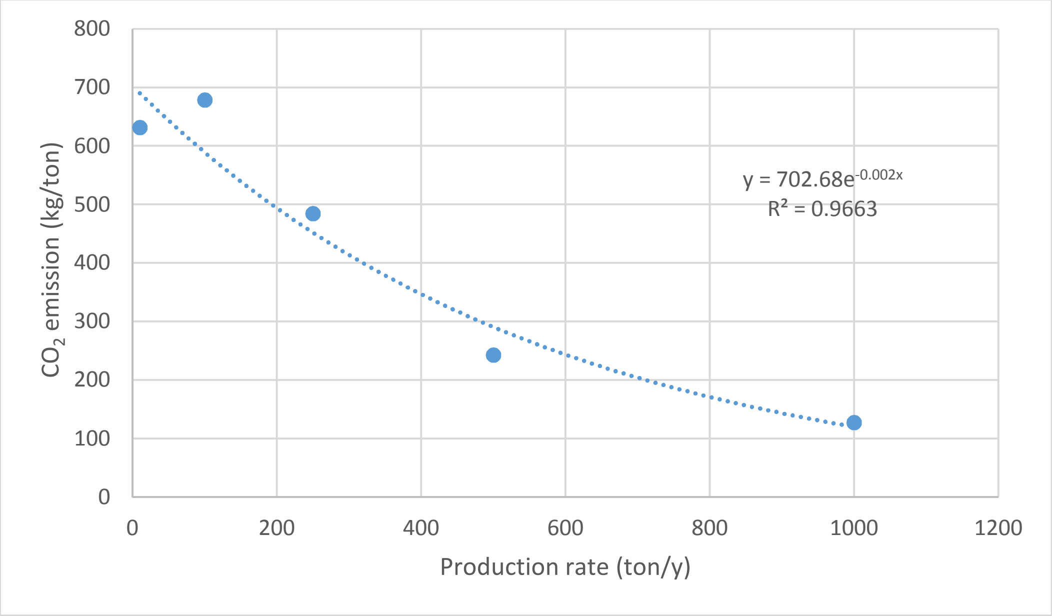

Figure 3.7. Annualized unit CO$_2$ emission as determined by LCA for fish feed production in the State of Indiana

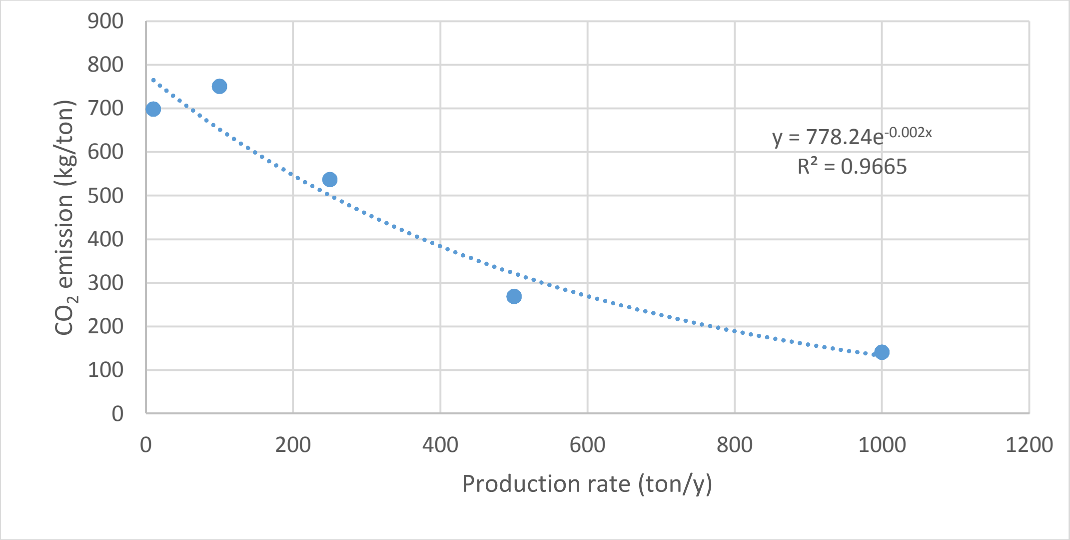

Figure 3.8. Annualized unit CO$_2$ emission as determined by LCA for fish feed production in the State of Ohio

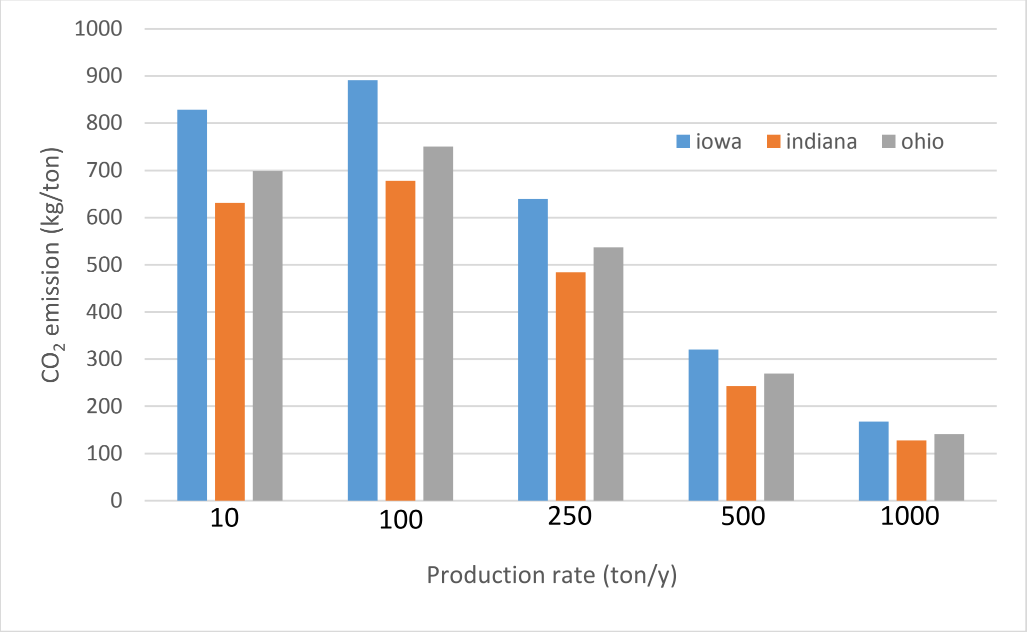

Figure 3.9. Annualized unit CO_2 emission for fish feed production in the states of Iowa, Ohio, and Indiana

Tables 3.1. Assumptions made for fish feed production

Assumptions	
Equipment service life	15y
Electricity use	Lighting and motor power
Electricity use efficiency	Motor reductions of 75%
1hp is equivalent to 746W-h (0.746kW-h)	
CO_2 emission as a result of electricity and natural gas generation	
The building was already in place	
The system boundary for LCA does not include the transportation or emissions from freight	

Table 3.2. List of ingredients for fish feed production - Rainbow trout (Suleiman et al., 2015; Fallahi et al., 2012)

Ingredient for Feed	Total mass (ton)	Inclusion level (%)	Material cost ($/ton)	Scenarios ($)				
				I	II	III	IV	V
Menhaden Fishmeal	0.002	20	800	1600	16000	40000	80000	160000
Soybean Meal	0.002	20	800	1600	16000	40000	80000	160000
Blood Meal	0.0005	5	450	225	2250	5625	11250	22500
Wheat Bran	0.0012	12.2	180	216	2160	5400	10800	21600
Corn Gluten Meal	0.0025	25	750	1875	18750	46875	93750	187500
Fish Oil	0.0011	11	720	792	7920	19800	39600	79200
Hydrogenated Soybean Lecithin	0.0001	1	550	55	550	1375	2750	5500
Corn starch	0.00038	3.8	550	209	2090	5225	10450	20900
Stay-C	0.000005	0.05	500	2.5	25	62.5	125	250
Vitamin premix	0.000095	0.95	800	76	760	1900	3800	7600

Table 3.2. Continued

Mineral Premix	0.0001	1	500	50	500	1250	2500	5000
Total	0.01	100		6700.5	67005	167513	335025	670050

Table 3.3. Variable costs input as determined by TEA for fish feed production

	Variable costs ($/ton)
Electricity	0.07
Water	0.02
Raw ingredients	670.41
Maintenance and repairs	3
Miscellaneous supplies	1
Others	0.25

CHAPTER FOUR

CHARACTERIZATION OF THERMOPHYSICAL AND RHEOLOGICAL CHANGES DURING AMARANTH GRAIN MILLING

Abstract

Amaranth grain is gluten free and has high levels of protein. The total mineral content of amaranth grain is generally greater than that observed in conventional grains. This study focused on amaranth milling with three different mills (burr mill, roller mill, and nutrimill), with three corrugations (0.002 in., 0.005 in. and 0.010 in.) and three moisture levels (10%, 20%, and 24% w.b.). The following physical properties were measured in the grain: seed dimension, one thousand seed weight, and moisture content before and after tempering. The following physical properties were measured in the flour: mean particle size, bulk density, color, angle of repose, moisture content, thermal conductivity, thermal diffusivity, and specific heat capacity. Results show that one thousand seed weight (W_{1000}) of the amaranth grains increased linearly with an increase in moisture content, from 0.75 to 0.88 grams. The mean particle size of the flour increased with an increase in moisture content. It was observed that changes in the physical properties correlated with moisture content. The results of this study give understanding of changes that ought to be considered in the processing and handling of amaranth flour. These results will be relevant when incorporating amaranth flour into gluten-free food products.

Keywords: Amaranth grain, gluten intolerance, particle size distribution, physical properties.

4.1. Introduction

There has been an increase in the population of people opting for gluten-free diets. Larger segment of the general public is picking this dietary alternative for an assortment of reasons, such as the celiac disease. Gluten intolerance is becoming very pronounced in the United States (Caitlin and Rosentrater, 2014), and more people are opting for gluten-free diets; numerous individuals additionally partake in gluten free diet for non-therapeutic reasons. There has been growth in the gluten-free market because of these listed reasons (Caitlin and Rosentrater, 2014). Amaranth grain is gluten free and has very high levels of protein. Interest in amaranth grain has been on the increase recently because of the high protein level and quality of the grain (Antoinette et al., 1981; Birthe et al., 1987).

Amaranthus or Amaranth is a traditional Mexican plant. It is a cosmopolitan genus of herbs with approximately 60 plant species, the majority of which are wild (Stallknecht and schulzschaeffer, 1993). *Amaranthus* plants have inflorescences and foliage with different colors, ranging from purple to red and gold. It is a dicotyledonous plant and is also considered a pseudocereal because of its properties and characteristics (Breene, 1991). Amaranthus are known for high tolerance to arid conditions and poor soil conditions, locations where cereals find it challenging to grow (Saunders and Becker, 1984). *Amaranthus* has an excellent capacity to produce high biomass and is used as grains, leafy vegetables, and ornamentals. Several species of amaranth are often considered as weeds (Narpinder and Prabhjeet, 2011). Amaranth grain yield is dependent on the cultivar selection and the growing season, particularly on the availability of moisture in the soil (Abalone et al., 2004).

When compared to conventional grains, amaranth has higher level of mineral content. The phytic acid content of amaranth was reported to range from 2.2 to 3.4 mmol/100g of seeds (Becker et al., 1981; Betschart et al., 1981). Abalone et al., (2004) reported relatively high lysine, tryptophan content, and protein content (16% to 18%). Shrinkage coefficient, porosity, specific volume, bulk density, and true density of amaranth grain were evaluated and correlation was reported between changes in the physical properties and moisture content of amaranth grain.

The operator of a unit can conduct trial milling to optimize milling conditions of a sample, this is referred to as experimental milling (Elieser and Arthur, 1997). Grains can be conditioned for milling by adjusting the amount of moisture added when tempering, increasing or reducing the duration allotted for tempering, temperature and utilization of different mill settings can be tested to obtain optimal results. The environment of the laboratory where the milling study is conducted should be monitored as well. Studies have shown that environmental conditions, such as temperature and relative humidity can affect milling performance. Although, changes in relative humidity had no significant effect in non-pneumatic laboratory mills (Shollenberger, 1921). Al-Obaidy (1982) reported an increase in flour moisture; decrease in flour ash content, protein content, flour extraction, milling loss, grinding and sifting performance in the evaluation of flour milling with respect to changes in relative humidity.

Paulk et al., (2015) reported decrease in mean particle size of sorghum by 100um improved weight gain of finishing pigs by 1.23%. Energy requirement for reducing particle size of material increase when reducing the material to finer sizes. Size reduction has advantages in the food industry. This advantages incudes, increased overall surface area per unit volume; this allows greater access to digestive enzymes and increase the efficiency at which food is digested (Goodband et al., 2002), pelleting, increased ease of management, mixing, and modification of physical characteristics of the material (Koch, 1996). Probst et al., (2013) evaluated grinding performance for corn and corncob using hammer mill. The study reported substantial loss of moisture from ground materials, this was observed more with samples with higher initial moisture content, and ground cob had comparatively higher particle size compared to ground corn.

Studies have been reported on the milling performance of other cereal, but none has been reported on amaranth milling. Hence, the objective of this study was to evaluate characteristics of amaranth grain using different mills at various moisture content and to evaluate physical properties and quality of amaranth flour from different mills and moisture content (burr mill, roller mill, and nutrimill).

4.2. Materials and methods

4.2.1. Sample Preparation

Organic amaranth grain harvested in California USA and certified by the Organic Crop Improvement Association (OCIA) was used for this study. The crude protein (16.2%), crude fiber (4.1%), ash content (2.5%), and fat content (7.7%) of the grain were all measured in dry basis. The amaranth grains were cleaned and mixed thoroughly. About 27kg of the grain was sampled for this study. The initial moisture content of the grains was evaluated using the ASAE (2001) method. The desired moisture content of grains was tempered by adding the amount of distilled water calculated using equation 1 (Sacilik et al., 2003)

$$Q = \frac{W_i(M_f - M_i)}{(100 - M_f)} \tag{1}$$

W_i is the initial sample weight, M_i is the initial moisture content, M_f is the final moisture content

4.2.2. Seed Dimensions

To determine the seed dimensions (maximum length L, maximum width W), 85 Amaranth grains were randomly selected. Image j software (version, 1.49p, 2015) was used to determine seeds dimensions. The arithmetic mean (A) and standard deviation (SD) were obtained from the data, using equation 2 and 3.

$$A = \frac{1}{n} * \sum_{i=1}^{n} xi \tag{2}$$

n is the sample size, x is individual value

$$SD = \sqrt{\frac{\sum (x - \bar{x})^2}{n}} \tag{3}$$

x is individual score, n is the sample size, $\bar{x}$ is the mean

4.2.3. One Thousand Seed Weight

One thousand grain was determined by weighting 100 kernels of the grain, which were picked at random from the bulk seeds, with an electric weighing scale (Denver Instrument, DI4K, Bohemia, NY, USA). There were three replications for each measurement (Tunde-Akintunde et al., 2004; Ixtaina et al., 2008; Vilche et al., 2003).

4.2.4. Grain Milling

The amaranth samples were ground using roller mill, nutrimill, and burr mill. The roller mill used for this study had a corrugation of 1/32 inches, the spacing between the rollers was adjusted to 0.002in., 0.005in., and 0.010in. (fine, medium, and coarse respectively). The burr mill had settings ranging from 1 to 10, but the setting used for this study were 1, 2 and 3 to represent fine, medium and coarse respectively. The nutrimill had a labeled with fine and coarse. The mid-point of this two points was used as the medium point for this study while the fine and coarse position represented the fine and coarse setting for the milling processes. The grains were measured conditioned to three different moisture levels (10%, 20%, and 24% w.b) before the milling process. There were two replicates of each treatment, weighing 500grams each.

4.2.5. Mean Particle Size

The ground amaranth samples were analyzed for particle size distribution using a Tyler Ro-tap (ASABE S319.4). In this study, the samples were poured into a stack of seven sieves and the Ro-tap machine was set to shake these sieves for 10 minutes (Probst et al., 2013). The geometric mean particle size for each treatment was calculated using equation 4.

$$d_{gw} = log^{-1}\left[\frac{\sum_{i=1}^{n}(W_i \log \overline{d}_i)}{\sum_{i=1}^{n}(W_i)}\right] \tag{4}$$

Wi is the weight of retained sample, di is the sieve diameter

4.2.6. Bulk Density

In this study, bulk density of ground samples was measured using a volumeter, the ground amaranth was poured into the hopper, with a one liter cylindrical vessel of stainless steel placed directly under it. The closure below the hopper was opened, and the ground samples were allowed to flow freely into the vessel. Then the top was leveled in a zigzag motion, and the weight of the ground was measured (Suleiman et al., 2015; Singh and Goswami, 1996; Cetin, 2007; Paksoy and Aydin, 2004).

4.2.7. Angle of Repose

The angle of repose is the angle with the horizontal at which the materials will stand when piled (Mohsenin, 1986). The angle of repose in this study was determined as described by Tunde-Akintunde et al., (2004). The angle of repose was calculated from the diameter and height of heap using equation 5.

$$\theta = \tan^{-1} height/(0.5xbase\ length) \tag{5}$$

4.2.8. Thermal Properties

The thermal properties evaluated were, thermal conductivity (k), diffusivity (d) and heat capacity (c). Thermal conductivity of a material is a measure of its ability to transmit heat; it is expressed in the unit W/m◦K. Thermal diffusivity quantifies a material's ability to conduct heat relative to its ability to store heat, and its unit is m^2/s. Specific heat of a material is the amount of heat required to increase the temperature of a unit mass of the material by one degree, and its unit is kJ/kg◦K (Stroshine, 2004). The thermal properties of the amaranth flour were determined using a thermal properties meter (KD2, Decagon Devices, Pullman, Wash).

4.2.9. Color

Color is vital attribute when grading and inspecting flour and grains. In this study, the seed color was measured using a Chroma meter CR-410 (Konica Minolta Optics, Japan). Colorimeter readings were expressed by Hunter values for L*, a* and b*. L* values measure black (0 value) to white (100 value), a* values measure red (+a*) and green (-a*), and b* values measure yellow (+b*) to blue (-b*) of a material (Amir et al., 2015).

4.2.10. Statistical Analysis

These experiments were carried out with two replications for each mill setting and moisture level unless stated otherwise. The arithmetic mean values and standard deviations were reported. All figures were plotted using Microsoft Office Excel, and Statistix 10 was used to run analysis of variance (ANOVA). The significance level (alpha value) of the statistical analysis in this study was set at 0.05. The moisture content, bulk density, angle of repose, thermal properties and color measurements had three replications while the mean particle size had duplicates.

4.3. Results and Discussion

4.3.1. Moisture Content

Table 4.1 shows the moisture content of the grains before milling. The moisture content of the samples was measured prior to milling, 10%, 20% and 24% was obtained as shown in Table 4.1. The moisture content of the flour was measured after milling. Table 4.2 shows the moisture content of amaranth flour, the moisture loss in the feedstock increase in the samples with higher initial moisture content. According to Probst et al., (2013) this higher moisture loss observed in the samples can be attributed to higher heat generated inside grinding chambers. The interaction between grain particle to particle, and milling chambers to particle friction during size reduction would generate heat. The moisture lose from the feedstock material in the milling chamber can be as a result of temperature increase during the milling process. This same trend was observed for corn and corncobs by Probst et al., (2013). The burr Mill plugged at fine setting and could not grind the samples at 24% moisture level (w.b.); these could be due to more heat generated as a result of friction in the plates and between grain particles.

4.3.2. Seed Dimensions

The average maximum seed length and width were 1.20 ± 0.22mm and 1.10 ± 0.20 respectively. These values are less than the range of values obtained from chia seeds but slightly higher than the values obtained for kaňiwa (Suleiman et. al., 2015). They are of the same range as the results obtained by Abalone et al., (2004) for amaranth seeds.

4.3.3. One Thousand Seed Weight

The one thousand seed weight (W_{1000}) of the amaranth grains increased linearly with increase in moisture content, from 0.75g to 0.88grams. The relationship between one thousand seed weight and moisture content of amaranth can be expressed as shown in equation 6.

$$W_{1000} = 0.73 + 0.0048x \qquad (R^2 = 0.94) \qquad (6)$$

Figure 4.1 shows the W_{1000} of the grains with increasing moisture content. Increase in $W_{1000,}$ observed and the same trend was reported for chia seeds, kaniwa, farro and triticale by Suleiman et. al., (2015). This same trend was also observed for guna seeds (Aviara, et al., 1999), coriander seed (Coskuner and karababa, 2007), green wheat (Al-Mahasneh and Rababah,, 2007), barley (Sologubik et al., 2013), rapeseed (Calisir et. al., 2005) and caper seed (Dursun and Dursun, 2005).

4.3.4. Mean Particle Size

Table 4.3 shows the data obtained from particle size analysis carried out in this study. The mean particle size of the flour increased with increase in moisture content. The results obtained for the particle size distribution are similar to that for milling corn kernel and corncob with hammer mill reported by Prost et al., (2013). The mean particle size for the nutrimill (fine, 10% MC w.b.) was the lowest compared to the mean particle size for the fine corrugation and 10% MC (w.b.) for the roller mill and burr mill (Figure 4.2).

4.3.5. Bulk Density

There is no definite trend for bulk density of the ground samples as regards increase in moisture content (Table 4.4). Bulk density decreased as moisture content of treatments increased for burr mill (Figure 4.3). Similarly, Bernhart and Fasina, (2009) also reported decrease in the particle density with increase in moisture content. Prost et al., (2013) also observed decrease in bulk density as moisture content of corn increased, the decrease was attributed to increase in particle volume.

4.3.6. Angle of Repose

Figure 4.4 shows the angle of repose for all ground samples; it can be observed that there is no definite trend in the chart. The angle of repose did not increase as the moisture or mill setting increased. The 0.005in., and 0.010in. of the roller mill tends to show increasing angle of repose at all moisture levels, but this trend does not stand for other treatments.

4.3.7. Thermal Properties

The variation in thermal conductivity, diffusivity and specific heat capacity for the amaranth grain before milling and ground samples for 10%, 20%, and 24% moisture level (w.b.) are shown in Table 4.5, 4.6 and 4.7 respectively. The specific heat capacity tends to increase linearly with increasing from 10% to 24% (w.b.). A similar trend was observed for minor millet grains and flour by Subramanian and Viswanathan (2003); Chia, Kañiwa, Farro and Triticale by Suleiman et al., (2015); gram by Dutta et al. (1988); and Roselle seeds by Bamgboye and Adejumo (2010). With respect to this trend, it can be said that moisture content of a material has significant effect on the specific heat capacity of the material.

No specific trend was observed for the thermal diffusivity and thermal conductivity across all treatments. The results obtained for thermal diffusivity, and thermal conductivity was in the range of 0.09 to 0.12 and 0.13 to 0.20 respectively. Mahapatra et al., (2013) reported an increase in thermal diffusivity and thermal conductivity of increasing moisture in cowpea flour, Božiková (2003) reported the same trend for corn and wheat flour. In contrast, Mahapatra et al. (2011) reported a decrease in thermal diffusivity of rice flour with the increase in moisture content.

4.3.8. Color

The colorimeter readings for the amaranth grain before milling and ground samples for 10%, 20%, and 24% moisture level (w.b.) are shown in Table 4.8, 4.9, and 4.10 respectively. The milling corrugation of the three mills had no significant effect on the brightness of the flour in this study, as shown in comparison within mills in Table 4.11, 4.12 and 4.13. The moisture content of the grains has significant impact on the L* of amaranth flour in all treatments. The a* value of the roller milled samples was significantly different in the samples with 10% MC (0.005in. mill corrugation), 10% MC (0.010in. mill corrugation), 24% MC (0.005in. mill corrugation), and 20% MC (0.005in. mill corrugation). The samples with 10% (w.b.) had higher values, indicating that they had more red appearance compared to other samples. The b* value for samples milled with the roller mill were all negative; this indicates that they were best described as blue. There were significant difference between 24% MC (0.002in. mill corrugation), 24% MC

(0.005in. mill corrugation), and 10% MC (0.010in. mill corrugation), and 10% MC (0.002in. and 0.005in. mill corrugation).

4.4. Conclusion

The effect of three mill settings (fine, medium, coarse) and moisture levels (10% to 24% w.b.) on the milling behavior of amaranth grain at three moisture levels was studied. Heat generated by friction during the milling process resulted in substantial decrease in the moisture content of amaranth flour. Also, the burr mill plates plugged when high moisture level grain and fine setting was combined. It would be most appropriate to account for moisture losses that occur in ground materials when designing milling systems. The mean particle size for all burr mill, roller mill and nutrimill increased with increase in moisture content for all mill setting.

The results of this study gives understanding of changes that ought to be considered in the processing and handling of amaranth flour. This result would also be relevant when incorporating amaranth flour into gluten free products.

4.5. References

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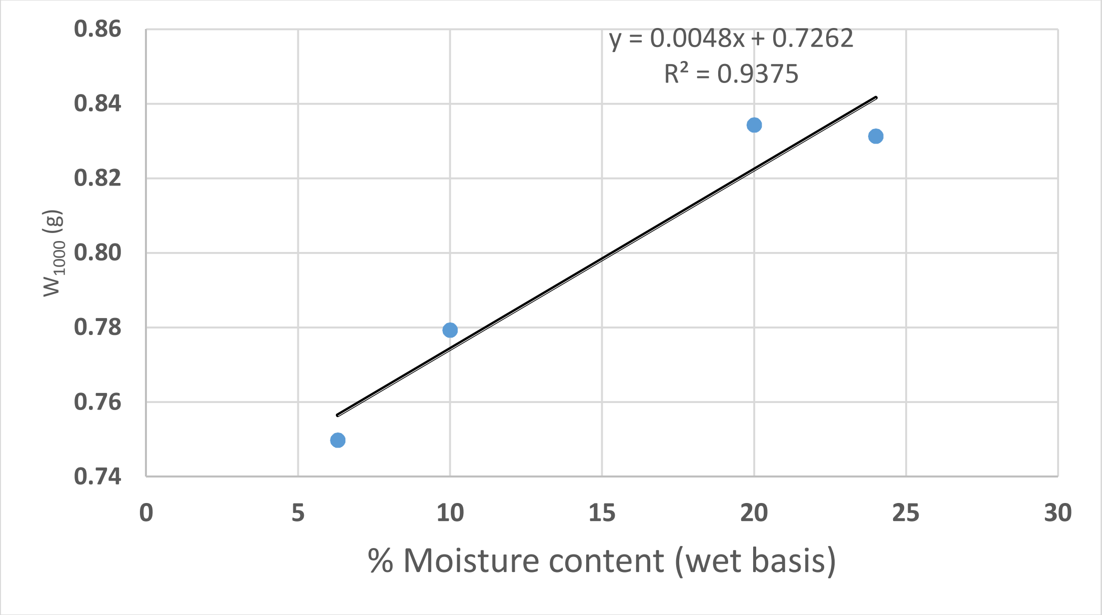

Figure 4.1. One thousand seed weight of amaranth grain with increasing MC

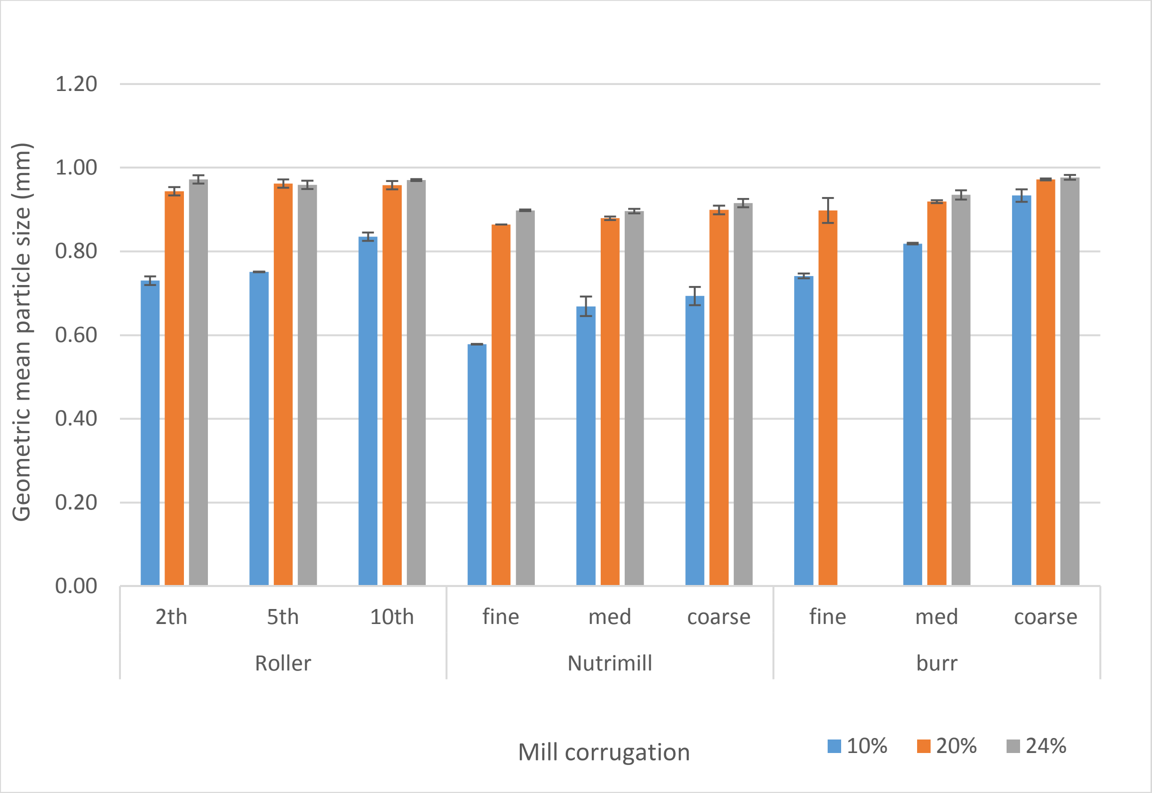

Figure 4.2. Mean particle size distribution of amaranth flour
Error bars are ± standard deviation. n is 2 for each treatment

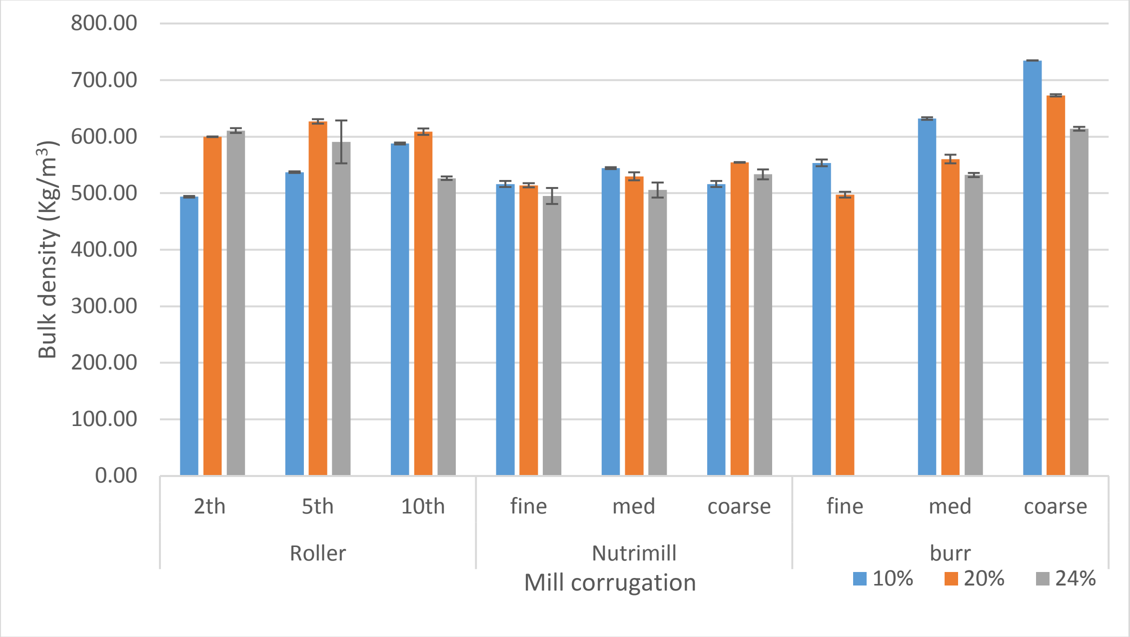

Figure 4.3. Bulk density of amaranth flour
Error bars are ± standard deviation. n is 3 for each treatment
All pairwise comparisons are shown in Table 4.11, 4.12, and 4.13

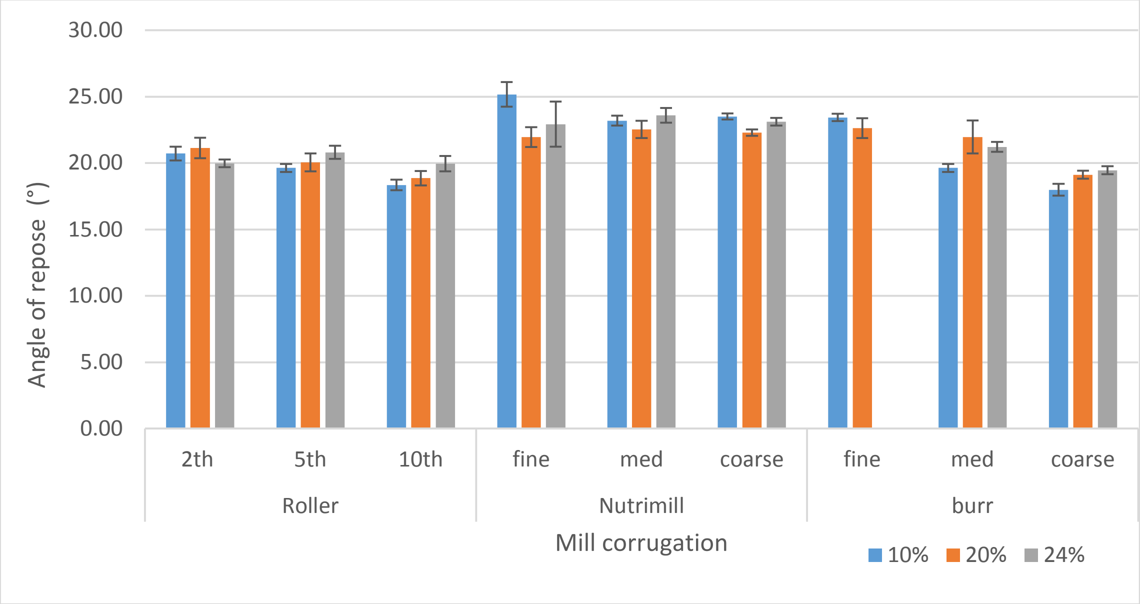

Figure 4.4. Angle of repose of amaranth flour
Error bars are ± standard deviation. n is 3 for each treatment
All pairwise comparisons are shown in Table 4.11, 4.12, and 4.13

Table 4.1. Initial moisture content of amaranth grain (w.b. %)

Target MC	Mean	SD
10%	10.23	1.08
15%	20.76	1.56
20%	24.31	1.05

Table 4.2. Moisture content of amaranth flour

		10% (w.b.)		20% (w.b.)		24% (w.b.)	
		mean	SD	mean	SD	mean	SD
Roller mill	2th	12.00	4.67	19.37	0.55	21.35	3.20
	5th	12.58	3.09	18.91	3.50	22.94	2.61
	10th	13.44	0.34	20.95	2.52	27.27	0.00
Nutrimill	fine	11.67	2.89	19.79	3.50	26.52	1.31
	med	11.51	3.03	22.03	3.51	25.72	1.76
	coarse	14.09	0.79	19.60	4.42	17.63	7.64
Burr mill	fine	11.21	2.10	20.26	1.36		
	med	9.70	0.52	20.91	1.57	24.60	1.71
	coarse	12.21	3.06	18.50	0.96	23.92	5.28

All pairwise comparisons are shown in Table 4.11, 4.12, and 4.13

Table 4.3. Mean particle size of distribution amaranth flour (mm)

		10% (w.b.)		20% (w.b.)		24% (w.b.)	
		mean	SD	mean	SD	mean	SD
Roller mill	2th	0.73	0.01	0.94	0.01	0.97	0.01
	5th	0.75	0.00	0.96	0.01	0.96	0.01
	10th	0.83	0.01	0.96	0.01	0.97	0.00
Nutrimill	fine	0.58	0.00	0.86	0.00	0.90	0.00
	med	0.67	0.02	0.88	0.00	0.90	0.01
	coarse	0.69	0.02	0.90	0.01	0.92	0.01
Burr mill	fine	0.74	0.01	0.90	0.03		
	med	0.82	0.00	0.92	0.00	0.94	0.01
	coarse	0.93	0.01	0.97	0.00	0.98	0.01

All pairwise comparisons are shown in Table 4.11, 4.12, and 4.13

Table 4.4. Bulk density of amaranth flour (kg/m^3)

		10% (w.b.)		20% (w.b.)		24% (w.b.)	
		mean	SD	mean	SD	mean	SD
Roller mill	2th	493.73	1.47	599.77	0.58	610.67	4.10
	5th	537.10	1.44	626.87	3.81	590.80	37.99
	10th	587.70	1.82	608.83	5.58	526.43	3.06
Nutrimill	fine	516.07	5.30	513.83	3.63	494.97	14.10
	med	544.37	1.57	529.80	6.84	505.60	13.29
	coarse	516.07	5.30	554.50	0.80	533.43	8.69
Burr mill	fine	553.57	6.02	497.33 5	5.11		
	med	632.07	2.42	560.27	7.49	532.33	3.71
	coarse	734.50	0.20	673.00	1.71	613.77	3.32

All pairwise comparisons are shown in Table 4.11, 4.12, and 4.13

Table 4.5. Thermal properties of 10% (w.b.) MC amaranth flour

		Thermal conductivity (W/m-k)		Diffusivity (mm^2/s)		Specific heat capacity (MJ/m^3-k)	
		mean	SD	mean	SD	mean	SD
sample (as is)		0.14	0.03	0.09	0.00	1.31	0.16
Roller mill	2th	0.13	0.01	0.11	0.00	1.19	0.09
	5th	0.13	0.01	0.10	0.00	1.28	0.06
	10th	0.14	0.01	0.10	0.00	1.35	0.11
Nutrimill	fine	0.13	0.01	0.10	0.00	1.22	0.10
	med	0.13	0.00	0.10	0.00	1.35	0.06
	coarse	0.13	0.00	0.10	0.00	1.29	0.04
Burr mill	fine	0.13	0.01	0.10	0.00	1.25	0.03
	med	0.14	0.01	0.10	0.00	1.42	0.10
	coarse	0.15	0.00	0.09	0.00	1.65	0.03

All pairwise comparisons are shown in Table 4.11, 4.12, and 4.13

Table 4.6. Thermal properties of 20% (w.b.) MC amaranth flour

		Thermal conductivity (W/m◦K)		Diffusivity (mm^2/s)		Specific heat capacity (MJ/kg◦K)	
		mean	SD	mean	SD	mean	SD
sample (as is)		0.16	0.01	0.09	0.00	1.78	0.81
Roller mill	2th	0.17	0.02	0.11	0.00	1.56	0.15
	5th	0.15	0.01	0.11	0.01	1.43	0.04
	10th	0.16	0.01	0.10	0.00	1.50	0.09
Nutrimill	fine	0.15	0.00	0.10	0.00	1.50	0.04
	med	0.16	0.01	0.11	0.00	1.48	0.09
	coarse	0.16	0.01	0.10	0.00	1.52	0.13
Burr mill	fine	0.16	0.00	0.11	0.00	1.44	0.01
	med	0.17	0.01	0.11	0.00	1.57	0.08
	coarse	0.17	0.00	0.10	0.00	1.64	0.04

All pairwise comparisons are shown in Table 4.11, 4.12, and 4.13

Table 4.7. Thermal properties of 24% (w.b.) MC amaranth flour

		Thermal conductivity (^{W}/m-◦K)		Diffusivity (mm^2/s)		Specific heat capacity (MJ/kg◦K)	
		mean	SD	mean	SD	mean	SD
sample (as is)		0.16	0.03	0.09	0.00	1.77	0.30
Roller mill	2th	0.17	0.01	0.11	0.00	1.54	0.03
	5th	0.16	0.01	0.11	0.00	1.51	0.05
	10th	0.17	0.00	0.12	0.00	1.39	0.05
Nutrimill	fine	0.16	0.01	0.11	0.00	1.43	0.03
	med	0.16	0.01	0.11	0.00	1.51	0.04
	coarse	0.17	0.01	0.11	0.00	1.52	0.04
Burr mill	med	0.17	0.01	0.11	0.00	1.56	0.12
	coarse	0.19	0.01	0.11	0.00	1.71	0.07

All pairwise comparisons are shown in Table 4.11, 4.12, and 4.13

Table 4.8. Colorimeter reading for amaranth flour with 10% (w.b.) MC

		L*		a*		b*	
		mean	SD	mean	SD	mean	SD
sample (as is)		46.14	1.00	0.41	0.03	-1.65	0.23
Roller mill	2th	53.52	1.69	1.95	0.16	-10.86	1.66
	5th	54.03	1.36	2.02	0.06	-10.37	0.54
	10th	53.00	0.64	1.83	0.10	-8.88	0.56
Nutrimill	fine	57.08	0.70	2.03	0.13	-13.51	0.89
	med	54.50	1.54	1.71	0.21	-11.08	1.36
	coarse	54.93	1.06	1.67	0.12	-11.08	0.82
Burr mill	fine	53.58	0.93	1.78	0.20	-9.96	1.08
	med	52.34	0.95	1.75	0.08	-9.08	0.27
	coarse	50.73	1.26	1.21	0.18	-6.03	1.24

All pairwise comparisons are shown in Table 4.11, 4.12, and 4.13

Table 4.9. Colorimeter reading for amaranth flour with 20% (w.b.) MC

		L*		a*		b*	
		mean	SD	mean	SD	mean	SD
sample (as is)		43.64	0.83	0.99	0.07	-1.16	0.17
Roller mill	2th	46.81	0.82	1.24	0.15	-3.93	0.98
	5th	47.56	0.56	1.11	0.08	-3.29	0.65
	10th	46.66	0.31	1.16	0.02	-3.30	0.25
Nutrimill	fine	46.19	0.69	1.04	0.86	-2.48	0.87
	med	44.86	0.76	1.06	0.14	-3.00	0.99
	coarse	45.43	0.86	1.04	0.13	-2.42	0.74
Burr mill	fine	45.41	0.97	1.41	0.06	-3.06	0.46
	med	45.73	1.15	1.36	0.06	-3.32	0.66
	coarse	44.94	0.94	1.04	0.09	-2.18	0.30

All pairwise comparisons are shown in Table 4.11, 4.12, and 4.13

Table 4.10. Colorimeter reading for amaranth flour with 24% (w.b.) MC

		L*		a*		b*	
		mean	SD	mean	SD	mean	SD
sample (as is)		41.16	0.68	1.10	0.09	-2.18	0.47
Roller mill	2th	46.27	0.62	1.23	0.03	-2.93	0.34
	5th	47.43	0.59	1.30	0.05	-4.27	0.56
	10th	47.49	0.59	1.16	0.05	-3.89	0.36
Nutrimill	fine	42.62	1.45	0.80	0.14	-1.23	0.73
	med	43.43	1.06	0.78	0.08	-1.54	0.42
	coarse	42.28	1.01	0.88	0.10	-1.13	0.41
Burr mill	med	44.72	0.48	1.36	0.05	-2.04	0.39
	coarse	44.20	0.52	1.36	0.05	-1.62	0.36

All pairwise comparisons are shown in Table 4.11, 4.12, and 4.13

Table 4.11. All pairwise comparison for mean of treatments within mill – roller mill

MC	10% (w.b.)			20% (w.b.)			24% (w.b.)		
corrugation	2th	5th	10th	2th	5th	10th	2th	5th	10th
Mean particle size	0.73^{e}	0.75^{d}	0.83^{c}	0.94^{b}	0.96^{ab}	0.96^{ab}	0.97^{a}	0.96^{ab}	0.97^{a}
%MC w.b. after milling	12.00^{c}	12.58^{c}	13.44^{c}	19.37^{b}	18.91^{b}	20.95^{b}	21.35^{b}	22.94^{ab}	27.27^{a}
L	53.52^{a}	54.03^{a}	53.00^{a}	46.81^{bc}	47.56^{b}	46.66^{bc}	46.27^{c}	47.43^{bc}	47.56^{b}
a*	1.95^{ab}	2.01^{a}	1.83^{b}	1.24^{cd}	1.16^{cd}	1.16^{cd}	1.23^{cd}	1.30^{c}	1.11^{d}
b*	-10.86^{d}	-10.37^{d}	-8.88^{c}	-3.93^{ab}	-3.29^{ab}	-3.30^{ab}	-2.93^{a}	-4.27^{b}	-3.91^{ab}
Bulk. density	493.73^{e}	537.10^{d}	587.7^{c}	599.77^{bc}	626.87^{a}	608.83^{abc}	610.67^{ab}	590.80^{bc}	526.43^{d}
Angle of Repose	20.72^{ab}	19.63^{cd}	18.35^{e}	21.14^{a}	20.05^{bc}	18.86^{de}	19.97^{bc}	20.81^{ab}	19.96^{bc}
k (^{W}/m-k)	0.13^{b}	0.13^{b}	0.14^{b}	0.17^{a}	0.15^{a}	0.16^{a}	0.17^{a}	0.16^{a}	0.17^{a}
d (mm^2/s)	0.11^{b}	0.10^{cd}	0.10^{d}	0.11^{cd}	0.11^{c}	0.10^{cd}	0.11^{bc}	0.11^{bc}	0.12^{a}
c (MJ/m^3-k)	1.19^{e}	1.28^{de}	1.35^{cd}	1.56^{a}	1.43^{abc}	1.50^{ab}	1.54^{a}	1.51^{ab}	1.39^{bcd}

Means with different alphabets $^{a\text{-}e}$ within the same row are significantly different, at $P = 0.05$

Table 4.12. All pairwise comparison for mean of treatments within mill – Nutrimill

MC	10% (w.b.)			20% (w.b.)			24% (w.b.)		
corrugation	fine	medium	coarse	fine	medium	coarse	fine	medium	coarse
Mean particle size	0.58^{e}	0.67^{d}	0.69^{d}	0.86^{c}	0.88^{bc}	0.90^{ab}	0.90^{ab}	0.90^{ab}	0.92^{a}
%MC w.b. after milling	11.67^{e}	11.51^{e}	14.09^{de}	19.79^{bcd}	22.03^{abc}	19.60^{bcd}	26.52^{a}	25.72^{ab}	17.63^{cde}
L	57.08^{a}	54.50^{b}	54.93^{b}	46.19^{c}	44.86^{d}	45.43^{cd}	42.61^{f}	43.43^{e}	42.28^{f}
a*	2.03^{a}	1.71^{b}	1.67^{b}	1.04^{c}	1.06^{c}	1.04^{c}	0.80^{d}	0.78^{d}	0.88^{d}
b*	-13.51^{d}	-11.08^{c}	-11.08^{c}	-2.48^{b}	-3.00^{b}	-2.42^{b}	-1.23^{a}	-1.54^{a}	-1.13^{a}
Bulk density	516.07^{d}	544.37^{ab}	516.07^{d}	513.83^{d}	529.80^{c}	554.50^{a}	494.97^{e}	505.60^{de}	533.43^{bc}
Angle of Repose	25.17^{a}	23.19^{bc}	23.51^{b}	21.96^{c}	22.54^{bc}	22.29^{bc}	22.93^{bc}	23.59^{b}	23.11^{bc}
k (^{W}/m-k)	0.13^{d}	0.13^{d}	0.13^{d}	0.15^{c}	0.16^{bc}	0.16^{bc}	0.16^{bc}	0.16^{ab}	0.17^{a}
d (mm^2/s)	0.10^{de}	0.10^{f}	0.10^{f}	0.10^{ef}	0.11^{bcd}	0.10^{cd}	0.11^{ab}	0.11^{abc}	0.11^{a}
c (MJ/m^3-k)	1.22^{d}	1.35^{bc}	1.29^{cd}	1.50^{a}	1.48^{a}	1.52^{a}	1.43^{ab}	1.51^{a}	1.52^{a}

Means with different alphabets $^{a-f}$ within the same row are significantly different, at P = 0.05

Table 4.13. All pairwise comparison for mean of treatments within mill – burr mill

MC	10% (w.b.)			20% (w.b.)			24% (w.b.)	
corrugation	fine	medium	coarse	fine	medium	coarse	medium	coarse
Mean particle size	0.74^{e}	0.82^{d}	0.93^{b}	0.90^{c}	0.92^{bc}	0.97^{a}	0.94^{b}	0.98^{a}
%MC w.b. after milling	11.21^{d}	9.70^{d}	12.21^{d}	20.26^{bc}	20.91^{abc}	18.50^{c}	24.61^{a}	23.92^{ab}
L	53.58^{a}	52.34^{b}	50.73^{c}	45.41^{d}	45.73^{d}	44.94^{de}	44.72^{de}	44.20^{e}
a*	1.77^{a}	1.75^{a}	1.21^{cd}	1.41^{b}	1.36^{bc}	1.04^{d}	1.36^{bc}	1.36^{bc}
b*	-9.96^{e}	-9.08^{e}	-6.03^{d}	-3.06^{bc}	-3.32^{c}	2.18^{ab}	-2.04^{ab}	-1.62^{a}
Bulk density	553.57^{e}	632.07^{c}	734.50^{a}	497.33^{g}	560.27^{e}	673.00^{b}	532.33^{f}	613.77^{d}
Angle of Repose	23.43^{a}	19.63^{d}	17.99^{e}	22.62^{ab}	21.96^{bc}	19.12^{d}	21.22^{c}	19.46^{d}
k (^{W}/m-k)	0.13^{e}	0.14^{d}	0.15^{c}	0.16^{c}	0.17^{bc}	0.17^{b}	0.17^{b}	0.19^{a}
d (mm^2/s)	0.10^{cd}	0.10^{d}	0.09^{e}	0.11^{ab}	0.11^{bc}	0.10^{bcd}	0.11^{ab}	0.11^{a}
c (MJ/m^3-k)	1.25^{d}	1.42^{c}	1.65^{ab}	1.44^{c}	1.57^{b}	1.64^{ab}	1.56^{b}	1.71^{a}

Means with different alphabets $^{a-g}$ within the same row are significantly different, at P = 0.05

CHAPTER FIVE

EVALUATION OF RHEOLOGICAL, PHYSIOCHEMICAL, AND SENSORY CHARACTERISTICS OF GLUTEN-FREE BREAD BASED WITH RICE AND AMARANTH FLOUR

Abstract

Celiac disease is an immunological reaction to gluten and is a common food intolerance in the U.S. This has led to an increase in the demand for gluten-free food products. A variety of whole grains (for example, corn, rice, sorghum, buckwheat, amaranth, and quinoa) are gluten-free (GF) and are excellent sources of fiber, iron, and B vitamins. GF food manufacturers are investing in the formulation of GF products using these types of whole grains. This study focused on formulating gluten-free bread with amaranth and rice flour. Bread flour served as the control, while rice and amaranth flour were used at different combination ratios. The protein and moisture content of the flour were obtained, and other flour properties were measured using a mixograph. Bread quality was investigated by measuring specific volume, hardness, color (bread crust and crumb), and sensory evaluation using 77 consumer panelists. Consumers did not like breads formulated with amaranth. However, bread made with a combination of amaranth and rice flour had higher scores than bread with pure amaranth, improvement seems plausible.

Keywords: Celiac disease, consumer panel, product development

5.1. Introduction

Celiac disease is becoming a common food intolerance in the U.S. and has led to increased demand for gluten-free (GF) food products. Celiac disease is a digestive disorder which damages the villi, tiny hair-like projections in the small intestine that absorb nutrients, due to an immunological reaction to gluten (King, 2006). But gluten is paramount for the structure formation of baked products because it is a structure-building protein essential for formulating leavened baked goods. Gluten retains gas, which helps obtain the desired volume, structure and texture in a dough system. Obtaining high-quality GF bread is a technological challenge (Torbica et al., 2010).

GF food manufacturers are investing in the use of whole grains including corn, rice, sorghum, buckwheat, amaranth and quinoa; since the majority of these are excellent source of fiber, iron and vitamin B (Thompson, 2009). The pseudocereals are considered as potentially GF grains with beneficial nutrient profile, which are capable of diversifying this rising market for GF products (Alvarez-Jubete et al., 2010).

Different factors influence the choices of consumers; these factors can be either sensory or non-sensory factors (Jaeger, 2006). For GF products, personal health might be considered more important factor than sensory quality. Individuals with celiac disease still have trouble finding desirable GF products because of the high price, poor sensory properties, and limited variety and availability of the products. The quality of most commercially available GF breads are substandard in quality compared to gluten-containing bread (Gallagher et al., 2003). The relative poor shelf life of GF product has also been reported (Gallagher et al., 2003).

Development of GF bread remains a technological challenge due to the high dependence of bread's properties on gluten. GF flours are not enriched or fortified, the resulting GF products are also less enriched when compared to their wheat-based counterparts. Hence, GF products may lead to nutritional deficiencies. The crumb, which is wet after baking and sticks together, becomes dry, rough and crumbly the next day (Gambus et al., 2007). Preserving desirable sensory quality of bread during storage is vital because products are expected to stay the same for a couple of days (Gambus et al., 2007). Getting a balance between good nutritional quality and good sensory properties in GF bread is a challenge.

Studies have reported that rice flour is increasingly utilized as substitute for wheat flour in GF food products, which are focused on individuals with special dietary needs. Rice flour has a bland taste, is easily digestible, and has other desirable properties which makes it suitable for GF products (Rosell et al., 2007, Rosell and Marco, 2008, Blanco et al., 2011). Amaranth flour, on the other hand, has very high levels of protein. The protein level and the quality of amaranth have contributed to a renewed interest in amaranth grain (Betschart et al., 1981; Pedersen et al., 1987). Amaranth flour contains a higher content of minerals as calcium, potassium, phosphorus, as well as dietary fiber, than many cereal grains (Pedersen et al., 1990, Whittaker and Ologunde, 1990). Amaranth is also very suitable for fortification of baked products (Ana et al., 2010). Amaranth flour was used in GF biscuit (Tosi et al., 1996) and bread (Schoenlechner et al., 2010). Moore et al. (2004) compared the texture of GF and wheat-based doughs, batters, and bread. The results show a gluten-like matrix in the GF bread, that, in turn, enhanced loaf volume, improved crumb texture and delayed staling of the bread.

Miles et al. (2012) studied the relationship between mixograph parameters and grain milling characteristics for hard red bread wheat. The study reported that grain kernel diameter correlated with the dough consistency reading obtained from the mixograph. A strong correlation was not inferred from the results achieved from the mixograph, physical property measurement of the grains and the milling characteristics. Mahmoud et al. (2013) studied the physical, sensory, and staling properties of GF balady flat bread formulation based on rice flour, corn, and potato starch blends with different levels of hydrocolloids. The results showed that gums clearly improved the weight and roundness of gluten free balady flat bread.Alencar et al. (2015) evaluated the influence of sweeteners and pseudocereals in GF bread formulations. The quality parameters evaluated were specific volume, firmness, color, water activity, proximate composition, gross energy, sensory properties and an image analysis of the crumb. The results of the study showed that it is possible to develop GF bread with pseudocereals and sweeteners with similar sensory and physicochemical properties to those produced using starch-based formulations.

The objective of this study was to formulate GF bread from amaranth and rice flour, they will be fortified with garbanzo bean to increase the protein content of the GF bread.

5.2. Materials and Methods

Calculate amount of total protein in each of the formulations.

5.2.1 Flour Mix and Baking Process

Ingredients used in this study were amaranth flour, white rice flour, potato flour, tapioca starch, corn starch, high gluten flour, cane sugar, salt, water, active yeast, shortening, xantham gum, and guar gum, which were all acquired from a local grocery store (Hy-Vee and Wheatfield). The composition of each flour mix in the treatments tested in this study is shown in Table 5.1.

Figure 1 shows the baking procedure for control, and Figure 2 shows the baking procedure for treatment two, three and four. The control was placed in the proofing oven with had a temperature of 85^{O}F and 95% humidity (National Mfg. Co, Lincoln, NE) at three stages in the baking process while other treatments were proofed once because the GF flour have weak protein structure compared to the control flour. Treatment one (control) took less time to bake (25 minutes at 450^{O}F) compared to treatment two, three, and four (60 minutes at 350^{O}F).

5.2.2. Analytical Methods

Protein content and moisture content of flours were determined by standard AACC methods (1983). The moisture absorption rate for each flour mix was used as stated in the mixograph handbook. Mixing behavior of the high gluten wheat flour, rice flour, amaranth flour and the combination of rice and amaranth flour dough were evaluated using 10 g mixograph procedure (Method AACC 54-40A, AACC, 1983; Khatkar et al., 1996). The peak time, peak height, development angle, weakening angle, mixing tolerance angle, and tail width were measured by the mixograph (National Mfg. Co, Lincoln, NE).

5.2.3. Bread Quality Evaluation

The following bread quality characteristics were analyzed: specific volume (cm^3/g), height (cm), crumb and crust color, and crumb hardness (N). The volume and weight of bread samples were measured five minutes after they were removed from the oven. Loaf weight was measured using a digital scale (Denver Instrument company, A-250) while loaf volume was measured using rapeseed displacement method (AACC method 10-05.01). The bottom compartment of measuring unit was emptied of seeds, a wood block with a volume of 400 cc was placed inside. The seeds were allowed to flow into the lower compartment. When the compartment was full, and the seeds were clearly present in the viewing tube, the gate controlling entrance of the seeds into the bottom compartment was shut. This preliminary procedure was carried out to calibrate the measuring instrument before the volume of bread was measured. The dummy of known volume (400 cm^3) was replaced with bread sample and volume of the bread was read off the viewing tube. Height was measured with a ruler in the middle section of each bread sample. Bread height, weight, and volume were measured on three (3) loaves for each treatment.

The digital colorimeter used in this study was Chromameter CR-410 (Konica Minolta Optics, Japan). The crust and crumb of the baked loaves were analyzed for the following color parameters: L* (lightness), a* (redness to greenness) and b* (yellowness to blueness). Crumb color determinations were made in four slices from the center of the loaves, and crust color determinations were made in the slices from the ends of each loaf (Gómez et al. 2010).

5.2.4. Texture Profile Analysis

Texture analysis was performed using a TA.XT2i Texture Analyzer (Stable Microsystems, Surrey, UK). The bread samples were stored in a plastic container for 24 hours and texture profile was carried out on bread slices (10 mm thickness) compressed to 50% of their original height at 1.0 mm/s using a ceramic probe (32 mm x 12.7 mm, diameter flat contact surface plate) with elapsed time between compressions being 10 s (Hung et al., 2007). Bread crumb hardness as defined by Bourne (2002), was evaluated. Compression test was followed according to AACC Method 74-09, crumb hardness was calculated by using a texture analysis program (version V1.22), which was coupled to the texture analyzer. Six (6) readings were obtained per treatment.

5.2.5. Experimental Design of Sensory Evaluation

Untrained (77) panelists were recruited from the faculty, staff and students of Iowa State University; the use of human subjects was approved by the Iowa State University Institutional Review Board (IRB). Before testing, panelists were required to read and sign an informed consent document, and all potential risks and benefits were explained to them. Three samples and control were assigned 3-digit random numbers and presented separately in randomized order. Sensory evaluation of bread was conducted using a consumer acceptability test (Meilgaard et al., 2007). Attributes selected for testing the bread were appearance, aroma, flavor and texture. Panelists were asked to scale their acceptance of the bread samples on a 9-point hedonic scale (ranging from strongly dislike (1) to strongly like (9)). Panelists were provided with plain water to remove residual taste between samples. All sensory sessions were carried out in individual booths equipped with white lighting and guidelines for suitable sensory evaluation room were followed (Meilgaard et al., 2007).

5.2.6. Statistical Analysis

Differences among means in texture, color and acceptability (??) were analyzed by analysis of variance using Statistix 10 (Analytical Software, Tallahassee, FL). The significance level (alpha value) of the statistical analysis in this study was set at 0.05.

5.3 Results and Discussion

5.3.1. Mixograph Parameters and Analytical Methods

The MC and protein content of the flours used in this study are shown in Table 5.2. The data obtained from running all four treatments on the mixograph for 10 minutes is shown in Tables 5.3, 5.4, 5.5, 5.6 and Figures 5.3, 5.4, 5.5, 5.6 for control, 18.7% rice flour, 18.7% amaranth flour and 9.3% amaranth and rice flour, respectively. The first phase of the mixograph indicates the protein characteristics of the flour (Torbica et al., 2010). The mixing time obtained for 18.7% rice flour, 18.7% amaranth flour and 9.3% were all below one minute (Tables 5.4, 5.5, and 5.6), meaning the protein structure in GF flours collapsed easily compared to that of the control (Table 5.3 and Figure 5.3). Similarly, Torbica et al., (2010) investigated rheology of dough using mixolab and observed a decrease in mixing time for rice and buckwheat-based doughs compared to the mixing time for wheat dough.

5.3.2. Bread Quality Evaluation

All GF treatments had less rise compared the control, which is not surprising, because the GF flours lack the elasticity that gluten provides in the control. The specific volume for control was significantly different from that of GF treatments, as shown in Table 5.7. The bread made with rice and amaranth flour had higher rise and specific volume than bread with only rice flour but was similar in specific volume to the bread with only amaranth flour (Table 5.7). This is not surprising because flour substitution in bread formulation is known to result in significant decreases in the bread volume. The decrease in specific volume can be attributed to limited amount of water-binding substances in the mix (Korus et al., 2015). Xantham gum and guar gum was used in the GF formulation to aid the structure formation but this didn't seem sufficient to overcome lack of gluten. A similar trend was observed for GF made from rice flour (Matos and Rosell 2012), GF bread with soy bean isolate (Smerdel et al. 2012), and acorn flour (Korus et al. 2015).

The crust and crumb of the loaves are shown in Figure 5.7 and 5.8. 18.7% rice flour treatment had the highest L* for bread crust color (Table 5.7) while 9.3% amaranth and rice flour treatment overlapped with control and 18.75 amaranth flour. Torbica et al. (2010) also showed that bread with rice flour is lighter than breads made with wheat or amaranth flour. Rice flour is lighter than amaranth flour.

Saunders et al., (2014) conducted a study on substituting bread flour with distiller's dried grains with solubles (DDGS). It was observed that the physical property of the loaves varied significantly as the ratio of DDGS increased. The decrease in volume of the loaves were attributed to the dilution of gluten (Saunders et al., 2014). In other studies, no significant difference was observed for texture of GF bread with buckwheat compared to GF bread from rice flour (Torbica et al., 2010, Lin et al., 2009).

5.3.3. Texture Profile Analysis

The results obtained from TAXT2 are shown in Table 5.7. Hardness differed between control and breads made with predominantly rice flour or amaranth flour. Bread made with the rice-amaranth blend did not significantly differ from the control in hardness. The bread made with predominantly rice flour had highest mean for hardness, this could be because it had the lowest protein content (10.67% d.b) compared to other treatments in this study.

5.3.4. Sensory Evaluation

Sensory results are shown in Table 5.8. The results indicated that panelists did not like the breads made with amaranth flour (disliked slightly to moderately), while the bread made with rice flour was neither disliked nor liked, and slightly liked the control bread. Bread with rice flour (18.7% rice flour and 9.3% rice flour+amaranth flour) were considered similar for color, texture and flavor. Common comments indicated a distaste for the strong taste with lingering after-taste from amaranth flour (Table 5.9). Because of the significantly higher flavor and overall acceptability scores, it appears that the 9.3% rice flour was able to mask some unpleasant flavor from amaranth flour in the bread. But the rice also appeared to have a positive impact on texture, as the blended flour bread had a higher score than the pure amaranth flour bread (remember to be consistent with what you call these). The particularly low mean flavor score allotted to the bread with predominantly amaranth flour could be attributed to the presence of intrinsic compounds in amaranth which produces nutty flavor when subjected to high temperature (NPC, 1984; Sanicheze et al., 1985) such as in baked products. (is nutty that objectionable? Other off-flavors?) There was negative correlation between the sensory texture mean acceptability score and mean instrumental springiness (-0.32) and cohesiveness (-0.25) of 18.7% RF, while hardness had positive correlation (0.17). The treatment with 18.7% AF had positive correlation for springiness (0.34), cohesiveness (0.48) and negative correlation for hardness (-0.55). When comparing the correlation observed for 18.7% AF and 18.7% RF, the treatments seemed to have correlate in the opposite direction for the same attribute. The control and 9.3% AF+RF flour treatment had positive correlation for all attributes tested, springiness (0.54, 0.26 respectively), cohesiveness (0.12, 0.38 respectively) and hardness (0.01, 0.44 respectively).

5.4 Conclusion

Formulating gluten free bread is a challenge. From the results obtained in this study, panelists gave more negative feedback on the taste and overall acceptance of the treatment with only amaranth flour. Masking of the strong taste of amaranth flour should be considered when amaranth flour is considered in GF bread.

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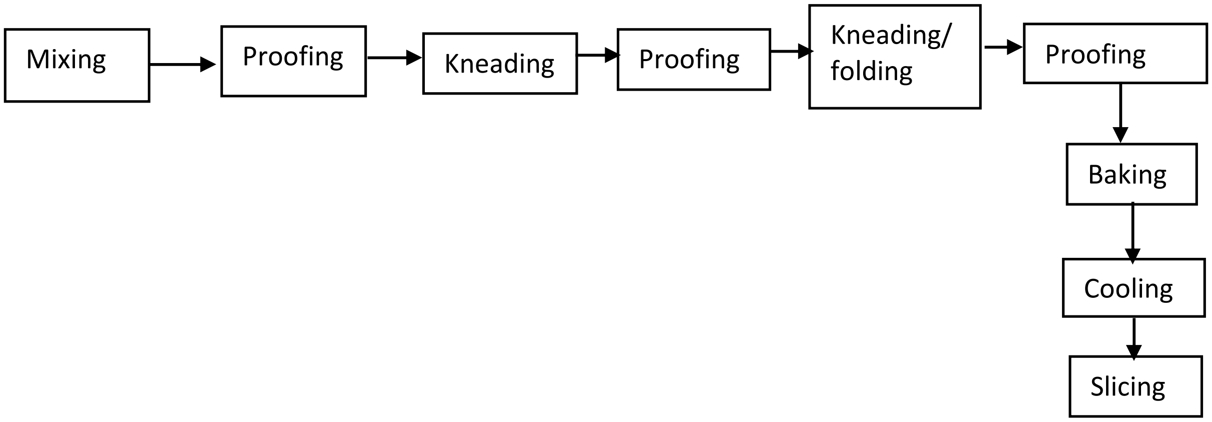


Figure 5.1. Baking process for treatment one (control) adapted from Arendt et al., (2008)

Figure 5.2. Baking process for treatment two, three, and four adapted from Arendt et al., (2008)

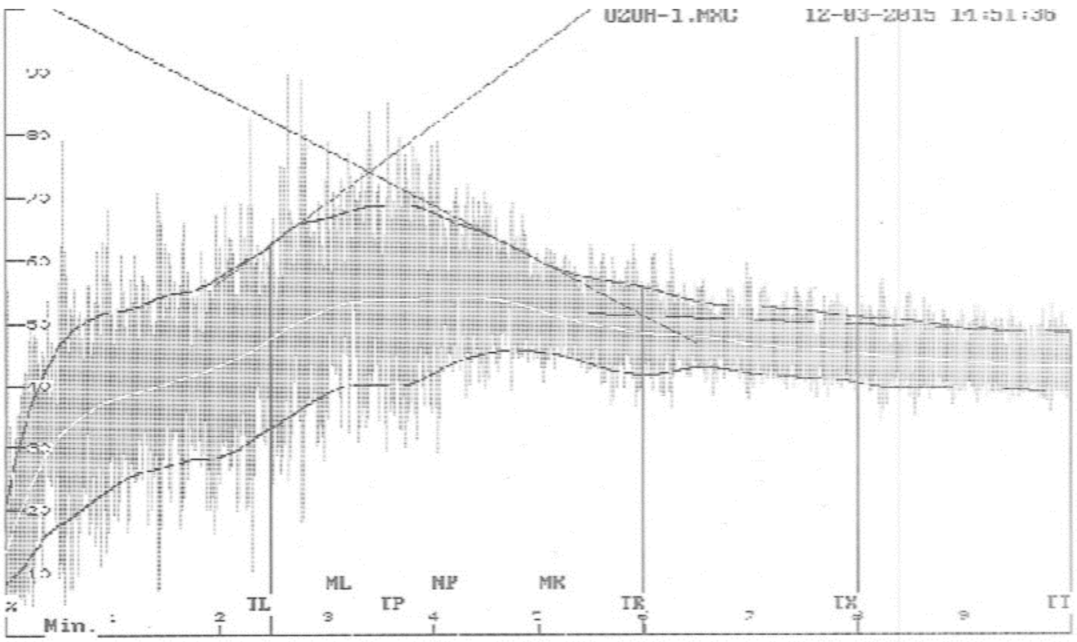


Figure 5.3. Mixograph plot for Treatment one (Control)

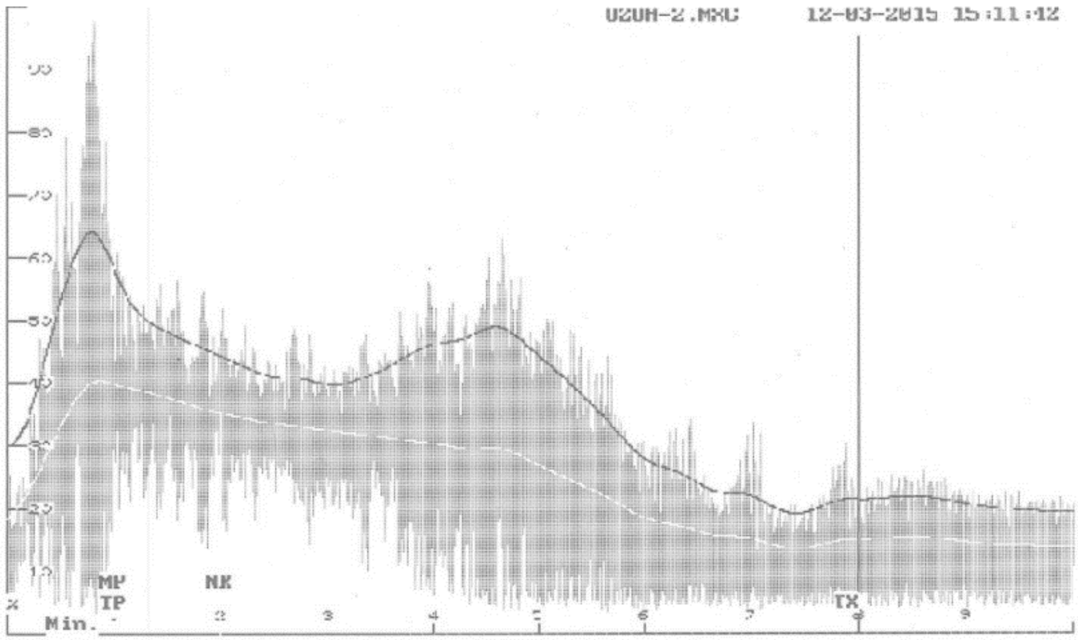


Figure 5.4. Mixograph plot for Treatment two (18.7% rice flour)

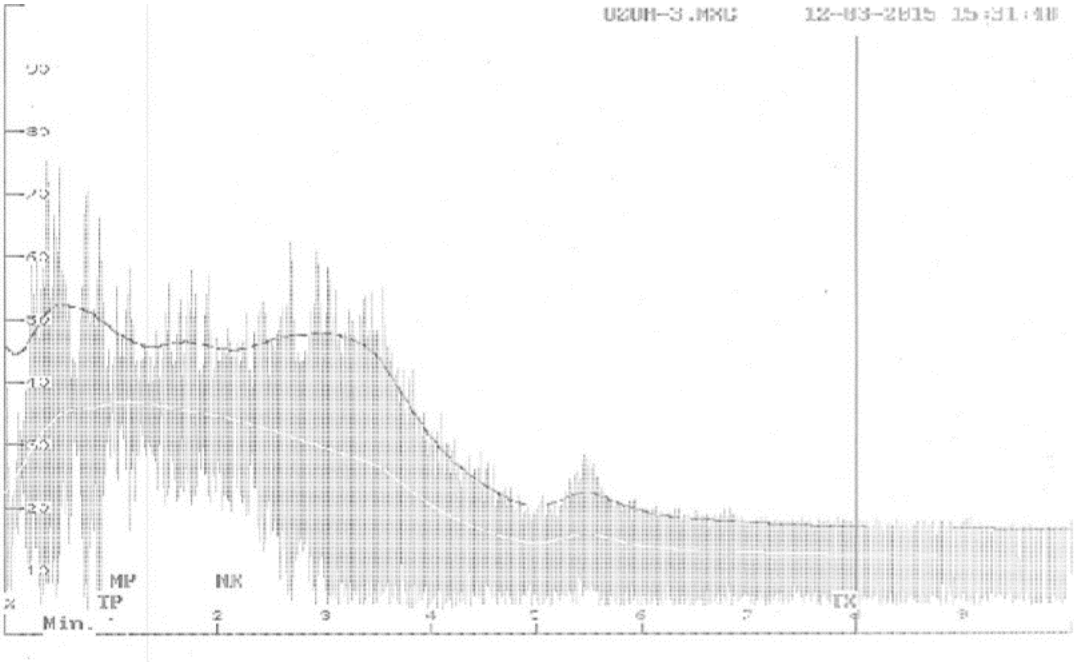


Figure 5.5. Mixograph plot for Treatment three (18.7% amaranth flour)

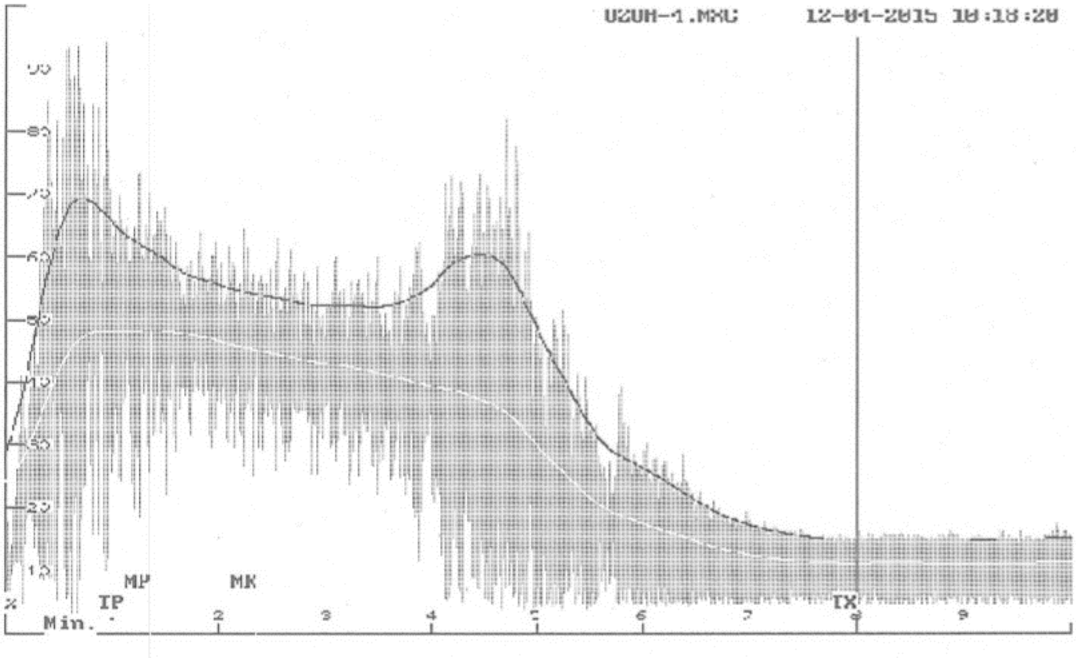


Figure 5.6. Mixograph plot for Treatment four (9.3% amaranth and 9.3% rice flour)

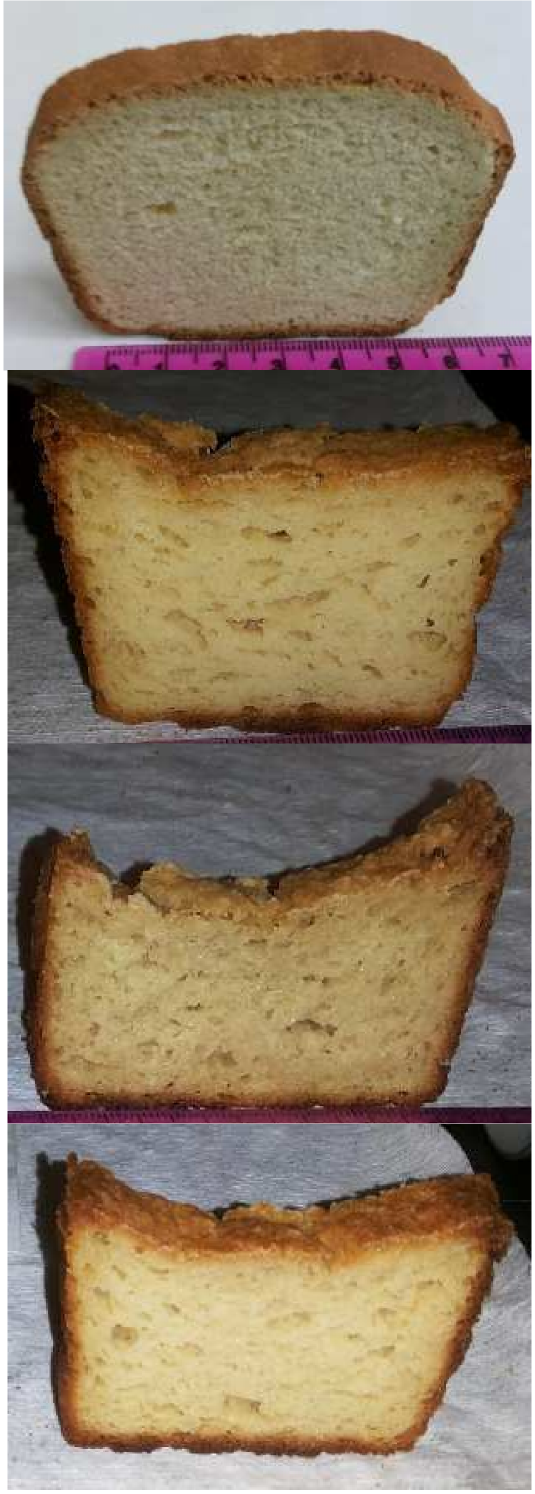
Control

18.7% Rice flour

18.7%
Amaranth flour

9.3% Amaranth
flour + rice flour

Figure 5.7. Bread crust for all treatments



Control

18.7% Rice flour

18.7% Amaranth flour

9.3% Amaranth flour + rice flour

Figure 5.8. Bread crumb for all treatments

Table 5.1. Bread flour composition for all treatments

	Control %	18.7%RF %	18.7%AF %	9.3% AF+RF %
High gluten flour	54.91	-	-	-
Sugar	3.29	2.43	2.43	2.43
Salt	0.82	0.61	0.61	0.61
Shortening	1.65	1.22	1.22	1.22
Yeast	4.72	3.69	3.69	3.69
Water	34.60	51.09	51.09	51.09
Amaranth flour	-	-	-	9.33
Rice flour	-	18.65	18.65	9.33
Guar gum	-	0.20	0.20	0.20
Xantham gum	-	0.20	0.20	0.20
Potato flour	-	6.08	6.08	6.08
Garbanzo flour	-	8.92	8.92	8.92
Corn starch	-	2.03	2.03	2.03
Tapioca flour	-	4.87	4.87	4.87
Total	99.99	99.99	99.99	99.99

RF is rice flour, AF is amaranth flour, % in wet basis

Table 5.2. Moisture and protein content of flours used for bread

Flour	MC % w.b.	MC % d.b.	Protein w.b.%	Protein d.b.%
wheat	13.06	15.02	14.64	16.84
rice	13.46	15.55	6.84	7.90
amaranth	12.99	14.94	13.79	15.85
potato	9.43	10.41	8.84	9.76
corn	9.95	11.04	0.46	0.51
tapioca	12.34	14.08	0.3	0.34
Garbanzo	9.79	10.85	22.56	25.01

n=2 for each treatment

Table 5.3. Mixograph parameter for treatment one (Control)

Envelope analysis	time (min)	Value (%)	slope (%/min)	Width (%)	Integral (%Tq*min)
Left peak	2.49	62.41	12.40	29.11	67.78
peak	3.67	68.55	0	28.66	101.33
right peak	5.97	55.43	-8.85	13.99	143.26
curve tail	10	48.12	-0.73	9.76	185.59
time X	8	50.66	-1.46	10.51	165.62

n=1 for each treatment

Table 5.4. Mixograph parameter for treatment two (18.7% rice flour)

Envelope analysis	time (min)	Value (%)	slope (%/min)	Width (%)	Integral (%Tq*min)
Left peak	-	-	-	-	-
peak	1	58.42	0	37.17	34.71
right peak	-	-	-	-	-
curve tail	-	-	-	-	-
time X	8	21.39	1.50	15.06	195.30

n=1 for each treatment

Table 5.5. Mixograph parameter for treatment three (18.7% amaranth flour)

Envelope analysis	time (min)	Value (%)	slope (%/min)	Width (%)	Integral (%Tq*min)
Left peak	-	-	-	-	-
peak	1	48.51	0	24.73	31.33
right peak	-	-	-	-	-
curve tail	-	-	-	-	-
time X	8	17.08	-0.51	11.20	171.52

n=1 for each treatment

Table 5.6. Mixograph parameter for treatment four (9.3% amaranth and 9.3% rice flour)

Envelope analysis	time (min)	Value (%)	slope (%/min)	Width (%)	Integral (%Tq*min)
Left peak	-	-	-	-	-
peak	1	65.48	0	35.17	36.91
right peak	-	-	-	-	-
curve tail	-	-	-	-	-
time X	8	15.00	-0.02	9.13	198.62

n=1 for each treatment

Table 5.7. Bread quality evaluation for all treatments

	Control	18.7% RF	18.7% AF	9.3% AF+RF
Bread rise (cm)	7.33^{a} (0.31)	4.00^{c} (0.24)	3.70^{c} (0.18)	4.47^{b} (0.31)
Specific volume(cm^{3}/g)	3.26^{a} (0.28)	1.85^{c} (0.08)	1.94^{bc} (0.18)	2.10^{b} (0.09)
Crust L*	32.58^{c} (2.06)	41.15^{a} (2.73)	35.87^{b} (2.76)	33.13^{bc} (3.22)
Crust a*	5.38^{a} (0.47)	1.85^{c} (1.01)	3.42^{b} (1.56)	4.54^{ab} (1.27)
Crust b*	2.91^{b} (0.82)	6.83^{a} (0.58)	5.98^{a} (0.75)	5.90^{a} (0.97)
Crumb L*	58.62^{a} (0.68)	50.94^{b} (0.51)	41.36^{c} (2.79)	46.74^{d} (0.32)
Crumb a*	-0.84^{b} (0.12)	-2.33^{d} (0.27)	-0.13^{a} (0.19)	-1.28^{c} (0.27)
Crumb b*	-13.10^{c} (0.62)	-3.98^{b} (0.50)	-3.68^{ab} (1.10)	-2.76^{a} (0.74)
Hardness (N)	2.93^{c} (0.68)	7.81^{a} (3.77)	6.24^{ab} (2.46)	4.62^{bc} (0.84)
Springiness	0.59^{a} (0.03)	0.58^{a} (0.10)	0.31^{c} (0.07)	0.44^{b} (0.07)

Table 5.7. Continued

Cohesiveness	0.35^a (0.03)	0.40^a (0.03)	0.42^a (2.09)	0.35^a (0.03)

${}^{a\text{-}d}$ means followed by different letters within the same row are significantly different. Alpha value is 0.05. n=6 for each treatment, RF is rice flour, AF is amaranth flour
Values in parenthesis are standard deviation

Table 5.8. Mean score for sample acceptability on a scale of 1-9 by 77 panelists

Attributes	Control	18.7% RF	18.7%AF	9.3%AF+9.3%RF
Color	7.12^a (1.54)	6.24^b (1.73)	5.25^c (2.03)	5.63^c (1.76)
Texture	6.38^a (1.64)	5.07^b (2.02)	4.20^c (1.95)	5.11^b (2.05)
Taste	6.21^a (2.05)	4.55^b (1.98)	2.91^c (1.76)	4.07^b (2.18)
Overall	6.24^a (1.72)	4.86^b (1.87)	3.20^c (1.72)	4.37^b (1.97)

Means with different superscripts ${}^{a\text{-}c}$ within the same row are significantly different ($p < 0.05$).
RF is rice flour, AF is amaranth flour
Values in parenthesis are standard deviation

Table 5.9. Summary of trends in panelists' comments and observations about breads from different treatments
RF is rice flour; AF is amaranth flour

Treatment	Comments
Control	Tasteless, normal, nice crust, satisfactory
18.7% RF	Odd texture, looked tasty, wet/moist, no strong aftertaste, bland, nice consistency, nice crust
18.7% AF	Too moist, doughy texture, strong flavor, strong lingering taste, undercooked appearance, weird unpleasant taste, grainy taste
9.3% AF+RF	Too moist, gummy texture, crunchy crust, dense texture, grainy taste, taste like bean

CHAPTER SIX

CONCLUSION AND FUTURE WORK

6.1 Conclusion

6.1.1. TEA and LCA of Extruded Aquafeed

LCA and TEA showed that operation scale influenced the economic feasibility for extruded aquafeed production. Increasing the production rate reduced the unit cost of production; this also applied to CO_2 emission. The Unit CO_2 emission decreased as production rate increased. Aquafeed production companies do not exist in the state of Iowa, this tool can be used by start-up companies in Iowa to estimate costs of producing aquafeed and CO_2 emission during production.

6.1.2. Characterization of Thermophysical and Rheological Changes during Amaranth Grain Milling

Milling of Amaranth grain was studied, the heat generated by friction during the milling process resulted in significant moisture loss from amaranth flour at higher initial moisture contents. High MC also caused plucking of the burr mill plates at the fine setting. This moisture loss must be accounted for when computing the mass balance of the milling system and the desired yield of flour. The mean particle size for all burr mill, roller mill, and nutrimill increased with increase in moisture content for all mill settings.

6.1.3. Gluten-free Bread

Formulating GF bread is a challenge. From the results obtained in this study, panelists had more negative feedback about the taste and overall acceptance of the treatment with only amaranth flour than combined flours. Masking of the strong taste of amaranth flour should be considered when amaranth flour is considered as a substitute for wheat flour in bread. There were significant differences (color, texture, taste and overall acceptance) between the GF bread samples and the control in all treatments.

6.2 Future Work

6.2.1. TEA and LCA of Extruded Aquafeed

The system boundary for this study was restricted. It would be very helpful to conduct TEA and LCA on a broader systems boundary. The cost of labor might also vary in different states in the US since most states have different minimum wages; it would be very helpful to look at more production locations and also factor the different costs of labor according to the state where the fish feed production site would be.

6.2.2. Characterization of Thermophysical and Rheological Changes during Amaranth Grain Milling

Data for burr fine (24% MC) was not reported in this study because the burr could not mill the grain at that moisture level. Comparing flour using lower moisture level in the future study will be very helpful to have a better comparison between the fine settings of all three mills.

6.2.3. Gluten-free Bread

Masking of the strong taste of amaranth flour should be considered when using amaranth flour as a substitute for wheat flour in bread making. The texture of the GF bread is also a concern; this might be as a result of the amount of water added to the mix. Further experiments can be conducted to obtain the adequate amount of water required to improve the texture of GF bread. Also image analysis of GF bread slices should be considered for future study. TEA can be used as a tool to analyze cost of producing GF bread; this would help understand the cost implication of GF bread better.