

FORTIFICATION OF PASTA WITH CHICKPEA AND QUINOA FLOURS

---

A Thesis presented to  
the Faculty of the Graduate School  
at the University of Missouri

---

In Partial Fulfillment  
of the Requirements for the Degree  
Master of Science

---

by

MELISSA SLINKARD

Dr. Andrew D. Clarke, Thesis Supervisor

MAY 2014

The undersigned, appointed by the dean of the Graduate School, have examined the thesis entitled

FORTIFICATION OF PASTA WITH CHICKPEA AND QUINOA FLOURS

Presented by Melissa Slinkard,

a candidate for the degree of Master of Science,

and hereby certify that, in their opinion, it is worthy of acceptance.

---

Dr. Andrew D. Clarke, Food Science

---

Dr. Ingolf Gruen, Food Science

---

Dr. Fu-hung Hsieh, Biological Engineering

## **ACKNOWLEDGEMENTS**

First of all, I would like to thank my advisor, Dr. Andrew D. Clarke. He tirelessly provided me teaching, guidance, comments, and direction as I learned my way through this process. His willingness to take on an engineer to train in food science, gave me a chance to pursue a field that I have and will continue to truly love. I would also like to thank my committee members, Dr. Ingolf Gruen and Dr. Fu-hung Hsieh, for their guidance and assistance. I am grateful for your contributions to my work.

I would like to thank Harold Huff for his guidance in instructing me how to operate and understand the Texture Analyzer, and Dr. Mark Ellersieck for his assistance in statistical analysis. Additionally, many thanks go out to JoAnn Lewis and Starsha Ferguson for their endless administrative assistance throughout my graduate career.

Special thanks to my fellow lab mates, Ayca Gedikoglu, Huisuo Huang, Shuhui Jia, and Kangzi Ren, for their company and assistance.

## TABLE OF CONTENTS

ACKNOWLEDGEMENTS.....	ii
LIST OF FIGURES.....	vi
LIST OF TABLES.....	vii
ABSTRACT.....	viii
Chapter	
1. INTRODUCTION.....	1
2. LITERATURE REVIEW.....	3
2.1 Pasta.....	3
2.1.1 Overview.....	3
2.1.2 Durum Wheat.....	5
2.1.3 Wheat Protein Complex.....	7
2.1.4 Nutritional benefits.....	9
2.2 Chickpea.....	10
2.3 Quinoa.....	13
3. MATERIALS AND METHODS.....	19
3.1 Pasta preparation.....	19
3.2 Cooking time.....	22
3.3 Cooking loss.....	22
3.4 Texture measurement.....	23
3.4.1 Texture profile analysis (TPA).....	23
3.4.2 Firmness.....	25

3.5 Color measurement.....	25
3.6 Proximate composition.....	26
3.7 Amino acid analysis.....	26
3.8 Consumer acceptance testing.....	26
3.9 Data analysis.....	27
4. RESULTS AND DISCUSSION.....	28
4.1 Pasta preparation.....	28
4.2 Cooking time.....	29
4.3 Cooking Loss.....	29
4.4 Texture measurement.....	30
4.4.1 Hardness.....	33
4.4.2 Adhesiveness.....	33
4.4.3 Springiness.....	33
4.4.4 Cohesiveness.....	34
4.4.5 Chewiness.....	34
4.4.6 Firmness.....	35
4.5 Color measurement.....	35
4.5.1 Lightness.....	36
4.5.2 Redness.....	36
4.5.3 Yellowness.....	37
4.6 Proximate composition.....	38
4.6.1 Crude Protein.....	38
4.6.2 Moisture.....	38

4.6.3 Crude Fat.....	39
4.6.4 Crude fiber.....	39
4.6.5 Ash.....	39
4.7 Amino acid analysis.....	39
4.8 Consumer acceptance testing.....	42
5. CONCLUSION.....	43
REFERENCES.....	46

## LIST OF FIGURES

<b>Figure</b>		<b>Page</b>
2.1	Diagram of wheat kernel (Hill 2012).....	6
2.2	Illustration of gliadin and glutenin protein structures (left) Scan electron micrograph of structural interaction of proteins (right) (Fasano 2011).....	8
2.3	Graph of global chickpea production from 1980-2012 (FAOSTAT 2014).....	12
2.4	Graph of global quinoa production from 1980-2012 (FAOSTAT 2014).....	17
3.1	Pasta preparation.....	21
3.2	Texture profile analysis of pasta perpendicular and parallel to grooves.....	24
3.3	Typical texture profile analysis curve (Dhanasettakorn 2008).....	24
3.4	Firmness test on pasta noodles.....	25
4.1	Prepared pasta samples.....	28

## LIST OF TABLES

<b>Table</b>		<b>Page</b>
2.1	Nutritional comparison of semolina and bread wheat flour (USDA 2013).....	6
2.2	Proximate analysis of raw chickpea seeds (USDA 2013).....	11
2.3	Mineral content of raw chickpea seeds (USDA 2013).....	11
2.4	Amino acid content of raw chickpea seeds (USDA 2013).....	11
2.5	Proximate analysis of raw quinoa (USDA 2013).....	16
2.6	Mineral content of raw quinoa (USDA 2013).....	16
2.7	Amino acid content of raw quinoa (USDA 2013).....	16
3.1	Pasta formulations.....	19
4.1	Cooking loss of cooked pasta noodles, as percent of original weight.....	30
4.2	Texture profile and firmness of cooked pasta noodles.....	32
4.3	Color values of cooked pasta noodles.....	36
4.4	Proximate composition of dry pasta noodles.....	38
4.5	Amino acid profile of dry pasta noodles.....	40
4.6	Results from consumer acceptance test.....	42

# **FORTIFICATION OF PASTA WITH CHICKPEA AND QUINOA FLOURS**

**Melissa Slinkard**

**Dr. Andrew D. Clarke, Thesis Supervisor**

## **ABSTRACT**

Pasta was fortified with 30% chickpea and quinoa flours (5:25, 10:20, 15:15, 20:10, and 25:5 CQ) and evaluated against a control made of 100% semolina flour (CTRL) for cooking quality, texture, color, proximate and amino acid analysis, and consumer acceptance. Pasta products containing chickpea and quinoa flours had a decreased cooking time than CTRL. Cooking loss of fortified pastas was significantly ( $p < 0.05$ ) greater than the CTRL, but were within the acceptable range of 7-8% (Dick and Youngs 1988). Hardness and adhesiveness of the pasta noodles increased as the percentage of quinoa fortification increased. Adhesiveness and springiness were not significantly ( $p > 0.05$ ) affected by fortification, and cohesiveness was moderately affected. Firmness of pasta products made with chickpea and quinoa flours was less than that of CTRL. Pasta 20:10 CQ was found to have the lowest firmness, as well as having the least acceptability in sensory testing. Pasta was darker and more brown in color ( $L^*$  and  $b^*$  values decreased while  $a^*$  values increased) with the increased addition of quinoa flour. Chickpea flour supplementation was found to increase protein, fat, fiber, ash, and amino acid content of pasta, while quinoa flour had adverse effects on protein content and amino acid profile when compared to CTRL. The untrained consumer panel ( $n=102$ ) significantly ( $p < 0.05$ ) preferred the CTRL pasta over those fortified with chickpea and quinoa flours. All pasta variations were deemed acceptable in sensory study. Pasta 25:5

CQ had the highest protein content and best amino acid profile while maintaining the most overall acceptable color, texture, and sensory scores in comparison with CTRL.

# **CHAPTER 1**

## **INTRODUCTION**

Pasta is a popular food in many cultures, and its simple ingredient list and ease of preparation make it a quick food option for people around the globe. As a wheat-derived staple food with a very long shelf life, it is second only to bread in world consumption (Mariani-Constantini 1988, Madhumitha 2011). The highest quality pasta is made solely from durum wheat semolina flour. This creates a product that has great rheological properties, cooking quality, and high consumer acceptance (Dexter and Matsuo 1979). Semolina flour, however, has a limited nutritional profile and is lacking in the amino acids lysine and threonine (Kies and Fox 1970, Abdel-Aal and Hucl 2002, Zhao and others 2005).

High protein diets are presently very popular and highly acceptable among health conscious consumers trying to watch their calorie intake, increase satiety, and lose weight. Quinoa and chickpeas are two foods that have been gaining a lot of recognition in the market for their high quality nutritional profile. Chickpeas are legumes that contain a large quantity of high quality protein, along with a good balance of amino acids (Sabanis and others 2006). Quinoa, a pseudo-cereal, is rich in histidine and lysine, amino acids that traditional semolina flour lack (Mastromatteo and others 2011). Both of these foodstuffs can be milled and used to replace or fortify typical durum wheat flour.

Fortification of foods has been used by the food industry for years and continues to be beneficial in providing consumers with added nutrition. The World Health Organization (WHO) and the United States Food and Drug Administration (FDA) consider pasta to be a good product for nutritional improvement due to its low levels of

protein and fiber (Marconi and Carcea 2001). In 1949, the FDA made pasta one of the first foods to permit vitamin and iron enrichment allowing pasta manufacturers the ability to fortify their products with added nourishment (FDA 1999). Legume and pseudo-cereal flours are a new frontier that many companies are turning to for added fortification. Much research has been done on fortifying and supplementing pasta with different combinations of non-traditional flours, such as green pea, yellow pea, chickpea, and lentil flours (Zhao and others 2005), amaranth flour (Chillo and others 2008a), split pea and faba bean flours (Petitot and others 2010a), and quinoa, oat, and broad bean flours (Mastromatteo and others 2012). Studies have also been done on the effects of adding solely chickpea flour (Wood 2009) and quinoa flour (Lorenz and others 1993) to pasta; however, no studies have been identified using both chickpea and quinoa flour to fortify semolina pasta.

The objective of this research is to formulate a pasta product with increased levels of protein and an improved amino acid profile by adding chickpea and quinoa flours to traditional durum wheat semolina. The effects of fortification on texture, color, cooking quality, and consumer acceptance are to be analyzed, and the most desirable ratio of quinoa and chickpea flours is to be determined. It is postulated that the high levels of methionine and cysteine found in quinoa flour will balance out the lack of sulfur-containing amino acids in chickpea flour, while both would increase the amount of protein and lysine found in typical durum wheat pasta. The most desirable ratio is expected to be either 10:20, 15:15, or 20:10 CQ where the deficient amino acids are all increased without negatively affecting quality.

## **CHAPTER 2**

### **LITERATURE REVIEW**

#### **2.1 Pasta**

##### **2.1.1 Overview**

Due to its low price, ease of preparation, stable shelf life, and overall versatility, pasta is consumed by many people worldwide. Having originated in Asia and the Mediterranean, Italy is still most well-known for its pasta making and leads in national consumer consumption per capita (International Pasta Organization 2011). Setting a standard in innovation, Italian pasta makers formed trade associations by the 16<sup>th</sup> century. These organizations regulated the industry by requiring things such as special license to produce pasta made from anything other than durum wheat (Kill 2001a). This highly regulated nation has set the benchmark for quality and preparation everywhere.

The versatility of pasta allows it to be formed into almost any shape and size. It comes in varieties such as spaghetti, fettuccine, macaroni, rotini, and farfalle. It can even be stuffed with meats or cheeses to make ravioli. Pasta is prepared in two styles, fresh or dried. Fresh pasta eliminates the drying step and allows for a much quicker product to be made, but has only a portion of the shelf life of dried pasta.

According to R. C. Kill (2001a), creating good quality pasta relies on three crucial factors: raw material, mixing and production, and drying. Since basic pasta is made using flour and water, the use of quality flour is essential, hence, the strong preference to durum wheat. Another common variation of pasta is egg noodles. Adding egg increases nutritional value, changes mouth-feel, and makes for a stronger noodle (Kill 2001b). Another frequent practice in pasta making is altering the color from its traditional yellow

to red or green. This is done by adding powdered spinach or tomato to the flour before hydrating (Kill 2001b).

The mixing process in pasta making is essential for protein binding and gluten matrix formation. In this step, water is added to the dry ingredients to achieve a dough with moisture content of 30-32% (Dintheer 2001). There are three approaches to forming and extruding the pasta dough. The approach used most often at-home and in small scale pasta production utilizes a batch mixer and hand-held extruder. In this process, the dough is formed by hand or in a small mixer, and then run through the extruder. A semi-continuous approach requires first mixing the flour and water into a crumbly dough mass before being homogenized by screw presses and then extruded (Dintheer 2001). The last approach, most often utilized by industrial pasta manufacturers, is continuous mixing/kneading where flour and water are added directly to the twin-screw extruder and homogenized right before being extruded (Dintheer 2001). The temperature, moisture content, and pressure are all important parameters of pasta production and have a direct effect on pasta quality (Dintheer 2001). In commercial pasta production, these parameters have been carefully established and are closely monitored.

The third critical aspect of creating quality pasta is drying. Studies have shown that the drying of pasta is very important to the structure and stability of pasta, and when dried, the moisture content is similar to that of the original material (Kill 2001a). It is important to note that although the pasta drying process is important to pasta quality, it is not the focus of this research and will not be further discussed.

### 2.1.2 Durum Wheat

For centuries, durum wheat has been the preferred flour source for both commercial and at-home pasta making. Typical bread wheat, or common wheat, lacks the hardness, gluten quality, and yellow color that durum wheat boasts for excellent pasta products (Kill 2001a). Both durum wheat, or *Triticum durum*, and common wheat, or *Triticum aestivum*, are members of the genus *Triticum*, home to all wild and cultivated wheat (Wiseman 2001). These wheat are cereals and a part of the large grass family, *Gramineae [Poaceae]*. Durum wheat is rarer than common wheat, and can be grown in only certain parts of the world (Kill 2001a). While common wheat can adapt to a wide range of environments, durum wheat thrives in semi-arid climates, having 55-60% of its crops grown in the Mediterranean region (Kill 2001a, Wiseman 2001). Common wheat is easily milled and has a starchy, floury endosperm, making it ideal for use in breads (Wiseman 2001). Durum wheat, on the other hand, has a particularly hard endosperm, resulting in a coarse yellow milled product containing very few fine flour particles (Wiseman 2001). This milled product is called semolina.

Wheat kernels are made up of three main parts: the bran, endosperm, and germ. The bran is the outer coating of the wheat kernel and protects the endosperm and germ. It makes up approximately 13% of the kernel. The germ is the smallest part of the kernel, comprising only about 3% of its weight. It is home to the developing plant or embryo. The starchy endosperm is the storage site of food for the plant and home to most of its proteins. It is the largest component of the wheat kernel, making up approximately 82% of its weight (Orth and Shellenberger 1988). Figure 2.1 illustrates the different parts of the wheat kernel.

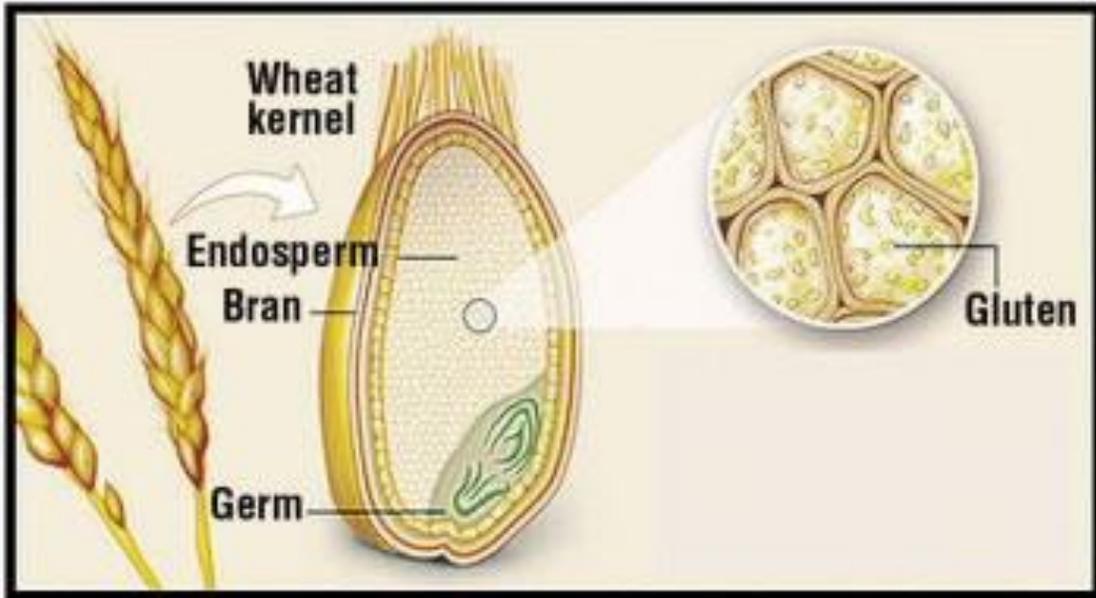


Figure 2.1 Diagram of wheat kernel (Hill 2012)

Milling is the multi-step process where the wheat kernel is broken up and the endosperm is separated from the bran and germ, resulting in wheat flour. Semolina flour has an amber color compared to common flour because of the carotenoid pigments in the endosperm (Donnelly 1991). Table 2.1 shows the nutritional values of semolina flour and bread wheat flour.

Table 2.1 Nutritional comparison of semolina and bread wheat flour (USDA 2013)

	<i>Semolina</i>	<i>Bread Wheat</i>
	<i>(Value per 100g)</i>	
<i>Water</i>	12.67 g	13.36 g
<i>Energy</i>	360 kcal	361 kcal
<i>Protein</i>	12.68 g	11.98 g
<i>Total lipid (fat)</i>	1.05 g	1.66 g
<i>Ash</i>	0.77 g	0.47 g
<i>Carbohydrates*</i>	72.83 g	72.53 g

Table 2.1 (continued) Nutritional comparison of semolina and bread wheat flour (USDA 2013)

<i>Minerals</i>	<i>Semolina</i>	<i>Bread Wheat</i>
	<i>(Value per 100g)</i>	
<i>Calcium, Ca</i>	17 mg	15 mg
<i>Iron, Fe</i>	1.23 mg	0.9 mg
<i>Magnesium, Mg</i>	47 mg	25 mg
<i>Phosphorus, P</i>	136 mg	97 mg
<i>Potassium, K</i>	186 mg	100 mg
<i>Sodium, Na</i>	1 mg	2 mg
<i>Zinc, Zn</i>	1.05 mg	0.85 mg

\*found by difference

### 2.1.3 Wheat Protein Complex

The two key components in pasta manufacturing are the gluten proteins and starch (Johnston 2001). Wheat consists of both soluble and insoluble protein fractions. Albumin and globulin are soluble proteins and are found mostly in the germ and bran of the kernel. The insoluble protein fractions, gliadin and glutenin, are found in the endosperm and make up approximately 85-90% of the protein fractions (Swanson 2007). Together, gliadins and glutenins form gluten. This protein complex “described as a cohesive, elastic and extensible fibrillar network covered with a protein membrane” (Swanson 2007) is responsible for maintaining the structure of wheat products, such as bread and pasta.

Gliadins are necessary for the elasticity of gluten. They are single-chained molecules distinguished by their intramolecular disulfide bonding which form compact globular molecules. Glutenins are responsible for providing strength and cohesion of the wheat gluten complex. They are characterized by intermolecular disulfide bonding making them large, multi-chained molecules, containing many exposed functional groups (Swanson 2007).

In the pasta making process, water is added to flour, hydrating the grains and forming hydrogen bonds between the water and protein molecules. This hydration combined with mechanical manipulation (or kneading), causes the gliadin and glutenin proteins to unfold and align, forming gluten (Swanson 2007). The gliadin and glutenin protein structures can be seen in Figure 2.2.

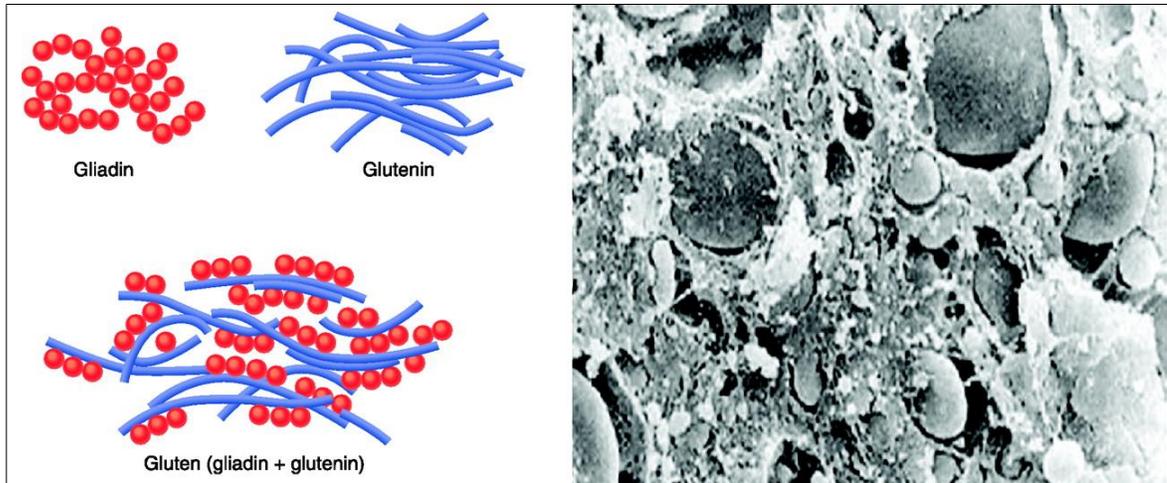


Figure 2.2 Illustration of gliadin and glutenin protein structures (left) Scanning electron microscope image of structural interaction of proteins (right) (Fasano 2011)

Protein content and quality of flour are both important factors in gluten formation. The greater amount of protein present, the stronger the gluten structure will be formed. However, if pasta contains too high a protein content, particularly gliadin and glutenin, then the yielded product is reported to stretch too much during extrusion (Dick and Matsuo 1988). Donnelly (1991) determined that flour with a minimum of 11% protein is needed to produce a good quality pasta. Durum wheat falls in the medium protein range with that which is commercially available containing 9-18% protein.

The protein matrix is crucial to the formation of pasta. If it is disrupted by other additives, it will negatively affect cooking quality leading to a decreased optimum

cooking time (Chillo and others 2007, Chillo and others 2008b) and a higher cooking loss (Ugarcic-Hardi and others 2003, Sabanis and others 2006). Gluten “contributes to the development of a strong protein network that prevents the dissolution of pasta during cooking” (Marconi and Carcea 2001). When pasta is cooked, an insoluble network of proteins is formed that entraps swollen and gelatinized starch granules (Smewing 1997). If less protein surrounds the starch granules, they swell and gelatinize faster, lowering the cooking time (Grzybowski and Donnelly 1977). If this network is weakened by too great of an addition, then the integrity of the pasta is compromised and the structure is weakened. Sabanis and others (2006) and Wood (2009) found that substituting non-gluten containing flours for greater than 30% of wheat flour negatively affected the protein matrix, creating pasta products that were difficult to extrude and overall unacceptable.

#### **2.1.4 Nutritional benefits**

On its own, the nutritional content of pasta is similar to that of semolina flour. In a review by Douglass and Matthews (1982), researchers compared the nutrient content of semolina flour and macaroni as a percent concentration of durum wheat, and found that the greatest change in nutritional content from processing occurs when durum wheat is milled into semolina flour. From this study, it can be seen that the processing of pasta does not adversely affect the nutritional content of semolina flour, but rather, pasta products remain closely similar to that of the flour used. Compared to durum wheat, the semolina and macaroni tested maintained most of the original protein, but lost almost 50% of both fat and ash (Douglass and Matthews 1982). Since semolina flour is limited in amino acids, such as lysine and threonine (Kies and Fox 1970, Abdel-Aal and Hucl

2002, Zhao and others 2005), it is understood that pasta is also deficient in these compounds.

Although pasta contains some nutritional content, it is rarely eaten on its own due to its simple lack of flavor. This is why it is typically used as a base to meals and served with sauces or other toppings.

## **2.2 Chickpea**

Chickpeas, or *cicer arietinum*, are part of the *Cicer* genus, and are to have originated in southeastern Turkey (Maiti 2001). The *Cicer* genus is a member of the *Fabaceae* family, home to beans, peas, and other grain legumes that are also referred to as pulses (Singh 2001). Chickpeas are consumed worldwide and are known under other common names such as gram in India and garbanzo in Latin America (Maiti 2001). Although they are commonly known for their high protein content (20.9-25.27%), their nutritional profile also boasts low lipid content comparable to cereals, and a high availability of iron and calcium (Dhawan and others 1991, Wesche-Ebeling and others 2001). Similarly to other pulse proteins, chickpeas have high amounts of lysine, but are limited in sulfur-containing amino acids such as methionine and cysteine (Dhawan and others 1991, Maiti 2001). This can be contributed to the high amounts of glutelins and globulins that are the major storage protein in the endosperm, making up about 53-60% (Dhawan and others 1991). The proximate analysis, mineral, and amino acid content of raw chickpea seeds can be seen in Tables 2.2 - 2.4. Chickpea seeds have many culinary uses and can be dried, canned, or milled into flour. A common form of consuming chickpeas is mashed and mixed with spices and oils in the Middle Eastern dish, hummus.

Chickpea seeds vary in size, shape, and color, but are usually “beaked” and wrinkled or ribbed (Maiti 2001). There are two types of chickpea seeds, desi and kabuli. Desi seeds, grown in semi-arid tropics, are smaller, angular in shape, and usually colored (Maiti 2001). Kabuli seeds are larger, rounded, cream colored, and are grown in temperate regions. Due to their larger size and greater nutritional value, Kabuli chickpeas are more popular for human consumption (Maiti 2001, Wesche-Ebeling and others 2001).

Table 2.2 Proximate analysis of raw chickpea seeds (USDA 2013)

<b><i>Proximates</i></b>	<b><i>(Value per 100g)</i></b>
<i>Water</i>	11.53 g
<i>Energy</i>	364 kcal
<i>Protein</i>	19.3 g
<i>Total lipid (fat)</i>	6.04 g
<i>Ash</i>	2.48 g
<i>Carbohydrate*</i>	60.65 g
<i>Fiber, total dietary</i>	17.4 g
<i>Sugars, total</i>	10.7 g

\*found by difference

Table 2.3 Mineral content of raw chickpea seeds (USDA 2013)

<b><i>Minerals</i></b>	<b><i>(Value per 100g)</i></b>
<i>Calcium, Ca</i>	105 mg
<i>Iron, Fe</i>	6.24 mg
<i>Magnesium, Mg</i>	115 mg
<i>Phosphorus, P</i>	366 mg
<i>Potassium, K</i>	875 mg
<i>Sodium, Na</i>	24 mg
<i>Zinc, Zn</i>	3.43 mg
<i>Copper, Cu</i>	0.847 mg
<i>Manganese, Mn</i>	2.204 mg
<i>Selenium, Se</i>	8.2 µg

Table 2.4 Amino acid content of raw chickpea seeds (USDA 2013)

<b><i>Amino Acids</i></b>	<b><i>(Value per 100g)</i></b>
<i>Tryptophan</i>	0.185 g
<i>Threonine</i>	0.716 g
<i>Isoleucine</i>	0.828 g
<i>Leucine</i>	1.374 g
<i>Lysine</i>	1.291 g
<i>Methionine</i>	0.253 g
<i>Cysteine</i>	0.259 g
<i>Phenylalanine</i>	1.034 g
<i>Tyrosine</i>	0.479 g
<i>Valine</i>	0.809 g
<i>Arginine</i>	1.819 g
<i>Histidine</i>	0.531 g
<i>Alanine</i>	0.828 g
<i>Aspartic acid</i>	2.270 g
<i>Glutamic acid</i>	3.375 g
<i>Glycine</i>	0.803 g
<i>Proline</i>	0.797 g
<i>Serine</i>	0.973 g

Chickpea flour is produced when chickpeas undergo a milling process. In this process, chickpeas are cleaned and graded (normally by size) before the hull is removed from the endosperm through stages of soaking and mechanical action (Wesche-Ebeling and others 2001). For desi chickpeas, the hull makes up 12-15% of the seed weight, resulting in a maximum flour yield of 85% (Wesche-Ebeling and others 2001). After being dehulled, the chickpea seeds are milled to flour and roasted.

Over the past five years, the major producers of chickpeas have been India, Australia, Turkey, Pakistan, and Myanmar (FAOSTAT 2014). In 2009, the world saw a large increase in chickpea production, producing over 10 million metric tons of product (FAOSTAT 2014). In recent years, the amount produced has remained above the historical average. Figure 2.3 shows the increase in chickpea production from 1980-2012.

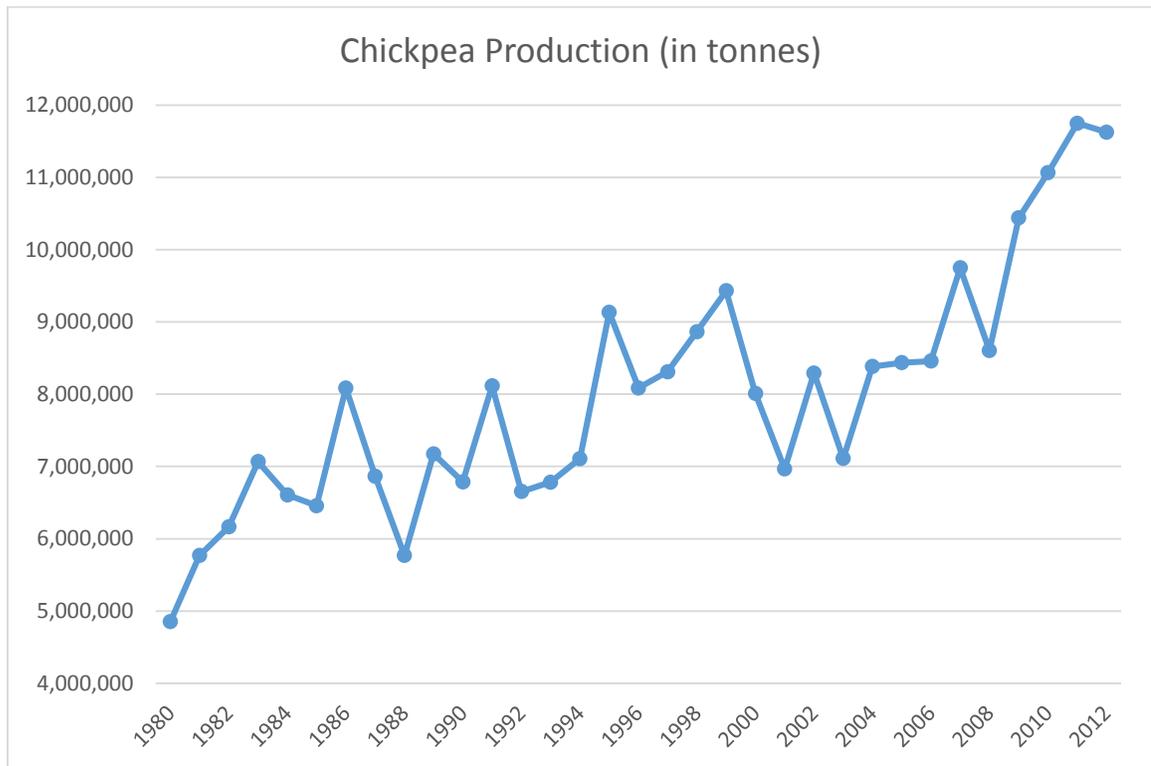


Figure 2.3 Graph of global chickpea production from 1980-2012 (FAOSTAT 2014)

Studies have shown that smaller chickpea seeds contain a higher content of essential amino acids (Wesche-Ebeling and others 2001). Singh (2001) reported that supplementing cereals with high protein legumes, such as chickpeas, was “one of the best solutions to the protein-calorie malnutrition, particularly in developing countries.” When combined with cereals, chickpeas have an increased digestibility of proteins (Wesche-Ebeling and others 2001). Adding 25% chickpea flour to pasta is also known to significantly lower the glycemic index of wheat pasta (Goni and Valentin-Gamazo 2003).

In 2009, Wood studied pasta fortified with varying amounts of chickpea flour (0-30%) and found that increasing the amount of chickpea flour significantly ( $p < 0.05$ ) decreased water absorption leading to less stable dough. Wood (2009) also concluded that pasta cannot be fortified with over 30% chickpea flour due to the weakening of the gluten matrix, and that chickpea flour increased all amino acids except for cysteine and methionine (no significant change) and glutamine/glutamic acid and proline (significantly decreased).

### **2.3 Quinoa**

Quinoa, or *chenopodium quinoa*, is a member of the *Amaranthaceae* plant family. Although it is a flowering plant, quinoa's grass-like uses and qualities cause it to be considered a pseudo-cereal. This ancient grain originated in the Andean region of South America where it was prevalently grown and consumed by the Inca Empire (Fleming and Galwey 1995). When the Spanish conquest entered the region, however, they replaced the crops with their European species of wheat and barley, leading to a severe decline in quinoa production (Fleming and Galwey 1995). It was not until the 1970's that the

indigenous crop began to receive attention from outside nations and researchers (Fleming and Galwey 1995).

Quinoa grains are disc-shaped and range from 1-3 millimeters in diameter. They come in various colors, such as white, yellow, orange, pink, red, brown, grey, and black (Fleming and Galwey 1995). The pericarp, or outer coating, of quinoa contains saponins, which are anti-nutritional compounds that give off a bitter flavor. Rinsing quinoa prior to use helps rid the grain of these compounds.

Quinoa grains can be used for many things. They can be toasted, ground into flour, boiled and added to soup, or cooked and served similar to rice. Quinoa flour can be used to make pasta or breads. Unlike cereals, quinoa has a soft outer layer that does not need to be removed before milling. This allows quinoa to yield roughly 100% flour (Fleming and Galwey 1995). After being rinsed of saponins, quinoa is usually dried before being ground into fine particles.

In 2011, the United Nations declared 2013 the International Year of Quinoa to recognize the indigenous people's preservation of the grain and to increase world knowledge of its nutritional, economic, environmental, and cultural properties (United Nations 2011). The aim of their initiative was to focus world attention on the role it can play in decreasing poverty and providing food security (United Nations 2011).

One attributing factor to the increased popularity of quinoa is its adaptability to various growing conditions. Quinoa grows well in poor environmental conditions, harsh climates, and is rarely affected by droughts and flooding (Fleming and Galwey 1995). Quinoa plants are classified into five different types based on their ecological adaptation zone and region. Valley quinoa is irrigated and grown in the Andean valleys, while

altiplano quinoa is grown in temperate conditions with low precipitation (Fleming and Galwey 1995, FAO 2013). Saltflat (or salar) quinoa is adapted to desert climates, while sea level quinoa is produced in humid conditions with regulated temperature, and subtropical quinoa is adapted to high precipitation and heat (Fleming and Galwey 1995, FAO 2013).

Studies have shown that quinoa is a good source of quality protein (10.4-17.0%), dietary fiber, polyunsaturated fats, and minerals (FAO 2013). At 6.3%, it contains more fat than most grains and legumes, but over half of that comes from polyunsaturated fats, which are essential to the body (FAO 2013). These fats are shown to maintain their quality due to the prevalence of vitamin E, a natural antioxidant (Su-Chuen and others 2007). The nutritional profile of raw chickpea seeds can be seen in Tables 2.5 – 2.7.

Although quinoa has a high amount of protein, it is the quality of protein that is most notable. Quinoa boasts an excellent amino acid balance comparable to that of casein protein in milk or skim milk powder (Fleming and Galwey 1995). It is rich in lysine and sulfur-containing amino acids that most grains lack, making it a good complement to wheat products (Lorenz and others 1993). The content and composition of quinoa protein depends largely on the variety and growing conditions (Fleming and Galwey 1995). It has been found to contain between 10-21% protein, with most products averaging around 13% (Fleming and Galwey 1995, Regional Office for Latin America and the Caribbean 2011). Since quinoa is gluten-free, most of the protein fractions contained are albumins and globulins, making up 44-77% (Jancurova and others 2009). These proteins are rich in lysine, which most grains lack (Fleming and Galwey 1995).

Others have noted that quinoa is also beneficial when paired with legumes such as chickpeas, due to their lack of methionine and cysteine (Jancurova and others 2009).

Quinoa has a relatively large amount of highly-available iron, making it a good source of the nutrient for the human diet (Allred and others 1976, Valencia and others 1999). Quinoa is also a rich source of magnesium (Vitali and others 2010), zinc, and the B-vitamins, riboflavin and folic acid (FAO 2013).

Table 2.5 Proximate analysis of raw quinoa (USDA 2013)

<i>Proximates</i>	<i>(Value per 100g)</i>
Water	13.28 g
Energy	368 kcal
Protein	14.12 g
Total lipid (fat)	6.07 g
Ash	2.38 g
Carbohydrate*	64.16 g
Fiber, total dietary	7.0 g
Starch	52.22 g

\*found by difference

Table 2.6 Mineral content of raw quinoa (USDA 2013)

<i>Minerals</i>	<i>(Value per 100g)</i>
Calcium, Ca	47 mg
Iron, Fe	4.57 mg
Magnesium, Mg	197 mg
Phosphorus, P	457 mg
Potassium, K	563 mg
Sodium, Na	5 mg
Zinc, Zn	3.1 mg
Copper, Cu	0.59 mg
Manganese, Mn	2.03 mg
Selenium, Se	8.5 µg

Table 2.7 Amino acid content of raw quinoa (USDA 2013)

<i>Amino Acids</i>	<i>(Value per 100g)</i>
Tryptophan	0.167 g
Threonine	0.421 g
Isoleucine	0.504 g
Leucine	0.840 g
Lysine	0.766 g
Methionine	0.309 g
Cysteine	0.203 g
Phenylalanine	0.593 g
Tyrosine	0.267 g
Valine	0.594 g
Arginine	1.091 g
Histidine	0.407 g
Alanine	0.588 g
Aspartic acid	1.134 g
Glutamic acid	1.865 g
Glycine	0.694 g
Proline	0.773 g
Serine	0.567 g

The main countries producing quinoa are Peru and Bolivia, accounting for more than 90% of the world's production (FAOSTAT 2014). With its gained popularity, crop production doubled in Bolivia and almost tripled in Peru and Ecuador from 1992-2010

(FAOSTAT 2014). Although quinoa is grown in every country located in the Andean region, the United States, Ecuador, Argentina, and Canada are among large producers of the crop. From 2008 to 2009, production increased significantly and is now over 80,000 metric tons per year. Figure 2.4 shows the increase in chickpea production from 1980-2012.

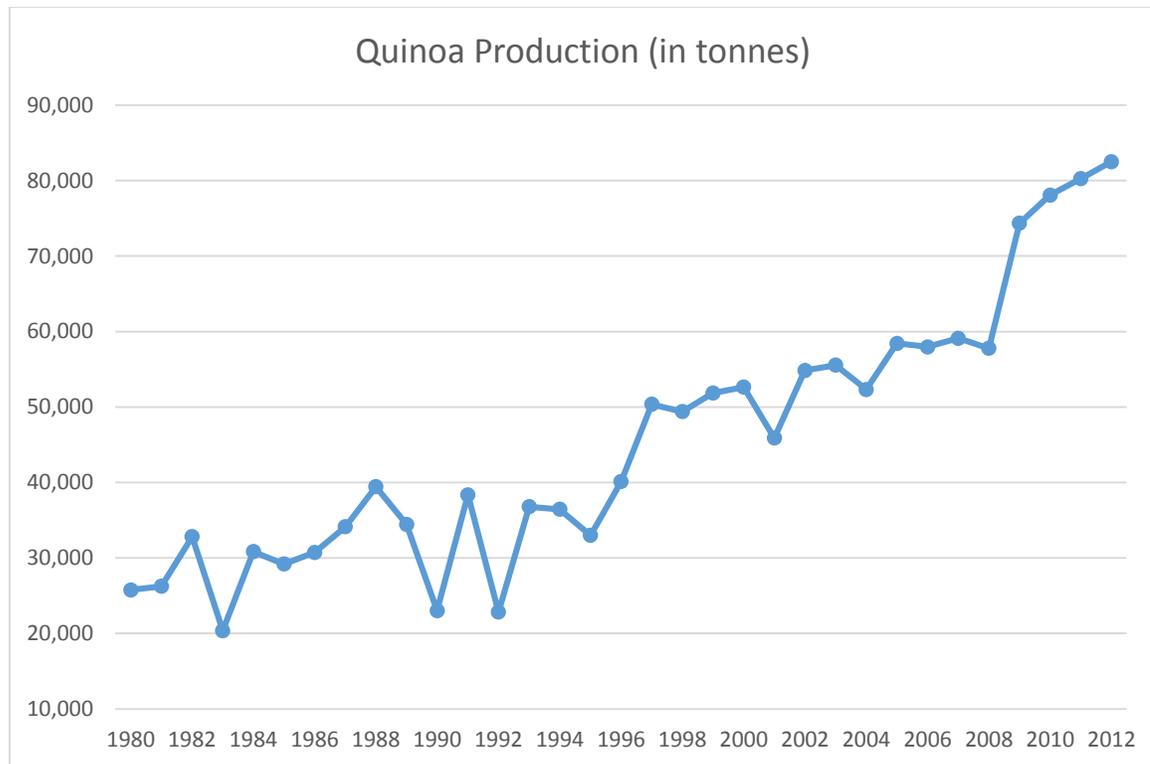


Figure 2.4 Graph of global quinoa production from 1980-2012 (FAOSTAT 2014)

Over the years, there have been increased studies on the utilization of quinoa flour in pasta products. In 1993, Lorenz and others experimented with adding 10, 30, and 50% quinoa flour to wheat pasta. The addition of quinoa required more water for mixing, made the pasta darker in color, and increased cooking loss. Pasta made with 50% quinoa flour was shown to be poor in flavor and texture and was deemed unacceptable (Lorenz and others 1993). In 2010, Schoenlechner and others attempted to make pasta with solely

quinoa flour and egg and found that it, too, was unacceptable due to high cooking loss. Due to its lack of gluten-forming proteins, others have attempted to make gluten-free pasta with quinoa and other non-traditional flours, such as amaranth and broad bean (Chillo and others 2008a), soy and maize (Mastromatteo and others 2011), and oat and chickpea (Mastromatteo and others 2012).

## CHAPTER 3

### MATERIALS AND METHODS

#### 3.1 Pasta preparation

Samples of semolina (Lot 255504), chickpea (Lot 313160GFGRBZFL), and quinoa (Lot 313160GFOQNAFL) flours were received from ConAgra Mills (Omaha, NE), kept in original packaging, and stored in air-tight containers until use. Pasta samples were produced by hand in a homemade style. The control sample (CTRL) was made of 100% semolina flour, while five different variations were made by replacing 30% semolina flour with different ratios of chickpea and quinoa flours. The ratios consisted of 5% chickpea flour and 25% quinoa flour (5:25 CQ), 10% chickpea flour and 20% quinoa flour (10:20 CQ), 15% each chickpea and quinoa flours (15:15 CQ), 20% chickpea flour and 10% quinoa flour (20:10 CQ), and 25% chickpea flour and 5% quinoa flour (25:5 CQ). The pasta formulations are shown in Table 3.1.

Table 3.1 Pasta formulations

<i>Formula</i>	<i>Semolina flour (g)</i>	<i>Chickpea flour (g)</i>	<i>Quinoa flour (g)</i>	<i>Water (mL)</i>
<i>5:25 CQ</i>	63.0	4.5	22.5	40.0
<i>10:20 CQ</i>	63.0	9.0	18.0	40.0
<i>15:15 CQ</i>	63.0	13.5	13.5	40.0
<i>20:10 CQ</i>	63.0	18.0	9.0	40.0
<i>25:5 CQ</i>	63.0	22.5	4.5	40.0
<i>CTRL</i>	90.0	0.0	0.0	40.0

The dry ingredients were combined into a homogenous mixture and poured onto a clean, smooth work area. Warm water at approximately 32-49° Celsius was slowly poured into a well formed in the center of the mounded flour. The water was incorporated by pulling flour from the inside wall using a fork. Once all the water was

added and mixing with a fork became difficult, the remaining flour was blended in by hand. The crumbly dough mass was then kneaded for approximately 10 minutes, forming a smooth, elastic dough. Kneading was done by the repeated action of flattening the dough with the palm of the hand, rotating the dough, and folding over. The kneaded dough was wrapped in plastic film and set to rest at room temperature for one hour. Once rested, the dough ball was divided into two pieces for processing. Each dough piece was flattened and sent through the pasta machine (Imperia Tipo Lusso SP150, Torino, Italy) starting on the thickest setting (number 1). The dough was folded into thirds and sent through again. It was then folded in half, run through, and cut into manageable lengths. Sheets of dough were fed through the pasta machine at decreasing thicknesses (numbers 2, 3, and 4, respectively). The thin, flattened sheets were laid to dry on a wire rack for 10 minutes (5 on each side) before being passed through the fettuccine cutter. The cut strands were laid on wire racks and covered with a towel to dry overnight. Pictures of the process can be seen in Figure 3.1. The dried pasta was stored in Ziploc bags at room temperature until further use.

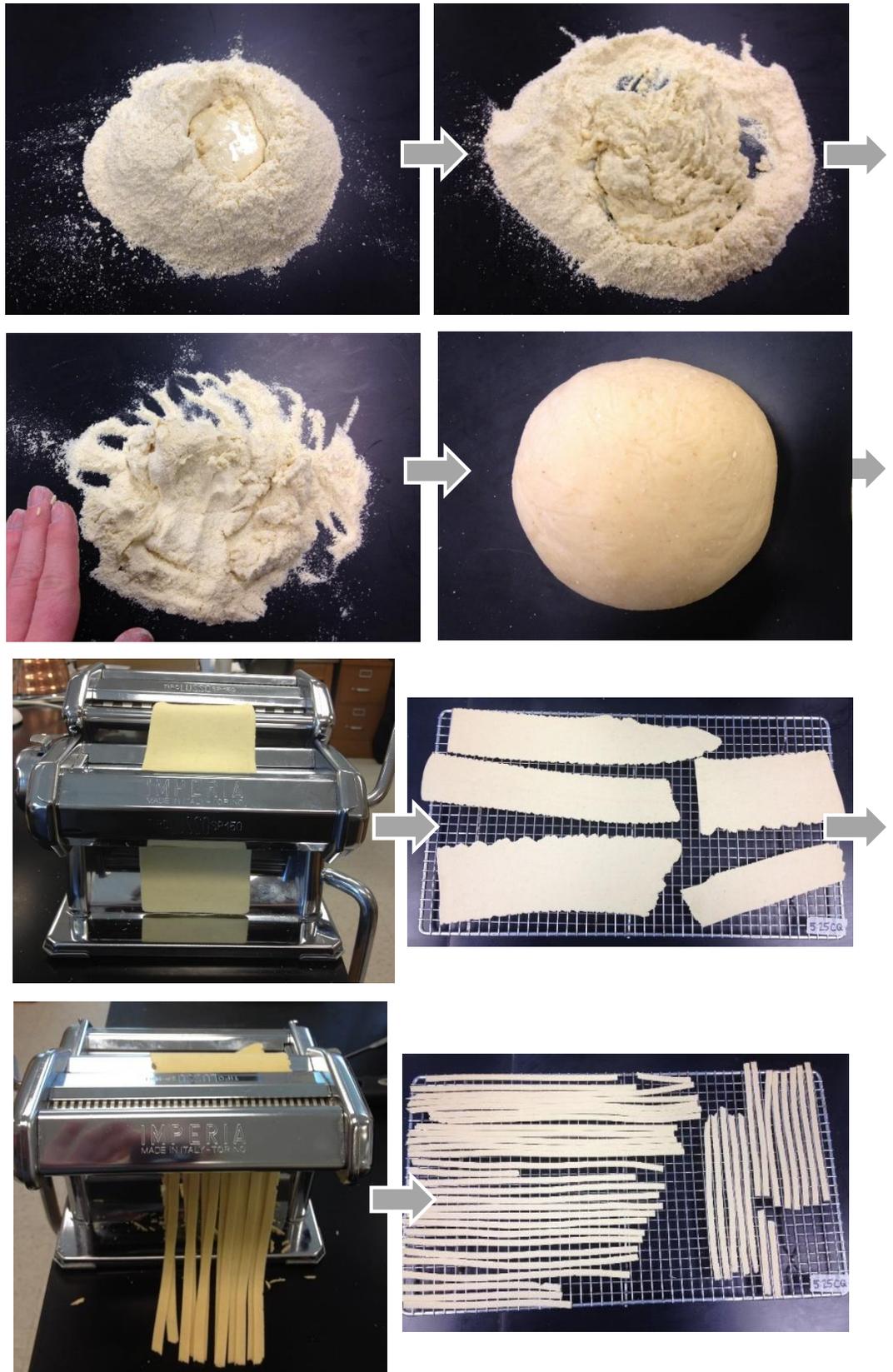


Figure 3.1 Pasta preparation

### **3.2 Cooking time**

Optimal cooking time was determined by a modified American Association of Cereal Chemists (AACC) approved method 16-50 (2000). Salt (0.6 grams) was dissolved with 300mL of tap water in a 750mL saucepan. The saucepan was placed on a stovetop burner set to medium-high heat and brought to a rolling boil (approximately 98° Celsius). Twenty-five grams of pasta, broken into five centimeter long pieces, was added to the boiling water. Cooking water was stirred occasionally and volume was maintained at 90% throughout procedure using another pot of boiling salt water. Samples were removed every 30 seconds and squeezed between 2 pieces of clear plastic. Optimal cooking time was determined when the white center core just disappeared. All subsequent analyses were conducted on pasta cooked for the optimal cooking time.

### **3.3 Cooking loss**

Cooking loss was determined by modifying AACC approved method 16-50 (2000). Three hundred milliliters of distilled water was brought to a rolling boil in a 750mL saucepan. Salt was not added to the cooking water as to not contribute to cooking water residue. Twenty grams of dried pasta were added and cooked for the optimal cooking time, stirring occasionally. Cooked pasta was strained over a large pot and rinsed for 5 seconds with distilled water. The cooking water was quantitatively transferred to a pre-weighed 400mL beaker and covered with perforated plastic wrap. The beakers were placed on a baking sheet and were dried in a convection oven heated by pilot light for three days. The oven maintained a temperature of 52-60° Celsius. Once all cooking water had evaporated and a constant weight was reached, the beakers were removed from the oven, cooled in a desiccator, and re-weighed. The remaining residue

was determined by difference in weight of beaker, and is expressed as percent of original weight. Testing of each pasta formula was performed in duplicate.

### **3.4 Texture measurement**

Texture profile analysis and firmness tests were conducted using a TA.HDi Texture Analyzer (Texture Technologies Corp., Scarsdale, NY) following the method described by Tang and others (1999). Since texture analyses are affected by temperature, each pasta formula was cooked fresh immediately prior to each test and stored in a Ziploc bag placed in a warm water bath to retain temperature. Data was obtained, calculated, and graphed using the texture analyzer PC software program Texture Expert Exceed (Version 2.62, Texture Technologies Corp., Scarsdale, NY).

#### **3.4.1 Texture profile analysis (TPA)**

In performing TPA, 4 strands of pasta were arranged side-by-side on a sample holder with a surface serrated by 90° vee grooves, 1.5 mm deep, and spaced at 3.6 mm. Four samples of each formula were tested, two readings were taken with pasta laying parallel to the grooves and two were taken with pasta placed perpendicular (Figure 3.2). Noodles were compressed to a 70% fixed strain (as a percentage of sample height) by a flat cylindrical plexiglass plunger, 25 mm in diameter, with a 5 kg load cell at a crosshead speed of 0.2 mm per second. Each sample was compressed twice to emulate human bite, resulting in a texture profile analysis curve (Figure 3.3). Results obtained from this analysis are given as hardness, adhesiveness, springiness, cohesiveness, gumminess, and chewiness. Tests were conducted in triplicate for each pasta formula.

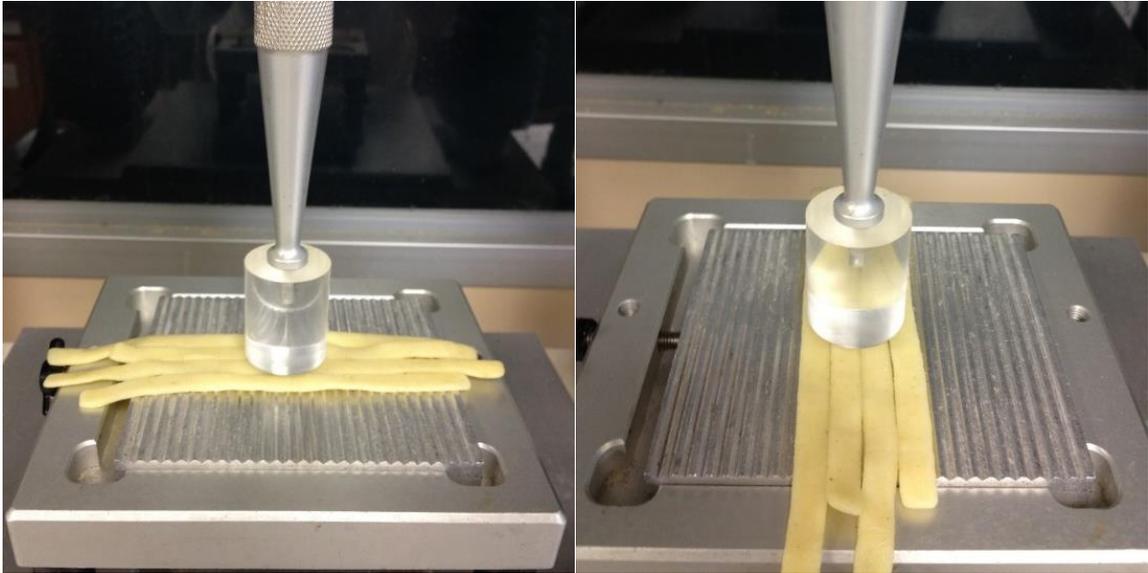


Figure 3.2 Texture profile analysis of pasta perpendicular (left) and parallel (right) to grooves

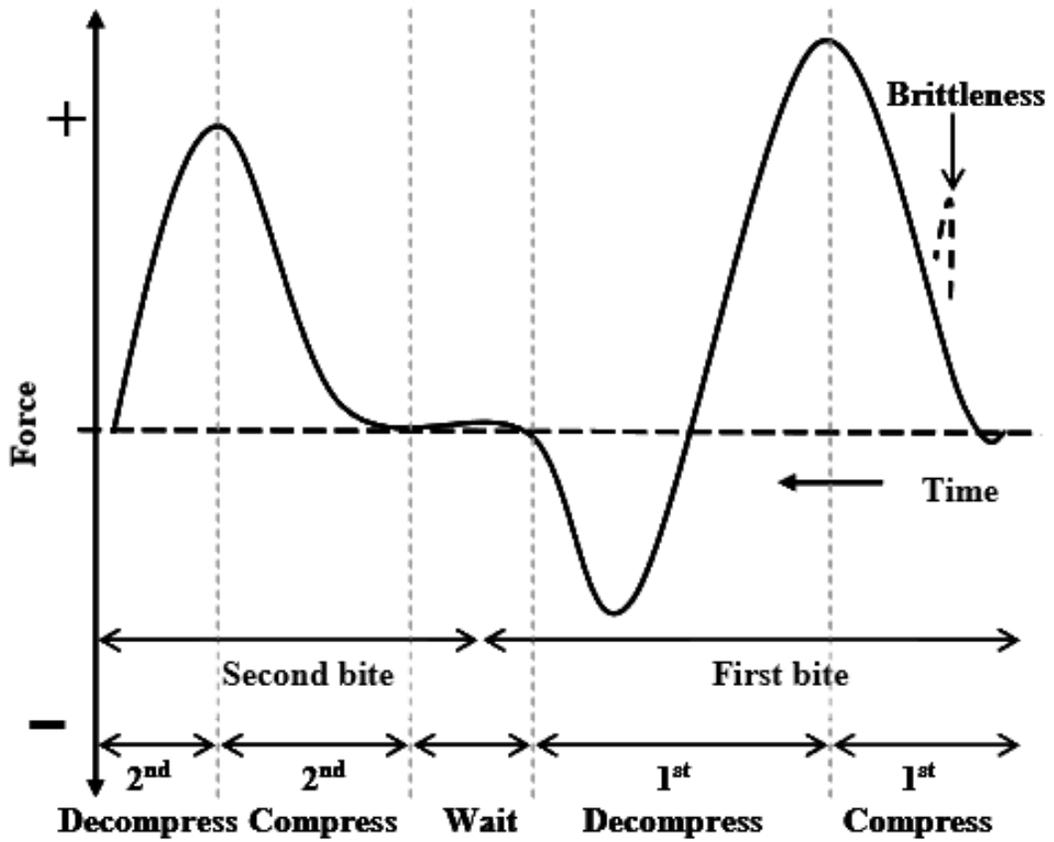


Figure 3.3 Typical texture profile analysis curve (Dhanasettakorn 2008)

### 3.4.2 Firmness

To test firmness, two strands of pasta were arranged side-by-side on a sample holder. Four samples from each formula were tested. Noodles were sheared crosswise by a plexiglass blade to 75% strain with a 5 kg load cell (Figure 3.4). Crosshead speed was set at 0.2 mm per second. Firmness is given as the peak force in grams required to shear two strands of pasta noodles at 75% of the sample's thickness (Tang and others 1999). Tests were conducted in triplicate for each pasta formula.

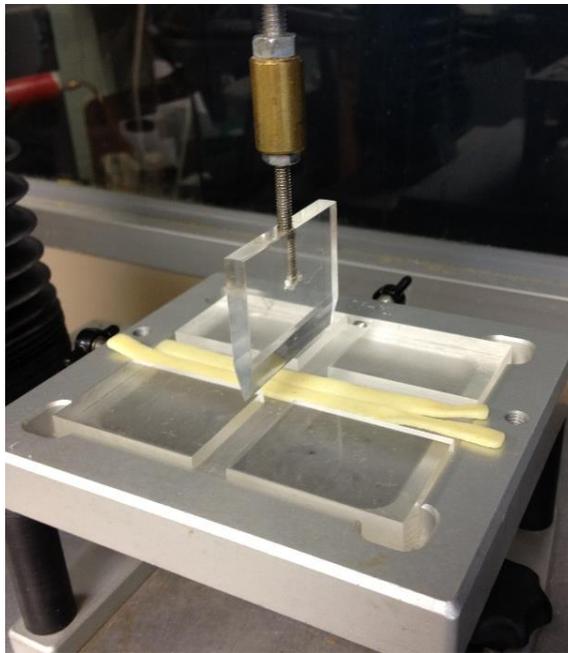


Figure 3.4 Firmness test on pasta noodles

### 3.5 Color measurement

Color values of cooked pasta noodles were obtained using a hand-held Konica Minolta Chroma Meter (Model CR-410, Konica Minolta Sensing, Inc., Japan). Values were reported as Hunter color values where  $L^*$  values denote lightness,  $a^*$  values signify redness, and  $b^*$  values determine yellowness. Immediately after being cooked, pasta noodles were arranged side-by-side in a single layer on a plastic covered white piece of

paper. A glass Pyrex petri dish was placed between the surface of the pasta noodles and the Chroma Meter. Four readings were taken from each pasta sample. Testing was performed in triplicate.

### **3.6 Proximate composition**

Proximate analyses were performed on dried ground uncooked pasta. Grinding was done using a Fresh Grind™ Coffee Grinder (Model 80335, Hamilton Beach®, Southern Pines, NC). Tests were completed by the Agricultural Experiment Station Chemical Laboratories (ESCL) at the University of Missouri (Columbia, MO). Total nitrogen, or crude protein, was found using Combustion Analysis (LECO) according to the Association of Official Agricultural Chemists (AOAC) official method 990.03 (2006) and multiplying by a nitrogen-to-protein factor of 5.70. Crude fat was obtained by ether extraction following the AOAC official method 920.39 (A) (2006). Moisture was determined in a vacuum oven by AOAC official method 934.01 (2006). AOAC official method 942.05 was used to determine ash content, and AOAC official method 978.10 (2006) was used for crude fiber. Total carbohydrates were found by difference.

### **3.7 Amino acid analysis**

Amino acid analyses were also performed by ESCL on dried ground uncooked pasta samples using AOAC official method 982.30 E (a, b, c), chapter 45.3.05 (2006).

### **3.8 Consumer acceptance testing**

Pasta formulations were evaluated for consumer acceptance by 102 untrained panelists. Panelists were recruited based on willingness to participate and consisted of people of various ages (at least 18 years old), genders, and ethnic backgrounds. Testing

was completed in the Sensory Lab in Eckles Hall at the University of Missouri following approval from the University of Missouri Human Subject Institutional Review Board.

Pasta noodles were prepared in advance and stored in Ziploc bags in the refrigerator. Upon a panelist's arrival, samples of pasta (5-10 grams) were individually reheated by being submersed in boiling water for 2-3 seconds, strained, and served in small plastic cups. A 3-digit random number was assigned to each of the 6 samples, and the order of the samples was randomized. Panelists were asked to taste each sample and rate overall liking before moving on to the next one. To reduce carry-over effect, panelists were given water to help cleanse their palates. A sensory ballot utilizing a 9-point hedonic scale was given with the descriptive options of dislike extremely, dislike very much, dislike moderately, dislike slightly, neither like nor dislike, like slightly, like moderately, like very much, and like extremely. Upon analysis, numbers were assigned to each description with 1 = dislike extremely, 5 = neither like nor dislike, and 9 = like extremely.

### **3.9 Data analysis**

Statistical analysis of collected data was performed by the software program SAS® for Windows™ (Version 9.2, SAS Institute Inc., Cary, NC) using the general linear model (GLM) procedure program. Data was analyzed by analysis of variance (ANOVA) at  $p < 0.05$  followed by Fisher's least significant difference (LSD) test to compute the smallest significant difference between two means.

## CHAPTER 4

### RESULTS AND DISCUSSION

#### 4.1 Pasta preparation

When making the pasta products, it was observed that the dough of formula 5:25 CQ was dry and hard to work with. There was a lot of cracking along the edges of the pasta sheets as the dough was being thinned, and although those elements were not used, when cooked, the pasta strands broke apart easily, resulting in much shorter pasta noodles than anticipated. The pastas containing a greater ratio of chickpea flour, such as 20:10 CQ and 25:5 CQ, were fairly moist and easily formed a dough. Extra care had to be taken, however, when the more moist dough was run through the pasta maker due to its tendency to stick to the rollers. The control pasta was the moistest and the easiest to form into a dough. During processing, it was extremely smooth with no cracking or sticking. Prepared pasta samples can be seen in Figure 4.1.

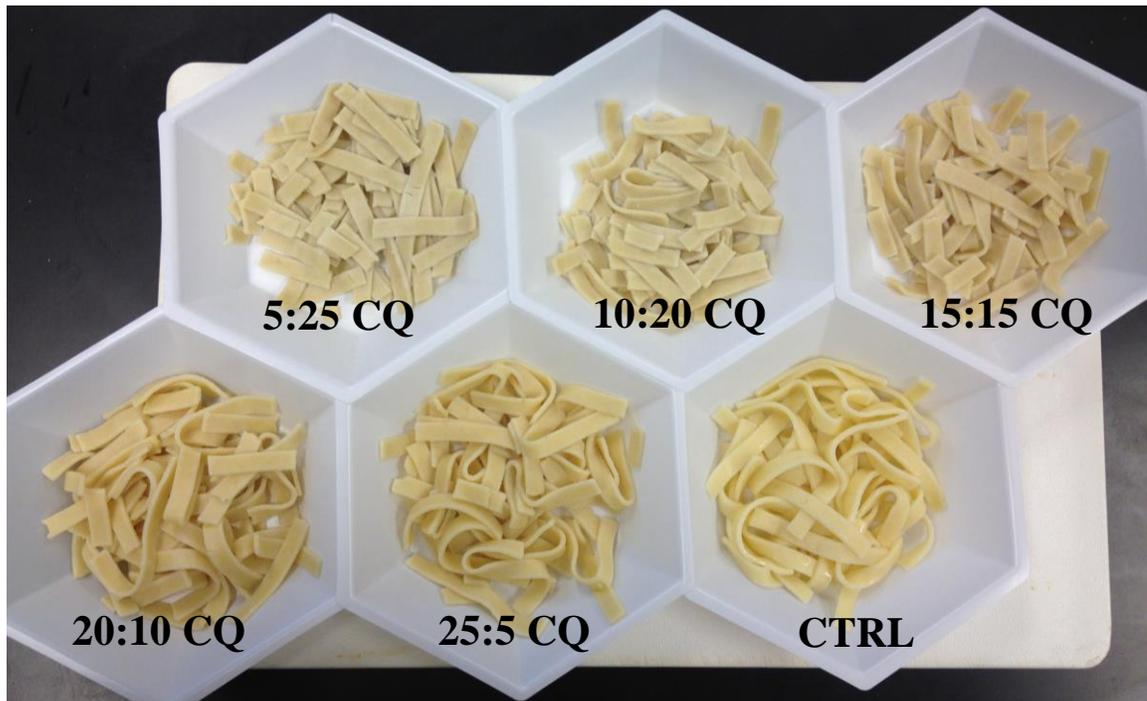


Figure 4.1 Prepared pasta samples

## **4.2 Cooking time**

The optimal cooking time for the control pasta was found to be 13 minutes, while the optimal cooking time for the fortified pastas was 11.5 minutes. The decrease in cooking time for pasta products containing non-gluten flour is in accordance with a study by Chillo and others (2008b) who attribute the increase in speed of water penetration of the core to the physical disruption of the gluten matrix caused by the addition of non-gluten material. Grzybowski and Donnelly (1977) found that when less protein surrounds starch granules, they swell and gelatinize faster. These results are similar to those found by Petitot and others (2010b) where the addition of legume flours (split pea and faba bean) led to a decrease in cooking time.

## **4.3 Cooking Loss**

Cooking loss was significantly ( $p < 0.05$ ) affected by the addition of chickpea and quinoa flours. Table 4.1 shows that the control pasta made with 100% semolina flour had significantly ( $p < 0.05$ ) less cooking loss, as percent of original weight, than the formulas containing chickpea and quinoa flours. This is in accordance to reports of others that fortifying pasta with legume flours (pea, lupin, chickpea, lentil, split pea, or faba bean) increases cooking loss (Nielson and others 1980, Rayas-Duarte and others 1996, Zhao and others 2005, Petitot and others 2010b). Lorenz and others (1993) also found that adding quinoa flour to pasta resulted in a higher cooking loss than the control made from wheat flour. As with cooking time, the increase in cooking loss can be attributed to the weakening of the gluten structure from the addition of non-gluten material, allowing more solids from the noodles to leach out into the cooking water (Rayas-Duarte and others 1996). Cooking loss, or cooking water residue, can also be attributed to starch

damage, where increased levels of starch damage lead to an increase in cooking loss (Lorenz and others 1993).

Table 4.1 Cooking loss of cooked pasta noodles, as percent of original weight

<i>Formula</i>	<i>Cooking loss (%)</i>
5:25 CQ	7.68 <sub>a</sub>
10:20 CQ	7.74 <sub>a</sub>
15:15 CQ	7.77 <sub>a</sub>
20:10 CQ	7.71 <sub>a</sub>
25:5 CQ	7.45 <sub>a</sub>
CTRL	4.22 <sub>b</sub>

<sub>a,b</sub> Means within same column followed by same letter are not significantly different ( $p > 0.05$ ).

The pasta products made with different ratios of chickpea and quinoa flours did not have significantly different ( $p > 0.05$ ) cooking losses. This shows that the type of fortification does not affect the cooking loss, but more so the amount of fortification. This is in accordance with Bahnassey and Khan (1986) and Lorenz and others (1993), who found that cooking loss increased as the level of fortification increased.

Although the fortified pastas have a significantly higher percent of cooking loss than the control, they do not exceed 7-8%, which Dick and Youngs (1988) state as the expected range for cooking loss for spaghetti made from semolina flour. Therefore, all pastas in this study have acceptable cooking loss levels.

#### **4.4 Texture measurement**

Texture measurement results can be seen in Table 4.2. The hardness, adhesiveness, springiness, cohesiveness, and chewiness of the pasta samples were determined from the texture profile analysis, while firmness was found by an independent test. According to definition, both gumminess and chewiness should not be analyzed for

the same sample. Gumminess is a measurement of semisolid foods, while chewiness is the attribute used for solid food products (Bourne 2002). Although the texture profile analysis gave results for gumminess of the samples, it will not be included in this discussion.

Table 4.2 Texture profile and firmness of cooked pasta noodles

<i>Formula</i>	<i>Hardness</i>	<i>Adhesiveness</i>	<i>Springiness</i>	<i>Cohesiveness</i>	<i>Chewiness</i>	<i>Firmness (g)</i>
<i>5:25 CQ</i>	4077 <sub>a</sub>	-91.13 <sub>a</sub>	0.9198 <sub>a</sub>	0.6462 <sub>a,b</sub>	2430 <sub>a</sub>	189.1 <sub>a,b</sub>
<i>10:20 CQ</i>	3846 <sub>a,b</sub>	-96.31 <sub>a</sub>	0.9267 <sub>a</sub>	0.6470 <sub>a,b</sub>	2311 <sub>a,b</sub>	176.4 <sub>b,c</sub>
<i>15:15 CQ</i>	3819 <sub>a,b</sub>	-86.28 <sub>a</sub>	0.9226 <sub>a</sub>	0.6379 <sub>a,b</sub>	2250 <sub>a,b,c</sub>	175.8 <sub>b,c</sub>
<i>20:10 CQ</i>	3647 <sub>b</sub>	-86.91 <sub>a</sub>	0.9101 <sub>a</sub>	0.6352 <sub>a,b</sub>	2111 <sub>c,d</sub>	161.4 <sub>c</sub>
<i>25:5 CQ</i>	3735 <sub>b</sub>	-92.53 <sub>a</sub>	0.9189 <sub>a</sub>	0.6308 <sub>b</sub>	2172 <sub>b,c</sub>	176.9 <sub>b,c</sub>
<i>CTRL</i>	3231 <sub>c</sub>	-113.9 <sub>a</sub>	0.9263 <sub>a</sub>	0.6508 <sub>a</sub>	1959 <sub>d</sub>	198.3 <sub>a</sub>

a,b,c,d Means within same column followed by same letter are not significantly different (p>0.05).

#### **4.4.1 Hardness**

Hardness of the pastas was significantly ( $p < 0.05$ ) affected by the addition of chickpea and quinoa flours. Hardness is the height of the force peak of the first compression cycle (Bourne 2002). In this study, it is the maximum force required to compress the sample to 70% of its original height, representing the effort of the jaw to bite down on the sample. The control pasta was found to be significantly ( $p < 0.05$ ) less hard than the fortified pasta products. Pasta formula 5:25 CQ was significantly ( $p < 0.05$ ) more hard than pastas 20:10 CQ and 25:5 CQ, while pastas 10:20 CQ and 15:15 CQ were not significantly ( $p > 0.05$ ) different. The addition of chickpea and quinoa flours increase hardness of pasta, and more so, the addition of quinoa flour has a greater effect on pasta hardness. These results are similar to those found by Petitot and others (2010b) where pasta fortified with 35% legume flours (split pea or faba bean) significantly increased the hardness of pasta, which they attributed to increased protein content and decreased water uptake.

#### **4.4.2 Adhesiveness**

The addition of chickpea and quinoa flours did not significantly ( $p > 0.05$ ) affect the adhesiveness of pasta made from 100% semolina flour. Adhesiveness is the negative force area of the first bite, or the work necessary to pull the molars away from the food (Bourne 2002). Although not significantly different, the control pasta had greater adhesiveness than those containing chickpea and quinoa flours.

#### **4.4.3 Springiness**

Springiness of the pasta products was not significantly ( $p > 0.05$ ) affected by the addition of chickpea and quinoa flours. Springiness, or elasticity, is the rate at which the

compressed sample returned to its original height after the deforming force was removed (Tang and others 1999). There was no pattern in springiness among samples.

#### **4.4.4 Cohesiveness**

The addition of chickpea and quinoa flours had a moderate effect on the cohesiveness of pasta. Cohesiveness is the ratio of positive force areas under the first and second compression, where the second is divided by the first (Bourne 2002). This shows the strength of the internal bonds of the food (Rosenthal 1999). The only pasta product significantly ( $p<0.05$ ) less cohesive than the control pasta was formula 25:5 CQ. Similar results were found by Petitot and others (2010b) where the addition of 35% legume flours had no impact on cohesiveness between samples. Overall, the pastas maintained a high level of cohesiveness, ranging from 63-65%.

#### **4.4.5 Chewiness**

Chewiness is the energy required to chew a solid food until it is ready for swallowing. It is determined as the product of hardness, cohesiveness, and springiness (Bourne 2002). The addition of chickpea and quinoa flours significantly ( $p<0.05$ ) affected the chewiness of the pasta products. All fortified pastas, with the exception of 20:10 CQ, were significantly ( $p<0.05$ ) more chewy than the control pasta. The pastas with the highest levels of chewiness were 5:25, 10:20, and 15:15 CQ. With the pastas containing the largest amounts of quinoa flour having the highest levels of chewiness, this again shows that quinoa flour has a profound effect on the textural properties of semolina pasta.

#### **4.4.6 Firmness**

The firmness of pasta was significantly ( $p < 0.05$ ) altered by the addition of chickpea and quinoa flours. Firmness is the maximum force, in grams, required to shear two strands of pasta noodles to the depth of 75% their original height (Tang and others 1999). The control pasta was found to be significantly firmer than the fortified pastas, with the exception of 5:25 CQ. This is inconsistent with the TPA results for hardness where the control pasta was found to require less force to compress than the pastas made with chickpea and quinoa flours. The 20:10 CQ pasta had the overall lowest firmness value, showing that it was the softest in texture of the pasta samples. This is similar to the hardness results where, with the exception of the control, 20:10 CQ was found to be the least hard pasta product.

In looking at the literature, similar results were found by Wood (2009), where pasta fortified at 20-30% had a decreased firmness when compared to the control. Bahnassey and Khan (1986), on the other hand, found opposing results in that the firmness of pasta increased as the percent of fortification increased. Zhao and others (2005) also determined that firmness increased with the addition of green pea and lentil flours. There was no significant change, however, in firmness of pasta made with chickpea and yellow pea flours.

#### **4.5 Color measurement**

Color values of cooked pasta noodles were significantly ( $p < 0.05$ ) affected by the addition of chickpea and quinoa flours. Table 4.3 shows the results of the color measurements taken by the Chroma Meter.

Table 4.3 Color values of cooked pasta noodles

<i>Formula</i>	<i>L*</i>	<i>a*</i>	<i>b*</i>
<i>5:25 CQ</i>	66.60 <sub>d</sub>	0.935 <sub>a</sub>	17.47 <sub>f</sub>
<i>10:20 CQ</i>	67.82 <sub>c</sub>	0.456 <sub>b</sub>	18.69 <sub>e</sub>
<i>15:15 CQ</i>	68.13 <sub>b,c</sub>	0.336 <sub>b,c</sub>	19.71 <sub>d</sub>
<i>20:10 CQ</i>	69.04 <sub>b</sub>	-0.028 <sub>c</sub>	21.24 <sub>c</sub>
<i>25:5 CQ</i>	68.95 <sub>b</sub>	0.126 <sub>b,c</sub>	22.07 <sub>b</sub>
<i>CTRL</i>	73.31 <sub>a</sub>	-2.848 <sub>d</sub>	24.27 <sub>a</sub>

a,b,c,d,e,f Means within same column followed by same letter are not significantly different (p>0.05).

#### 4.5.1 Lightness

Lightness of the pastas was significantly (p<0.05) affected by the addition of chickpea and quinoa flours. The control pasta was significantly (p<0.05) lighter in color than the other samples. The pasta then decreased in brightness (*L\** value decreased) as the amount of quinoa flour increased. Pasta 5:25 CQ was significantly (p<0.05) darker than all the other pasta products. This decrease in brightness of pastas containing legume flours is in accordance with many researchers who have experimented with legumes such as chickpea, green pea, yellow pea, split pea, faba bean, soy, and lentil, as well as pseudo-cereals like quinoa (Lorenz and others 1993, Ugarcic-Hardi 2003, Zhao and others 2005, Wood 2009, Petitot and others 2010b). Oliver and others (1993) attribute the decrease in brightness to a higher ash content in legume flours.

It is known that consumers prefer bright yellow translucent pasta products (Ugarcic-Hardi and others 2003), but the limit of acceptable brightness is undefined. It would be of interest to researchers to perform further consumer studies on the level of acceptability of pasta brightness.

#### 4.5.2 Redness

Redness of the pasta noodles was significantly (p<0.05) affected by the addition of chickpea and quinoa flours. The control pasta was significantly (p<0.05) less red than

the other pastas. Similar to lightness decreasing, redness increased ( $a^*$  value increased) as more quinoa flour was added. Pasta 5:25 CQ was significantly ( $p < 0.05$ ) more red than the other pasta products. It can be concluded that the amount of quinoa flour added to pasta significantly affects redness of the product. Similar results were found by Petitot and others (2010b) where pasta fortified with faba bean flour saw a significant increase in redness. Petitot and others (2010b) also noted that yellowness ( $b^*$  values) was not affected in this change. This is important to note because according to Ugarcic-Hardi and others (2003), bright yellow pasta is achieved by having both high  $b^*$  values and low  $a^*$  values.

### **4.5.3 Yellowness**

Yellowness of the pastas was significantly ( $p < 0.05$ ) affected by the addition of chickpea and quinoa flours. All  $b^*$  values were found to be significantly ( $p < 0.05$ ) different from one another. This shows that yellowness is affected not only the addition of chickpea and quinoa flours, but also by the ratio of the flours. The control pasta was found to be the most yellow (highest  $b^*$  value), with yellowness significantly ( $p < 0.05$ ) decreasing as more quinoa flour was added. This is in accordance with other researchers who have seen a decrease in yellowness of pastas containing chickpea, green pea, yellow pea, lentil, and quinoa flours (Lorenz and others 1993, Zhao and others 2005, Wood 2009). This decrease in yellowness may be due to the leaching and/or degradation of color pigments, such as carotenoids and xanthophyll (Wood 2009). Since traditional pasta is made of durum wheat which yields a bright yellow product, high levels of yellowness are desirable for pasta (Dexter and Matsuo 1977, Kill 2001a). As whole wheat pastas increase in popularity, pastas that are less yellow in color may become more

acceptable to consumers. The best way to test acceptability of pasta color is by consumer panel. In 2009, Wood included color in a sensory survey and found that there was not a statistical difference in panelist's perception of pasta color.

#### 4.6 Proximate composition

Due to cost, only one sample of each pasta product was analyzed for proximate composition; therefore, statistical analysis could not be done. The results of the study can be seen in Table 4.4.

Table 4.4 Proximate composition of dry pasta noodles (g/100g)

	5:25 CQ	10:20 CQ	15:15 CQ	20:10 CQ	25:5 CQ	CTRL
<i>Crude Protein*</i>	13.83	14.19	14.58	15.03	15.46	13.92
<i>Moisture</i>	9.18	9.37	9.35	9.08	9.13	9.95
<i>Crude Fat</i>	0.58	0.63	0.67	0.81	0.96	0.25
<i>Crude Fiber</i>	0.32	0.29	0.33	0.60	0.62	0.24
<i>Ash</i>	1.33	1.39	1.40	1.45	1.48	0.80
<i>Carbs**</i>	74.76	74.13	73.67	73.03	72.35	74.84

\* Percentage N X 5.70

\*\* Found by difference

##### 4.6.1 Crude protein

With the exception of formula 5:25 CQ, the addition of chickpea and quinoa flours increased the crude protein content of the control pasta. Formula 25:5 CQ had the highest crude protein content of the samples, while 5:25 CQ had the lowest. Discussion of protein content will be covered later since a more accurate one can be seen from the amino acid analysis.

##### 4.6.2 Moisture

The moisture content of dried pasta was highest in the control pasta. This could be linked to fat content because the control had the lowest fat content. There was no

clear pattern in moisture content of fortified pastas made with different ratios of chickpea and quinoa flours.

#### **4.6.3 Crude fat**

There was a difference in crude fat between the control and the pasta products containing chickpea and quinoa flours. The control pasta had the lowest amount of crude fat, while 25:5 CQ had the highest. The amount of fat increased as the percent of chickpea flour in the pasta samples increased. From this, it can be concluded that chickpea and quinoa flours contain more fat than semolina, with chickpea flour having the largest amount.

#### **4.6.4 Crude fiber**

The control pasta had the lowest crude fiber content of the samples analyzed. Formula 25:5 CQ had the largest amount of crude fiber, over twice as much as the control sample. Similar results were found by Bahnassey and others (1986) who determined that fiber levels of pasta made with legume flours exceeded that of the control. Kaur and others (2011) also found that adding chickpea flour to pasta increased the fiber while keeping the fat at an optimum level.

#### **4.6.5 Ash**

Ash content had a tendency to be greater in the pasta products made from chickpea and quinoa flours. The control pasta contained the lowest reported amount of ash. This is parallel with the results of Bahnassey and others (1986).

#### **4.7 Amino acid analysis**

Due to cost, only one sample of each pasta formula was sent in for amino acid analysis; therefore, statistical tests could not be done. The results of assessment,

however, can still be examined (Table 4.5). As seen in the proximate analysis, fortifying pasta with chickpea and quinoa flours resulted in an increased protein content than that of the control, with the exception of formula 5:25 CQ. The pasta with the greatest increase in protein content is 25:5 CQ. From this, it can be inferred that the addition of chickpea flour has a positive effect on the protein level of pasta, while quinoa flour negatively affects it.

Table 4.5 Amino acid profile of dry pasta noodles (g/100g)

	<i>5:25 CQ</i>	<i>10:20 CQ</i>	<i>15:15 CQ</i>	<i>20:10 CQ</i>	<i>25:5 CQ</i>	<i>CTRL</i>
<i>Taurine</i>	0.09	0.08	0.08	0.08	0.09	0.08
<i>Hydroxyproline</i>	0.06	0.04	0.00	0.05	0.04	0.00
<i>Aspartic Acid</i>	0.85	0.92	0.98	1.05	1.10	0.62
<i>Threonine</i>	0.43	0.44	0.45	0.47	0.48	0.38
<i>Serine</i>	0.62	0.65	0.66	0.68	0.71	0.63
<i>Glutamic Acid</i>	3.93	4.05	4.12	4.18	4.22	4.77
<i>Proline</i>	1.33	1.39	1.41	1.45	1.41	1.69
<i>Glycine</i>	0.55	0.55	0.56	0.57	0.57	0.46
<i>Alanine</i>	0.51	0.52	0.54	0.55	0.56	0.45
<i>Cysteine</i>	0.27	0.29	0.29	0.30	0.30	0.31
<i>Valine</i>	0.64	0.67	0.68	0.71	0.71	0.63
<i>Methionine</i>	0.25	0.26	0.26	0.26	0.26	0.23
<i>Isoleucine</i>	0.58	0.60	0.62	0.64	0.66	0.57
<i>Leucine</i>	1.06	1.10	1.13	1.17	1.18	1.07
<i>Tyrosine</i>	0.44	0.45	0.45	0.46	0.46	0.42
<i>Phenylalanine</i>	0.73	0.77	0.79	0.83	0.86	0.75
<i>Hydroxylysine</i>	0.07	0.08	0.08	0.09	0.09	0.05
<i>Lysine</i>	0.51	0.55	0.57	0.62	0.64	0.36
<i>Histidine</i>	0.40	0.41	0.41	0.43	0.42	0.38
<i>Arginine</i>	0.77	0.83	0.88	0.95	0.99	0.55
<i>Tryptophan</i>	0.18	0.19	0.19	0.19	0.19	0.18
<b><i>Total</i></b>	<b>14.27</b>	<b>14.84</b>	<b>15.16</b>	<b>15.74</b>	<b>15.95</b>	<b>14.59</b>

The results of this analysis confirm the findings of others that semolina lacks threonine and lysine (Kies and Fox 1970, Abdel-Aal and Hucl 2002, Zhao and others

2005), and that quinoa and chickpeas have a supplementing amount of those amino acids (Lorenz and others 1993, Dhawan and others 1991, Maiti 2001, and Mastromatteo and others 2011). Many results that were found by Wood (2009) in adding chickpea flour to pasta were confirmed in this study, such as the decrease in proline and glutamic acid in the fortified pastas and the lack of distinction in the amounts of cysteine and methionine. The decrease in glutamic acid reflects the decrease in gluten-forming proteins from the replacement of semolina flour with non-traditional flours.

The addition of quinoa flour did not contribute as much fortification as hypothesized. Research proposed that quinoa would make a good pair for chickpeas due to its greater amounts of the sulfur-containing amino acids, methionine and cysteine, which chickpeas lack (Dhawan and others 1991, Maiti 2001, Jancurova and others 2009). However, results from this analysis show that pasta products containing more chickpea flour had higher levels of those amino acids. This discrepancy may be due to loss in the milling process. Caperu and others (2000) found that milled quinoa contained less than 30% of the total protein of whole quinoa and a quarter of the amount of cysteine. A loss of cysteine in the milling process explains why the amount of cysteine only slightly varied in the samples made with quinoa flour. Another possible cause for quinoa not contributing as large of an amount of amino acids is due to quinoa flour proteins losing their solubility during storage (Abugoch and others 2009). Since quinoa protein content depends on the variety and growing conditions of the plant (Fleming and Galwey 1995), it would be advantageous to further analyze the flour used and compare it to others available.

#### 4.8 Consumer acceptance testing

The addition of chickpea and quinoa flours significantly ( $p < 0.05$ ) affected consumer acceptance of the pasta products. The average scores given by panelists can be seen in Table 4.6. The control pasta was significantly ( $p < 0.05$ ) more liked than pastas containing chickpea and quinoa flours. The least favored pasta was formula 20:10 CQ. This may be due to the poor textural properties of the samples as discussed earlier. Of the fortified pastas, 5:25 CQ was found to be the most favored. Overall, pasta made with chickpea and quinoa flours scored above neutral on acceptability, showing that the addition of non-traditional flours does not adversely affect the acceptability of pasta. It is important to note that the pasta was tasted without sauce which most consumers are not used to. This may explain why the control pasta received a score between slightly liked and moderately liked.

Table 4.6 Results from consumer acceptance test

<i>Formula</i>	<i>Sensory Score</i>
5:25 CQ	5.85 <sub>b</sub>
10:20 CQ	5.70 <sub>b,c</sub>
15:15 CQ	5.60 <sub>b,c</sub>
20:10 CQ	5.42 <sub>c</sub>
25:5 CQ	5.75 <sub>b,c</sub>
CTRL	6.84 <sub>a</sub>

<sup>a,b,c</sup> Means within same column followed by same letter are not significantly different ( $p > 0.05$ ).

These results are in accordance with other researchers who found that pasta made from 100% semolina flour received the highest overall acceptability when compared to pastas supplemented with legume and pseudo-cereal flours (Bahnassey and Khan 1986, Zhao and others 2005, Mastromatteo and others 2011). Chillo and others (2009) and Mastromatteo and others (2012) received similar scores (5-6) for pasta fortified with quinoa flour.

## CHAPTER 5

### CONCLUSION

In this study, the effects of non-traditional flours on cooking quality, texture, composition, and consumer acceptance of pasta were evaluated. Thirty percent of traditional semolina flour used to make pasta was replaced with different ratios of chickpea and quinoa flours. Parameters evaluated in this study were cooking loss, texture profile analysis, firmness, Hunter color values ( $L^*$ ,  $a^*$ ,  $b^*$ ), proximate composition, amino acid profile, and consumer acceptance. The variables assessed were the ratios (5:25, 10:20, 15:15, 20:10, and 25:5 CQ) of chickpea and quinoa flours used.

Results indicated that pasta containing 30% chickpea and quinoa flours had a decreased optimal cooking time of 11.5 minutes compared to the control pasta time of 13 minutes. Cooking loss was found to be significantly ( $p < 0.05$ ) greater for pasta products containing chickpea and quinoa flours. Although the addition of these flours negatively affected the cooking loss, the percentages were still found to be at an acceptable level.

The results of the texture profile analysis indicated that hardness and chewiness were significantly ( $p < 0.05$ ) affected by the addition of non-traditional flours. Hardness and chewiness were significantly ( $p < 0.05$ ) higher in pastas containing chickpea and quinoa flours compared to the control. More so, quinoa flour had a greater effect on hardness and chewiness than chickpea flour, leading to increased values as more quinoa flour was added. Adhesiveness and springiness were not significantly ( $p > 0.05$ ) affected by fortification, and cohesiveness was only moderately affected. Pastas maintained high cohesiveness at 63-65%, and formula 25:5 CQ was found to be significantly ( $p < 0.05$ ) less cohesive than the others.

The results of the firmness test were in opposition of the results for hardness from the texture profile analysis. The control pasta was found to be significantly ( $p < 0.05$ ) more firm than those made with chickpea and quinoa flours, with the exception of 5:25 CQ. Both hardness and firmness tests, however, revealed that pasta 20:10 CQ was the softest of the fortified pastas, which consumer testing later revealed leads to lower acceptability.

Results of the Hunter color test indicated that the control pasta was significantly ( $p < 0.05$ ) lighter than the pastas containing chickpea and quinoa flours, with those containing the highest amounts of quinoa being the darkest. Redness ( $a^*$  values) significantly ( $p < 0.05$ ) increased with the addition of chickpea and quinoa flours, while yellowness ( $b^*$  values) decreased. The yellowness of pastas was found to be affected not only by the addition of chickpea and quinoa flours, but also by the ratio of the two additional flours.

Although statistical analysis could not be performed on the results of proximate composition and amino acid analysis, the results were in agreement with many previous studies. The addition of chickpea flour greatly increased the protein, fat, fiber, ash, and amino acid content of pasta, with pasta 25:5 CQ having the highest values of all of these. From this, it can be determined that the addition of chickpea flour had the greatest effect on fortifying wheat pasta, while quinoa flour had little to no effect. This could be the result of nutritional composition being lost in the milling process or flour storage. Further studies should be done to better analyze and maintain the nutritional profile of quinoa flour.

Finally, results of the consumer acceptance test indicated that panelists significantly ( $p < 0.05$ ) preferred the control pasta. Formula 20:10 CQ received the lowest sensory score of 5.422, which is slightly above neutral. Since all pasta variations received scores above neutral, it was determined that the addition of chickpea and quinoa flours does not adversely affect the acceptability of pasta products.

In conclusion, the pasta product with the most beneficial ratio of chickpea and quinoa flours is that containing 25% chickpea flour and 5% quinoa flour. Formula 25:5 CQ had the highest protein content and best amino acid profile, along with increased fat and fiber content. Its cooking loss was found to be in an acceptable range, and besides having lower values of cohesiveness, the texture attributes were not adversely affected by fortification. The color characteristics of pasta 25:5 CQ were also closest to that of the control, leading to a high level of visual acceptability.

Further studies of proximate composition and amino acid profile are still needed to statistically evaluate the influence of adding chickpea and quinoa flours to pasta. Further assessment of the discrepancies between hardness and firmness should be completed. Finally, in order to better understand the nutritional composition of quinoa flour, it would be valuable to analyze different seed sources and milling processes.

## REFERENCES

- Abdel-Aal ESM, Hucl P. 2002. Amino acid composition and in vitro protein digestibility of selected ancient wheats and their end products. *J Food Compos Anal* 15(6):737.
- Abugoch L, Castro E, Tapia C, Anon MC, Gajardo P, Villarroel A. 2009. Stability of quinoa flour proteins (*chenopodium quinoa* willd.) during storage. *International J Food Sci Tech* 44(10):2013-20.
- Allred L, Hendricks DG, Mahoney AW. 1976. The availability of iron in quinoa. *Nutr Rep Int* 14(5):575-9.
- American Association of Cereal Chemists (AACC). 2000. Approved methods of the American Association of Cereal Chemists. 10<sup>th</sup> ed. St. Paul, MN: AACC International.
- Association of Official Agricultural Chemists (AOAC). 2006. Official methods of analysis of AOAC International. 18<sup>th</sup> ed. Arlington, VA: AOAC International.
- Bahnassey Y, Khan K. 1986. Fortification of spaghetti with edible legumes. II. Rheological, processing, and quality evaluation studies. *Cereal Chem* 63(3):216-19.
- Bahnassey Y, Khan K, Harrold R. 1986a. Fortification of spaghetti with edible legumes. I. physicochemical, antinutritional, amino acid, and mineral composition. *Cereal Chem* 63(3):210-215.
- Bourne MC. 2002. Principles of objective texture measurement. In: Bourne MC, editor. *Food texture and viscosity: concept and measurement*. 2nd ed. California: Academic Press. p107-88.
- Caperuto LC, Amaya-Farfan J, Camargo CR. 2000. Performance of quinoa (*chenopodium quinoa* willd) flour in the manufacture of gluten-free spaghetti. *J Sci Food Agric* 81:95-101.
- Chillo S, Laverse J, Falcone PM, Del Nobile MA. 2007. Effect of carboxymethylcellulose and pregelatinized corn starch on the quality of amaranthus spaghetti. *J Food Eng* 83:492-500.
- Chillo S, Laverse J, Falcone PM, Del Nobile MA. 2008a. Quality of spaghetti in base amaranthus wholemeal flour added with quinoa, broad bean and chick pea. *J Food Eng* 84:101-107.
- Chillo S, Laverse J, Falcone PM, Protopapa A, Del Nobile MA. 2008b. Influence of the addition of buckwheat flour and durum wheat bran on spaghetti quality. *J Cereal Sci* 47:144-52.
- Chillo S, Civica V, Iannetti M, Suriano N, Mastromatteo M, Del Nobile MA. 2009. Properties of quinoa and oat spaghetti loaded with carboxymethylcellulose sodium salt and pregelatinized starch as structuring agents. *Carbohydr Polym* 78:932-37.

- Del Nobile MA, Baiano A, Conte A, Mocci G. 2005. Influence of protein content on spaghetti cooking quality. *J Cereal Sci* 41:347-56.
- Dexter JE, Matsuo RR. 1979. Influence of protein content on some durum wheat quality parameters. *Can J Plant Sci* 57:717-27.
- Dhanasettakorn K. 2008. Coenzyme Q10 content, composition, texture and physiochemical characteristics of pasta fortified with freeze-dried beef heart [DPhil dissertation]. Columbia, MO: Univ of Missouri. 174p. Available from: <http://hdl.handle.net/10355/6636>.
- Dhawan K, Malhotra S, Dahiya BS, Singh D. 1991. Seed protein fractions and amino acid composition in gram (*cicer arietinum*). *Plant Food Hum Nutr* 41:225-32.
- Dick IW, Matsuo RR. 1988. Durum wheat and pasta products. In: Pomeranz Y, editor. *Wheat chemistry and technology*. St. Paul, MN: AACC. p507-48.
- Dick JW, Youngs VL. 1988. Evaluation of durum wheat, semolina, and pasta in the United States. In: Fabriani G, Lintas C, editors. *Durum wheat: chemistry and technology*. St. Paul, MN: AACC. p237-248.
- Dintheer W. 2001. Pasta mixing and extrusion: practical dosing, mixing and extrusion. In: Kill RC, Turnbull K, editors. *Pasta and semolina technology*. Oxford: Blackwell Science Ltd. p90-118.
- Donnelly BJ. 1991. Pasta: raw materials and processing. In: Lorenz KJ, Kulp K, editors. *Handbook of cereal science and technology*. New York: Marcel Dekker. p763-92.
- Douglass JS, Matthews RH. 1982. Nutrient content of pasta products. *Cereal Food World* 27(11):558-61.
- FAOSTAT [Internet]. Food and Agricultural Organization of the United Nations; 2014 [Accessed 2014 Mar 24]. Available from: <http://faostat.fao.org>.
- Fasano A. 2011. Zonulin and its regulation of intestinal barrier function: the biological door to inflammation, autoimmunity, and cancer. *Physiol Rev* 91(1):151-75.
- Fleming FE, Galwey NW. 1995. Quinoa (*chenopodium quinoa*). In: Williams JT. *Cereals and pseudocereals*. London: Chapman & Hall. p3-84.
- Food and Drug Administration. 1999. Food Labeling: Health Claims; Soy protein and coronary heart disease. *Federal Register* 64(206):57700-33.
- Food and Agriculture Organization (FAO). 2013. International Year of Quinoa. United Nations; 2013 [Accessed 2014 Mar 3] Available from: <http://www.fao.org/quinoa-2013/en/>.
- Goni I, Valentin-Gamazo C. 2003. Chickpea flour ingredient slows glycemic response to pasta in healthy volunteers. *Food Chem* 81:511-15.
- Grzybowski RA, Donnelly BJ. 1977. Starch gelatinization in cooked spaghetti. *J Food Sci* 42(5):1304-05.

- Hill M. 2012. Attack of the gluten. In: Bleam W, McKinney D, Tempest R, Jacobsen EK, editors. Chem Matters Teacher's Guide. ACS. p37-44.
- International Pasta Organization [Internet]. Oct 2012 [Accessed 2014 Mar 4]. Available from: [www.internationalpasta.org](http://www.internationalpasta.org).
- Jancurova M, Minarovicova L, Dandar A. 2009. Quinoa-a review. Czech J Food Sci 27(2):71-79.
- Johnston KW. 2001. Pasta mixing and extrusion: introduction and background. In: Kill RC, Turnbull K, editors. Pasta and semolina technology. Oxford: Blackwell Science Ltd. p86-90.
- Kaur G, Sharma S, Nagi HPS, Ranote PS. 2011. Enrichment of pasta with different plant proteins. J Food Sci Tech 50(5):1000-1005.
- Kies C, Fox HM. 1970. Determination of the first-limiting amino acid of wheat and triticale grain for humans. Cereal Chem 47:615-22.
- Kill RC. 2001a. Introduction. In: Kill RC, Turnbull K, editors. Pasta and semolina technology. Oxford: Blackwell Science Ltd. p1-10.
- Kill RC. 2001b. Additional Ingredients. In: Kill RC, Turnbull K, editors. Pasta and semolina technology. Oxford: Blackwell Science Ltd. p176-80.
- Lorenz K, Gifford H, Johnson DL. 1993. Quinoa in pasta products. Dev Food Sci 32:781-90.
- Madhumitha S, Prabhasankar P. 2011. Influence of additives on functional and nutritional quality characteristics of black gram flour incorporated pasta. J Texture Stud 42:441-450.
- Maiti RK. 2001. The chickpea crop. In: Maiti RK, Wesche-Ebeling P, editors. Advances in chickpea science. Enfield, NH: Science Publishers, Inc. p1-32.
- Marconi E, Carcea M. 2001. Pasta from nontraditional raw materials. Cereal Food World 46(11):522-30.
- Mariani-Constantini A. 1988. Image and nutritional role of pasta—changing food patterns. In: Fabriani G, Lintas C, editors. Durum wheat: chemistry and technology. St. Paul, MN: AACC p283-302.
- Mastromatteo M, Chillo S, Iannetti M, Civica V, Del Nobile MA. 2011. Formulation optimization of gluten-free functional spaghetti based on quinoa, maize and soy flours. Int J Food Sci Tech 46:1201-1208.
- Mastromatteo M, Chillo S, Civica V, Iannetti M, Suriano N, Del Nobile MA. 2012. A multistep optimization approach for the production of healthful pasta based on nonconventional flours. J Food Process Eng 35:601-621.
- Nielsen MA, Sumner AK, Whalley LL. 1980. Fortification of pasta with pea flour and air-classified pea protein concentrate. Cereal Chem 57(3):203-6.

- Oliver JR, Blakeney AB, Allen HM. 1993. The color of flour streams as related to ash and pigment contents. *J Cereal Sci* 17(2):169-82.
- Orth RA, Shellenberger JA. 1988. Origin, production, and utilization of wheat. In: Pomeranz Y, editor. *Wheat chemistry and technology*, vol 3. St. Paul, MN: AACC.
- Petitot M, Barron C, Morel MH, Micard V. 2010a. Impact of legume flour addition on pasta structure: consequences on its *in vitro* starch digestibility. *Food Biophys* 5:284-99.
- Petitot M, Boyer L, Minier C, Micard V. 2010b. Fortification of pasta with split pea and faba bean flours: pasta processing and quality evaluation. *Food Res Int* 43:634-641.
- Rayas-Duarte P, Mock CM, Satterlee LD. 1996. Quality of spaghetti containing buckwheat, amaranth, and lupin flours. *Cereal Chem* 73(3):381-87.
- Regional Office for Latin America and the Caribbean. 2011. Quinoa: an ancient crop to contribute to world food security. [Accessed 2014 Mar 3]. Available from: <http://www.rlc.fao.org/en/publications/quinoa-ancient-crop-food-security>.
- Rosenthal AJ. 1999. Relation between instrumental and sensory measures of food texture. In: Rosenthal AJ, editor. *Food texture: measurement and perception*. Maryland: Aspen Publishers, Inc. p 1–17.
- Sabanis D, Makri E, Doxastakis G. 2006. Effect of durum flour enrichment with chickpea flour on the characteristics of dough and lasagna. *J Sci Food Agri* 86:1938-1944.
- Schoenlechner R, Drausinger J, Ottenschlaeger V, Jurackova K, Berghofer E. 2010. Functional properties of gluten-free pasta produced from amaranth, quinoa and buckwheat. *Plant Food Hum Nutr* 65(4):339-49.
- Singh U. 2001. Functional properties of grain legume flours. *J Food Sci Tech* 38(3):191-99.
- Smewing J. 1997. Analyzing the texture of pasta for quality control. *Cereal Food World* 42:8-12.
- Su-Chuen N, Anderson A, Coker J, Ondrus M. 2007. Characterization of lipid oxidation products in quinoa (*chenopodium quinoa*). *Food Chem* 101(1):185-92.
- Swanson RB. 2007. Grains and legumes. In: Hui YH, editor. *Food chemistry: principles and applications*. 2<sup>nd</sup> ed. West Sacramento, CA: Science Technology System. p1-24.
- Tang C, Hsieh F, Heymann H, Huff HE. 1999. Analyzing and correlating instrumental and sensory data: a multivariate study of physical properties of cooked wheat noodles. *J Food Quality* 22(2):193-211.
- Ugarcic-Hardi Z, Hackenberger D, Subaric D, Hardi J. 2003. Effect of soy, maize and extruded maize flour addition on physical and sensory characteristics of pasta. *Ital J Food Sci* 15:277-286.
- United Nations. 2011. International year of quinoa, 2013. General Assembly: United Nations. A/RES/66/221. Available from <http://undocs.org/A/RES/66/221>.

United States Department of Agriculture (USDA) National Nutrient Database for Standard Reference, Release 26. [Internet]: U.S. Department of Agriculture; 2013, [2014 March 3]. Available from: <http://www.ars.usda.gov/ba/bhnrc/ndl>.

Valencia S, Svanberg U, Sandberg A, Ruales J. 1999. Processing of quinoa (*chenopodium quinoa*, willd): effects on in vitro iron availability and phytate hydrolysis. *Int J Food Sci Nutr* 50:203-11.

Vitali D, Amidzic Klaric D, Dragojevic IV. 2010. Nutritional and functional properties of certain gluten-free raw materials. *Czech J Food Sci* 28(6):495-505.

Wesche-Ebeling P, Maiti RK, Cuevas-Hernandez B, Verde-Star J. 2001. Food science and feed quality. In: Maiti RK, Wesche-Ebeling P, editors. *Advances in chickpea science*. Enfield, NH: Science Publishers, Inc. p189-214.

Wiseman G. 2001. Durum Wheat. In: Kill RC, Turnbull K, editors. *Pasta and semolina technology*. Oxford: Blackwell Science Ltd. p11-42.

Wood JA. 2009. Texture, processing and organoleptic properties of chickpea-fortified spaghetti with insights to the underlying mechanisms of traditional durum pasta quality. *J Cereal Sci* 49:128-33.

Zhao YH, Manthey FA, Chang SK, Hou H, Yuan SH. 2005. Quality characteristics of spaghetti as affected by green and yellow pea, lentil, and chickpea flours. *J Food Sci* 70(6):S371-76.

Zweifel C, Handschin S, Escher F, Conde-Petit B. 2003. Influence of high-temperature drying on structural and textural properties of durum wheat pasta. *Cereal Chem* 80(2):159-167.