ADDIS ABABA UNIVERSITY

COLLEGE OF NATURAL AND COMPUTATIONAL SCIENCES

CENTER FOR FOOD SCIENCE AND NUTRITION

Formulation of Nutritionally Enriched Macaroni with Blends of Durum Wheat, Tef and Chickpea

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Declaration

I, the undersigned, declare that this is original work and has never been submitted in partial fulfillment of the requirements for the degree of Master of Science at Addis Ababa University. All sources of materials used for this thesis have been duly acknowledged. This paper has never been submitted to and/or presented in any other university, college or institution in candidature of any other degree, diploma, or certificate.

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List of Abbreviations

AACC	Association of Analytical Cereal Chemists
AOAC	Association of Official Analytical Chemists
CSA	Central Statistics Authority
DZARC	Debre Zeit Agricultural Research Center
EAA	Essential amino acid
EIAR	Ethiopian Institute Agricultural Research
FDA	Food and Drug Administration
GF	Gluten-free
GI	Glycemic index
IFPRI	International Food Policy Research Institute
IPO	International Pasta Organization
KARC	Kulumesa Agricultural Research Center
MoA	Ministry of Agriculture
N	Newton
NAEGA	North American Export Grain Association
RGB	Red Green Blue color
USD	United State of America dollar
RSM	Response surface methodology
WAC	Water absorption Capacity
WAI	Water absorption index
WHO	World Health Organization

Abstract

Pasta is unleavened extruded product which is made from dough of durum wheat semolina or blends of durum wheat with rice, tef, sorghum, chickpea, lupin etc. In Ethiopia, pasta products made commonly with only semolina, which has lower quality in some important nutrients such as protein, fiber and minerals as compared with other cereals and legumes. Also, semolina is in shortage of supply due to low durum wheat local production. Despite these facts, there is still lack of research on formulating pasta products from composite flour with other cereals and legumes of higher nutritional quality and production rate. Therefore, in this study the usage of tef and chickpea flours to enrich pasta products (specifically macaroni) was investigated by using Response Surface Methodology (RSM). Macaroni was prepared using composite flours of durum wheat semolina (60-100%), tef (0-40%) and chickpea (0-15%) using D-optimal mixture design. For cold press extrusion, pilot scale single screw food extruder was used. Then, first order polynomial model was applied to describe the influence of semolina, tef and chickpea proportion on nutritional composition, cooking quality, textural analysis and sensory evaluation of macaroni products. Throughout the study durum wheat macaroni (100% semolina) was used as a control. Results indicate that an increasing proportion of tef and chickpea flour significantly improved the nutritional composition of the blend macaroni (protein, fiber, fat, iron and zinc content). Incorporation of chickpea flour only up to 15% with semolina produced a macaroni comparable sensory quality with semolina macaroni. Similarly, though the addition of tef flour considerably increased the cooking loss and it also considerably improved the water absorption capacity/index of the macaroni. Protein, fiber, firmness, stickiness, cooking loss and overall acceptability were deem as common optimum parameter for macaroni formula. The formula containing 73.46% semolina, 11.55% tef and 15% chickpea was selected as the best formulation to produce a nutrient rich macaroni product with desirable cooking, texture and sensory quality. Understanding the impact of the blending ratio to improve macaroni nutritional quality was considered useful to develop pasta products.

Keywords: Macaroni, tef, chickpea, cooking and textural property, RSM, D-optimal design

Chapter One

1. Introduction

1.1. Background of the study

Pasta is unleavened extruded product which is made from durum wheat semolina and water. Pasta is the most widely consumed food item across the world due to its versatility, ease of transport, handling, storage properties, availability in countless shapes and sizes and relatively low cost (Paola *et al.,* 2015). Pasta is abroad term which includes spaghetti, macaroni, noodle and vermicelli (Dick and Matsuo, 1988). For production of these pasta products durum wheat semolina is the most preferable raw material because of its excellent rheological properties of dough, superior color or high yellow pigment content, high gluten content, excellent cooking quality and consumer acceptance (Dexter and Matson, 1979; Kneipp, 2008). Additionally, the high level of gluten in semolina produces elastic dough that is easy to form different sizes and shape during pasta making (Fuad and Prabhasankar, 2010).

Pasta is an important starchy staple food product. Though it is a good source of complex carbohydrates, in contrary it is poor in protein, relatively low in fat with no cholesterol, low in sodium and some amino acid (Douglass and Matthews,1982; Sissons, 2005). Besides during durum wheat milling into semolina, bran and germ of the wheat (rich in dietary fiber, vitamins and minerals) are removed. As a result pasta is low in protein content (low levels of essential amino acids (EAA) like lysine, methionine, and threonine); poor in dietary fiber (Petitot *et al.,* 2010a) and low in micronutrient composition (Sissons, 2005).

Pasta is a well-liked food product in many cultures and consumed by all age groups. Pasta was one of the earlier food items that obtained approval by U.S. Food and Drug Administration (FDA) for iron and vitamin enrichment in 1949 (Borneo and Aguirre, 2008; De Pilli *et al.,* 2013). The World Health organization (WHO) and FDA recognize pasta products as a good vehicle for the incorporation of nutrients such as minerals, dietary fiber, proteins and vitamins (Marconi and Carcea , 2001; Chillo *et al.,* 2009).

In recent years, many researches focused on the protein fortification of pasta because of change in consumer trends and government guidelines towards plant or animal source (Kaur *et al.*, 2012). Similarly, dietary fiber has obtained increasing attention as a supplement of pasta products due to its benefits on the reduction of coronary heart-related diseases, diabetes incidence and gut neoplasia (Padalino *et al.*, 2011). Enrichment improves the protein and fiber content of pasta. Pasta with a protein content as high as 33.3 g/100g was obtained with 50% enrichment with peanut flour (Howard *et al.*, 2011), and a total dietary fiber content of 14.2 g/100 g dry matter was obtained with 30% enrichment with wheat bran (Aravind *et al.*, 2012a). Thus, production of pasta with high protein and fiber would be a potential way to address many health benefits to the consumer.

In Sub-Saharan African diet, the main energy sources are cereals which are adequate in methionine and cysteine and B vitamins but limited in lysine. In contrast, most legumes are rich in lysine but low in sulfur containing amino acids. Hence, the blends of cereals and pulses can complement their limited nutrients (Hellendoorn, 1979; Mensa-Wilmot *et al.*, 2004). The stable food in Ethiopian are mostly carbohydrate based cereal products and for the majority of the population it is difficult to afford high protein foods. Pasta is one of the highly consumed and affordable cereal based product (Chiari, 2014; Paola *et al.*, 2015). Therefore, fortifying the durum wheat semolina with other nutritious cereal and legumes is important to improve the nutritional quality of pasta products specifically the dietary fiber, protein and mineral contents can be improved.

Previous studies in other parts of the world on the replacements of durum wheat with non-traditional ingredients for production of pasta considered the following three main reason as objectives: substitute durum wheat with locally available grains, increase nutritional value and decrease allergenicity, particularly by replacing gluten (Steglich, 2013). These studies provided conclusions for future opportunities to use of non-traditional raw materials and to increase the nutritional quality of pasta.

With this regard, Ethiopian indigenous cereal crop tef is an ideal candidate to replace durum wheat semolina partially for the mentioned purposes. Tef (*Eragrostis tef* (Zucc.)) Trotter is an indigenous cereal stable crop in Ethiopia which is widely consumed as leavened pancake like product named *Injera* (Assefa *et al.*, 2013) and used in the form of whole meal flour. At present time, interest in tef based food products has increased worldwide because of its attractive nutritional profile and gluten free nature. Compared with other cereals such as wheat, barley and sorghum , tef has higher iron, calcium and zinc contents (Abebe *et al.*, 2007); higher content of insoluble polysaccharides (Hrušková *et al.*, 2012), low allergenicity and low glycemic index. Also tef considered as suitable ingredient in the bakery and pasta industry for its good starch gelling properties (Abebe and Ronda, 2014); better water absorption capacity (Bultosa, 2007); high content of dietary fiber (Stojceska *et al.*, 2010); good balance of all essential amino acid (Gebremariam *et al.*,2012) and high amount of unsaturated fatty acids (mainly Linoleic acid (18:2, 9, 12) and α-Linolenic acid(18:3 9, 12, 15))(Hager *et al.*, 2012a).

The other non-traditional potential substitute of durum wheat partially to enrich pasta products nutritionally is chickpea. Chickpea is the fifth most widely consumed pulse type in the world. It is a rich source of high quality protein, vitamins (thiamine and niacin), minerals (calcium, phosphorous, iron, magnesium, and potassium) , essential fatty acid (linoleic) and high dietary fiber (Zia-ul-haq *et al.*, 2007; Fuad and Prabhasankar , 2010; Kinfe *et al.*, 2015). The demand of chickpea is increasing in tropical and subtropical areas and it is an important component of the diets where the poor who cannot afford animal proteins in developing countries (Chibbar, 2010).

Though both tef and chickpea are good sources important nutrients, as to our knowledge their potential to fortify semolina in pasta making with important health promoting components is yet to be studied.

Therefore, this study was undertaken to develop macaroni rich in protein, dietary fiber and mineral from tef-chickpea-durum wheat blends with modeling and optimization of mixture Response Surface Methodology (RSM). The percentage of semolina, tef and chickpea flour that can influence the chemical composition, textural analysis and cooking quality of the macaroni were analyzed using a D-optimal mixture design.

1.2. Statement of the problem

In developing countries including Ethiopia improvements in nutrition will contribute significantly in reducing poverty and achieving health, education, and employment goals (IFPRI, 2014). On the other hand, consumers are becoming increasingly health conscious and are demanding natural, wholesome, health-promoting foods. One of the widely consumed food items worldwide is pasta.

Durum wheat is the raw material of choice for manufacturing pasta products with the most desirable end product characteristics. In Ethiopia, though the number of pasta producing industries is increasing, they are still dependent on imported durum wheat. This is due to unavailability of adequate supply of durum wheat from local produce. As a result pasta producing industries have been affected by the huge import costs and by the recurrent scarcity of hard currency (Chiari, 2014). As report by Chiari (2014) shows, from 2009 to 2013 Ethiopia spent 950 million (USD) for importation of durum wheat and 90 million (USD) to import pasta. Furthermore with regards to quality nutrition, pasta produced from pure semolina is low in protein, deficient in dietary fiber and low in micronutrient content (Abdelaland , 2002; Petitot *et al.,* 2010). Thus, fortification of pasta products with other cereals and legumes etc can play vital role in solving the mentioned two major problems of the industry.

Accordingly, tef and chickpea are selected as potential ingredients to substitute durum wheat semolina partially to formulate nutritionally enhanced pasta products such as macaroni. Tef is the principal ingredient of most Ethiopian population diet *injera*. Due to traditional and small scale tef processing techniques, the production of tef based products with industrial level are limited (Laike *et al.,* 2010) and limited knowledge on nutritional profile parallels the processing challenge (Baye, 2014). However, tef has great potential to develop food products that attracted international consumers because of its gluten free nature, high amount of minerals and good source of dietary fiber (Seyfu, 1997). The formulation of gluten free pasta or "tagliatelle" could be produced from partial replacement of tef flour with bean flour (Giuberti *et al.,* 2015) and gluten free tef spaghetti would be made from tef flour with fresh egg pasta (Hager *et al.,* 2013).

Similarly, chickpea is popular grain in most Ethiopian households and used in the form of *shiro,* boiled and roasted snacks. Chickpea contain high amount of protein (18.9-25.27%) and low glycemic index (Dhawan *et al.,* 1991; Wesch *et al.,* 2001). Chickpea has potential to mitigate protein- energy malnutrition in developing countries where people cannot afford animal protein sources (Singh, 2001). Considering its nutritional quality and lower cost, chickpea can be a candidate of pulse to develop value added products. Hence, chickpea was other ingredient selected in this study to formulate nutritionally enhanced pasta. To improve the protein content and produce gluten free pasta products has partially incorporated egg yolk with tef, oat and wheat flour (Hager *et al.,* 2013). However, price of animal based protein sources is increasing specifically in developing countries.

Therefore, the present study investigated formulation of nutritionally enriched macaroni product by partially substituting durum wheat semolina with tef and chickpea without compromising the expected nutritional, cooking quality, and sensory features of pasta products.

1.3. Objectives

General Objective

- To develop and optimize nutritionally enhanced macaroni through fortifying durum wheat semolina with tef and chickpea.

Specific Objectives

- To evaluate the nutrient composition of ingredients (semolina, tef and chickpea flours).
- To evaluate the functional properties of composite flours used to formulate tef and chickpea fortified macaroni.
- To formulate recipes (proportion of ingredients) for the preparation of acceptable macaroni using D- optimal mixture design.
- To evaluate proximate and mineral composition of the formulated macaroni.
- To study the cooking, textural and sensory qualities of the newly formulated macaroni.
- To optimize and identify the optimum values of developed nutritionally enhanced macaroni with acceptable cooking and sensorial quality.

1.4. Significance of the Study

- The study would provide an opportunity for pasta producing industries by introducing macaroni production from blends of durum wheat semolina with chickpea and tef flour for better nutritional quality and comparable sensory acceptability.
- Providing alternative nutritionally enriched pasta products to the consumer.
- Contributing in reduction of imported durum wheat semolina .
- Encourage farmers to cultivate and increasing production of tef and chickpea
- Macaroni gives an initial basis for tef and chickpea based products by using the application of response surface methodology for further new food product optimization and formulation.
- The study would give information for researchers, students and teachers of the field on the findings of the study as a reference material.

Chapter Two

2. Literature Review

2.1.Overview of pasta

Pasta is one of the most ancient and commonly consumed food product in many regions around the world. The term 'pasta' has generally been reserved to describe paste products fitting the Italian style of extruded foods such as spaghetti or lasagna, and is usually distinguished from the oriental style of sheeted and cut foods called 'noodles', which are commonly made from wheat other than durum (Dick and Matsuo, 1988). The main ingredients used to make pasta are durum wheat semolina and water.

Pasta products have more than 600 diverse shapes which depends mainly on the shape of the die that encompasses mainly into four:- short pasta (elbow macaroni, rigatoni, fusilli, shells, etc); long pasta (spaghetti, linguine, vermicelli, etc); egg noodles (pasta made with egg) and specialty items (like lasagna, manicotti, jumbo shells, and stuffed pasta). Spaghetti which is in the form of solid rods, elbow macaroni, lasagna, shells, and various noodle shapes are among the most popular shapes (Dick and Matsuo, 1988).

Pasta products are appreciated by consumers due to its cheap cost, widely available products, easiness to prepare, versatility, good sensory attributes, long shelf life and easy to transport (Pagini, 1986; Feillet and Dexter, 1996); thus is a quick food option for most people around the globe (Melissa, 2014).

Pasta is a well-liked food product in many cultures, consumed by all age groups. Therefore, it is considered as a good vehicle to improve the nutritive values of the diet of developing countries (Bressani, 1971).

Many countries produce, export and import pasta. About 13.5 million tons of pasta is produced worldwide in 2013 (International Pasta organization IPO, 2013). The top three dominating world pasta producer were Italy, USA and Brazil; while the top three pasta consumer in world were Italy, Venezuela and Tunisia and from this Africa contributes only 4.3%.

In Ethiopia, the use of pasta products is increasing. Currently, there are more than 20 different pasta producing companies (Chiari, 2014). Yearly consumption of pasta in Ethiopia was 5 kg per capital in 2014 (Chiari, 2014) and the major consumption was in urban areas. The same report indicated that the importation of durum wheat decreased from 800,000 tons in 2009 to 400,000 tons in 2013 (Figure 1).On the other hand, between the years 2009 and 2013 the imported pasta increased from 5,000 tons to 27,000 tons (Figure 2).

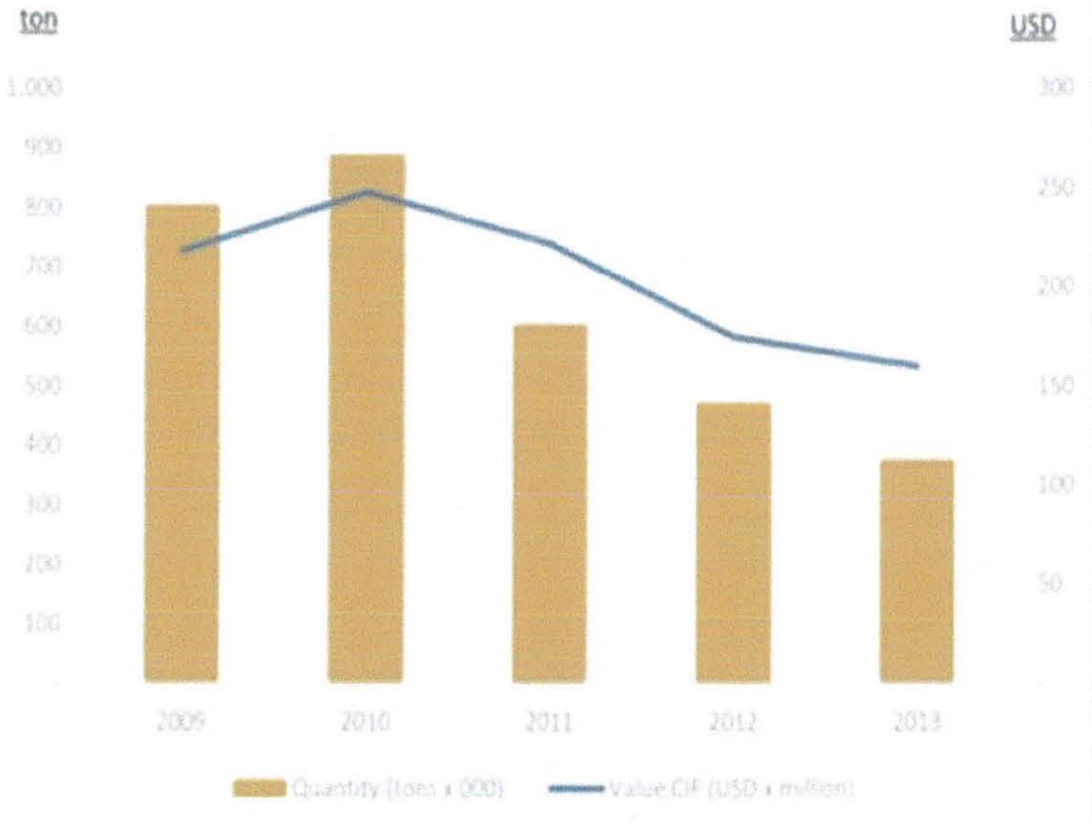


Figure 1: Import of durum wheat in Ethiopia from 2009 to 2013 (Source: Chiari(2014))

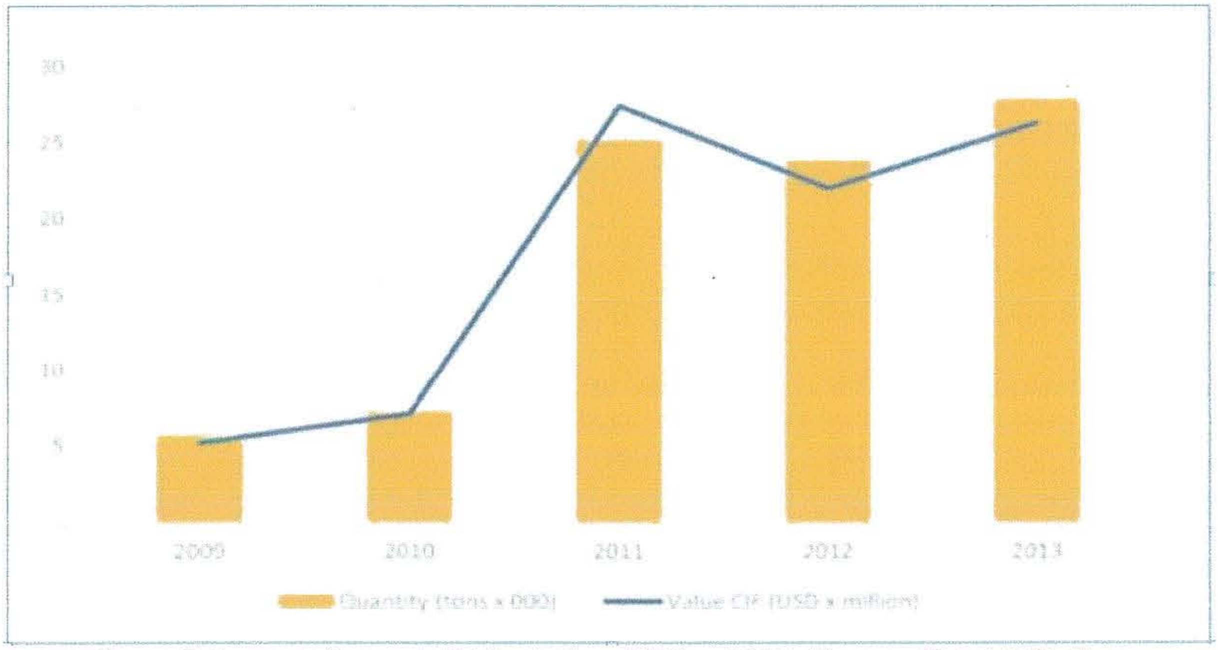


Figure 2: Import of pasta in Ethiopia from 2009 to 2013 (Source: Chiari (2014))

2.2. Nutritional composition of pasta

In average pasta products have high energy value (350kcal per 100g), protein content (11-12)% and has rapid digestibility. The mineral content of pasta products is unbalanced with a marked high prevalence of potassium and phosphorus but low in iron and zinc content (Ferrari and Piazza, 2006; USDA, 2016). In general, pasta contains most significant quantities of complex carbohydrates, while its protein content is lower (Hummel, 1966; Douglass and Matthews, 1988; Starta, 2004). The protein in pasta contains six of the eight essential amino acids lacking lysine and threonine. Similarly, macaroni products lack an adequate amount of vital minerals and vitamins (Hummel, 1966).

Hence, through adding high protein, mineral and fiber containing healthy ingredients with semolina a more healthy and nutritionally enhanced pasta products can be formulated.

Table 1. Average nutritional composition of dried pasta products

Composition per (100g)	Content
Moisture (g)	10.25 - 12.40
Protein (g)	10.80- 12.78
Lipids (g)	0.30- 0.67
Carbohydrate (g)	74.69 - 82.80
Starch(g)	72.20
Dietary fiber (mg)	0.27 - 2.60
Iron (mg)	1.30
Calcium (mg)	17.00
Phosphorus (mg)	165.00
Sodium (mg)	5.00
Potassium (mg)	160.00
Vitamin B1 (mg)	0.14
Vitamin B2 (mg)	0.11
Energy (kcal)	356.00

Source: (Drake *et al.*,1989; Ferrari and Piazza, 2006)

The main ingredients used to make pasta are durum wheat semolina and water. The summary of durum wheat agronomic, composition and other related facts are discussed below.

2.3. Durum wheat

Generally, wheat is mainly classified into bread wheat and durum wheat. Bread wheat (*Triticum aestivum*) is a common wheat and the most common cultivated crop taking a share up to 95 % (Fuad and Prabhasankar, 2010). It is mainly used for making white bread, noodles, all-purpose flour, doughnut and crackers. This is because it contains lower protein and has lower hardness compared with durum wheat.

Durum wheat (*Triticum durum*) is the most suitable raw material for the production of pasta products because of its hardest endosperm textures, larger and more vitreous kernel, and its endosperm contains high xanthophylls or luteins (not carotene) pigments which amounts twice the concentration in bread wheat.(Liu *et al.,*1996). It is estimated that around 50 percent of world durum wheat production is converted into pasta products such as spaghetti, macaroni, vermicelli, etc. The remaining is used for some other regional foods like puffed cereals, hot cereals, desserts, flat bread, leavened bread, and noodles. Additionally, pasta made from durum wheat cultivars of superior quality gives a bright yellow color and after cooking it retains the required firmness and do not have stickiness (Barrelli *et al.,* 1999).

The nutritional content comparison of durum wheat (semolina) and common wheat (farina) flours contain the percentage of protein (12.70, 10.60); damaged starch (11.50, 8.50); carbohydrate (77.80, 82.00); amylose (27.00, 23.00); lipids (1.00, 0.50) and dietary fiber (1.19,0.91), respectively (USDA, 2016; Steglich, 2013).

The three main distinct parts of durum wheat kernel are the bran, the starchy endosperm and the germ. During milling a product with bright yellow color, a low speck count and uniform granulation called semolina is produced mainly from the endosperm (Matsuo and Dexter, 1980). The bran and the germ are often removed. The bran layers are high in protein, cellulose and hemicelluloses, and minerals. The germ is rich in protein, lipids, sugar, and ash constituents. The endosperm consists of largely starch granules embedded in matrix of protein (Leonard and Martin, 1963).

In Ethiopia durum wheat has been under cultivation for thousands of years and the crop has been used for making different types of traditional foods and local drinks (Tesfaye, 2000). With the emergence of new food industries, macaroni and spaghetti have become important part of daily diet in the urban areas of Ethiopia and because of this the number of food industries processing these products in the country is increasing quickly. However, despite the production potential of durum wheat the country has pasta industries largely dependent upon imported durum.

Up to the year 2017, the durum wheat improvement project of the Debre Zeit Agricultural Research Centre (DZARC) has released around 25 wheat varieties in Ethiopia. Study made by

Abebe *et al.*(2011) reported that six Ethiopian released durum wheat varieties have convenient features for pasta making with acceptable cooking quality.

Durum wheat milling process

The durum wheat milling process has the following step:- cleaning, conditioning, de-braning, milling process (Breaker, Reduction and Purification) (Dexter and Marchylo, 2000).

Cleaning removes large impurities and the very small and lightweight impurities, such as fine dust, insect fragments and eggs, various types of dirt particles, etc.

The second process is conditioning. Durum wheat is tempered prior to milling to toughen the bran, thereby reducing the number of bran specks in the semolina. The temper time is short in order to retain the hard, vitreous nature of durum wheat thereby, maximizing the release of large endosperm particles and minimizing the yield of flour (Kruger *et al.*, 1998).

De-braning or scourer is the next milling process step for maximizing extraction rate, or compromising on flour quality without sacrificing semolina refinement. De-braning also removes the surface discoloration of durum wheat kernels and greatly enhancing the appearance of semolina from lower grade durum and 5% yield advantage over traditional semolina milling at comparable ash and color (Dexter *et al.*, 1994).

The Milling process continues after de-braning and it contains: breaker, reduction and purification. The break system is the first step for durum wheat milling process and it allows the gradual release of coarse endosperm particles with a minimum yield of flour. Passage through the rolling mills is alternated with sifting phases carried out by the plan sifters and the purifiers. The next step is a reduction process that helps to produce with semolina with finer granulation. Past studies showed negative relation between pasta quality and the size of semolina because reducing semolina greatly increases starch damage (Dexter and Marchylo, 2000). Damage of starches exposes them to enzymatic activity that causes the formation of reducing sugars that, in turn, are very harmful to the pasta. When low temperature drying is used in pasta making, This results in higher loss of solids during cooking and high surface break down, leading to stickiness (Matsue and Dexter,1980)

2.4. Durum wheat replacement with non-traditional ingredient

Pasta produced from durum wheat semolina lacks some essential amino acids like lysine and threonine, poor in fibers, low mineral and vitamin contents. Thus, it is getting less preferred by health conscious consumers (Jayasena and Nasar-Abbas, 2011). The need for gluten-free (GF) products is currently increasing as the demanding group extends from celiac disease patients to people looking for non allergenic ingredients like gluten which is abundantly found in durum wheat (Guarda *et al.,* 2004).

Steglich (2013) identified three driving forces in which non-traditional ingredients used as supplements or substitute to durum wheat pasta as: increase the nutritional level, replace durum wheat with local available grain and decrease allergenicity specifically reduce or replace gluten. Accordingly, different studies done in order to address these issues include fortification with non-traditional ingredients such as legume flours for protein source (Petitot *et al.,* 2010a); vegetable (tomato, spinach or carrot) for coloring (Cubadda, 1993), egg as supplemental for non-gluten pasta (Hager *et al.,* 2013), cereal bran for important source of insoluble dietary fiber (Kaur *et al.,* 2012) and commercial bran sources (inulin, pectin and others) for highly soluble fibers component (Robin *et al.,* 2012). Summarized review on the effects of nontraditional ingredients on the nutritional, heath and quality (sensorial and cooking) of the pasta formulated is presented in Table 2.

Table 2. List of non-traditional ingredients tested for nutritional profile and functional property enhancement of pasta.

Category	Type	Effects on nutritional, heath and quality (sensorial and cooking) of the pasta formulated	References
Cereal	Oat	Higher levels of fiber and mineral composition	Hager *et al.*, 2013
		Similar sensory properties with durum wheat	
		Lower gluten index <tef<durum wheat	
	Tef	Higher fiber content and mineral composition	Hager *et al.*, 2013
		Reduced sensory quality with durum wheat	
		Lower gluten index than durum wheat	
	Amaranthus	Lower cooking time and dry breakage susceptibility	Chillo *et al.*, 2008
		Higher cooking loss and lower stickiness	
	Cereal bran	Darker color and lower cooking time	Kaur *et al.*, 2012
		Highest protein and dietary fiber content with durum	
Legumes	Peanut	High protein content and balanced amino acid (lysine)	Howard *et al.*, 2011
		Darker color and higher cooking loss	
	Chickpea	Lower in cooking loss and less stickiness	Wood, 2009
		Equal or better retained firmness	
		Increased the cooking time, water absorption and stiffness	
	Lupin	Decrease in cooking time (40 and 50% lupin flour) and similar property with lower portion to durum.	Jayasena and Nasar-Abbas, 2011
		Increased the protein and dietary fiber contents	
	Broad bean	High protein and dietary fiber content	Giménez *et al.*, 2012
		Equal or similar cooking time	

2.5.Tef and chickpea as potential fortification ingredients of pasta products

2.5.1. Tef

Tef (*Eragrostis tef trotter*) is originated in Ethiopia where is owes the major diversity and it is a staple crop. It is one of the most preferably cultivated grain by Ethiopian farmers as it has high market value (grain and straw) and it performs better under moisture stress and waterlogged conditions (Assefa *et al.*, 2013). The grain can be stored long period for it is less susceptible for storage pests (Hailu and Seyfu , 2003). The crops covers about 3 million ha with 4.75 million tons of grain annual harvest (CSA, 2015).

In Ethiopia tef flour is widely used for making a fermented flat bread *injera*, traditional alcoholic beer (tella), local alcoholic drink or spirit (Arake or katikalla), sweet dry unleavened bread (kitta), gruel (muk)and porridge (genfo).

Bultosa and Taylor (2004) and Bultosa (2007) reported on physico-chemical composition of 13 tef varieties that tef grain was found with crude protein, crude fat and crude fiber contents ranged between (8.7–11.1)% , (2.0–3.0)% and (2.6 – 3.8)%, respectively.

Tef has an attractive nutritional profile and gluten free nature. This makes it suitable potential candidate to be used as ingredient in the formulation of new cereal based foods. Hence, it can be a substitute for wheat and other cereals in their food application and produces an alternative food products. Tef is being considered as a good option as functional food ingredient for gluten intolerant and celiac disease patients (Dekking *et al.,* 2004, Hager *et al.,* 2012b; Giuberti *et al.,* 2015). In addition, it is proved that it can give possibility to manufacture as a novel food and ingredient such as gluten-free beer and energy cereal bars (Gebremariam *et al.,*2012); tef based breads, breakfast cereals and waffles (Laike *et al.,* 2010; Tesfaye, 2000). It can also be used to make various kinds of recipe such as appetizers, brownies, cracker, desserts, pie crusts, cookies, cakes, pan cakes, muffins, pizza crusts, soups, tortillas and flat breads (Gamboa and Ekris, 2008; Dereje *et al.,* 2015).

For instance, Sirawdink and Ramasway (2011) tried to formulate protein-rich extruded products from tef, corn and soybean protein isolate (SPI) and reported that 20% tef, 60% corn, and 20% SPI gave extruded product with desirable attributes. The blend ratio with lower proportions of corn; higher proportion of tef and soybean protein isolates showed decreased color value and higher levels of product hardness.

2.4.2. Chickpea

Legumes are good sources of high-quality plant proteins among which chickpea (*Cicer arietinum* L.) is an important source of plant protein for human consumption. Chickpea is one of the important crops in Ethiopian agriculture as it is an alternative source of protein and source of micro-nutrients, cash income, and food security. It is also being utilized in crop rotation practices with major cereal crops like tef and wheat playing a significant role in restoring soil fertility by fixing atmospheric nitrogen. Hence, area of cultivation and gross grain production of chickpea in Ethiopia has been increasing. In 2015/2016 production season, chickpea covered 258,486.29 hectares of land from which 472,611.388 tons of grain was produced (CSA, 2016) and among legumes it took the third rank (in terms of area coverage and volume of production) next to faba bean and haricot bean.

There are two kinds of chickpea including kabuli and desi type which are distinguished by their seed size, shape, and color and geographical distribution. Desi seeds grow in semi-arid tropics, while kabuli seeds grow in temperate regions. The kabuli types are large (>0.3g), smooth surface, and cream color whereas desi type chickpea are small (0.1- 0.3g), more angular shaped, wrinkled surface and dark, thick seed coat (Chavan *et al.*,1986; Wood *et al.*, 2008). Due to their larger size and greater nutritional value, kabuli chickpeas are more popular for human consumption. The nutritional composition of kabuli type chickpea are protein (17.8-27.5)%, fat (4.5-5.7)%, carbohydrate (56.7-63.0)% and fiber (4.0-8.0)% whereas desi type are protein 22.9 %, fat 4.6%, carbohydrate 46% and fiber 24.6% (Chavan *et al.*, 1986; Wang *et al.*, 2009; Kinfe *et al.*,2015).

Legumes are especially valuable in providing human diets with well-balanced amino acid composition when mixed with processed cereals. For instance, fortified spaghetti with legumes was reported to provide high protein and nutritious diet for low- income people and for people wishing to improve the nutritional quality of their diet (Bahnassey and Khan, 1986).

Therefore, because of their availability in Ethiopia, their nutritional and heath benefit and their some functional attributes tef and chickpea flours were considered as potential candidates to formulate nutritionally enhanced and health promoting durum wheat based fortified pasta (i.e. macaroni).

2.6. Effect of durum wheat semolina replacement with non-traditional ingredient on pasta quality

Pasta quality attributes are classified into 7 categories: proximate composition, dough properties, drying properties, cooking properties, color, mechanical properties, and sensory properties (Mercier *et al.,* 2016). The proximate composition, cooking properties and color are the quality attributes most frequently considered.

The incorporation of pulses into cereals provides an opportunity to use non-traditional raw materials to increase the nutritional quality of pasta. Introduction of pulse flour into pasta ultimately increases the protein, insoluble fiber, vitamin (B_1, B_5, B_6 and B_9) and mineral (Fe, Mg and P) contents, although it affects the ease of processing and quality attributes of pasta (Farooq and Boye, 2011).

2.6.1. Effect of the non-traditional ingredients on nutritional, functional and phytochemical characteristics of the pasta

Gluten forming proteins are primarily responsible for the functional properties of wheat flour. The amount of gluten in flour is an index of the protein content and physical properties of the washed out gluten (i.e. index of flour strength). Wet gluten and dry gluten criteria are as a primary test of flour quality. This is likely due to the simplicity of the test and the quantitative information obtained relating to both gluten content and quality (Atwell, 2001). Semolina wet gluten is highly correlated to the protein content which is the most desired quality test parameter (Chinnaswamy *et al.*, 2005).

In the revised Codex Alimentarius standard (1998), a limit of gluten in product made only from naturally gluten-free ingredients is 20 ppm while only for foods containing a mixture of the two ingredients is 200 ppm. The average gluten-containing diet contains roughly 10-40 grams of gluten per day.

The gluten index method provides information on both quantity and quality of wet gluten. Gluten index value is a criterion defining whether the gluten quality is weak, strong or normal. Based on GI values, Cubadda *et al.*(1992) proposed seven gluten quality classes in durum wheat, GI values between 65 and 80 are considered good, while values above 80 are excellent. With this regard chickpea based pasta has decreased glycemic response level from glycemic index (GI) 73.5 to 58.6 compared with durum wheat pasta or control samples (Goni and Valentin-Gamazo, 2003).

Pulses are rich in essential amino acids, including lysine, threonine, isoleucine, leucine, phenylalanine and valine, and have a good mineral profile, containing K, Fe, Cu, Mg, Zn and Mn. In contrast, cereals are deficient in certain essential amino acids and also lose some of their mineral content when milled, owing to the removal of the aleurone layer, which is a rich source of minerals. To improve their amino acid profile and mineral complementarily, cereals may be fortified with pulses. Ensuring an optimal level of fortification requires studying the characteristics of flour and semolina, especially their particle size and composition, for acceptable product development (Farooq and Boye, 2011). Legume-fortified cereals therefore offer a broader spectrum for those who wish to improve the nutritional quality of their diet.

The chemical composition of semolina and legume flours also determines the nature and level of fortification. Lentil, dry pea, chickpea, field pea and dry bean are considered foods of great nutritional value and are also important sources of dietary fiber, an essential part of a healthy diet. Dietary fiber not only naturally promotes bowel health but also helps to lower cholesterol, balances blood glucose, and promotes healthy physiology and well-being (Padalino *et al.*, 2011).

Hence, replacing cereals with high protein legumes like chickpea is one of the recommended solutions to protein-energy malnutrition, particularly in developing countries (Singh, 2001). Because chickpea contains higher content essential amino acid and combined with cereals that increased the protein content (Wesche-Ebeling *et al.*,2001). Blending navy bean and pinto bean protein isolates with semolina produced spaghetti with high protein and lysine contents (Seyam *et al.*, 1983). Wood (2009) reported that incorporated chickpea flour (0-30)% into durum wheat semolina and with the increasing amount of chickpea flour total protein and all the amino acids amount increased. Moreover, with increased chickpea amount the mineral, fat and indigestible compound content increased; while starch hydrolysis of the pasta was lowered (Goni and Valentin-Gamazo, 2003; Besher *et al.,* 2012).

Enrichment affect the protein and fiber content of pasta. Mercier *et al.(*2016) review exhibited that the enrichment of pasta with pulse flour increased the protein content by an average of 1.8 ± 0.5 g/(100 g dry pasta) with the control pasta and for enrichment levels below 15% and by an average of 4.0 ± 1.0 g/(100 g dry pasta) for higher enrichment levels. An increased consumption of dietary fiber in daily diet has been recommended by nutritionists to improve health. But during durum wheat milling, the extraction of semolina from germ and bran (good source fiber). As a result pasta products are very low in dietary fiber contents, a number of studies have conducted aimed at increasing the dietary fiber contents. Jayasena and Nasar-Abbas (2011) reported that total dietary fiber in pasta enriched with 50 g/100g lupin kernel fiber increased from 1.5 to 15%. Addition legume flours such as soy flour (Shogren *et al*., 2006), quinoa, broad bean and chickpea flours (Chillo *et al.* 2008) when added to semolina to produce pasta could improve mainly protein contents but less impact on the dietary fiber contents. The addition of tef flour improved the dietary fiber content that provides beneficial effects on human health (Bultosa, 2007; Baye, 2014).

However, the quality of the fortified pasta products depends on the chickpea amount. Fortification of pasta with chickpea flour above 30% was not possible because of particle aggregation. This renders the feeding of the extrusion screw and difficult during mixing and weakening of the gluten matrix (Wood, 2009). Wang *et al* (2010) reported that increase the resistant starch content in chickpea increases in soluble dietary fiber. The presence of fiber causes a physical disruption of the gluten matrix, which may facilitate the penetration of water to the core of the pasta.

Study made by Hager *et al.*(2012a and 2013) shown gluten free egg based spaghetti was made from tef flour and the product was compared with that of oat and wheat based products. Tef based pasta are nutritionally superior to wheat in terms of fiber and mineral content. Besides, tef spaghetti had a lower predicted glycemic index (pGI) (45) than wheat spaghetti (67), and the pGI was higher than that of oat spaghetti (32). Similarly, Giuberti *et al.*(2016) evaluated the effect of partial substitution of tef up to 40% with common bean flour at different incorporation rates to produce gluten free "tagliatelle". The bean flour addition increased the dietary fiber and protein contents while decreasing the starch content and showed significant impact on cooking and sensory quality. The bean flour addition greatly increased the resistant starch content and reduced the GI from 60 to 39.

Phytates are the primary form of phosphorus storage in seeds which accounts for 60-90% of the total phosphorus and a common constituent of cereals and legumes (Schlemmer *et al.*, 2009). Tef contains high amounts of phytate with a wide range of variability, probably due to differences in varieties and growing conditions and likely to weaken the absorption of iron and zinc (Schlemmer *et al.*, 2009; Baye, 2014). The phytate interfere iron and zinc absorption in the gastrointestinal tract with the formation of insoluble phytate-mineral complexes (Manary *et al.*, 2002; Weaver and Kannan, 2002).

Traditional processing technologies (decortications, soaking, germination and fermentation) and extrusion technology are commonly applied to reduce the levels of antinutritional factors (trypsin inhibitor, tannins and phytates), denatures undesirable enzymes and retains natural colors and flavors of foods (Guy, 2001). But traditional processing technologies are limited by their laborious and time demanding nature.

2.6.2. Effect of the non-traditional ingredients on texture and cooking properties of pasta

The competence of gluten to form a protein network have an impact on cooking quality and textural properties of durum wheat pasta. Durum wheat proteins are composed mainly of glutenin and gliadins that form intra- and intermolecular disulfide bonds during processing. This phenomenon leads to the formation of a three-dimensional gluten network responsible for the unique textural properties of pasta (Farooq and Boye, 2011). But pulse proteins are composed mainly of salt-soluble globulins and water-soluble albumins. The addition of non-gluten material dilutes the gluten strength and likely weakens the overall structure of the pasta. As a consequence, more solids leach from the pasta into the cooking water (Rayas-Duarte *et al.*, 1996).

Effects of incorporation of legumes (like lupin, soybean; navy and pinto protein isolates) in durum wheat based pasta used for making pasta products are reported by Morad *et al.* (1980) and Seyam *et al.*(1983). The studies showed that increasing level of soybean flour (2-6)% in macaroni with increased cooked weight (Morad *et al.*1980). However, the same study showed that increasing the level of soybean flour decreased cooking quality and imparted undesirable grayish color. The increasing level of lupin flour (2-6)% with increased cooked weight, increased cooking quality and enhanced natural amber color of the lupin which is a desirable color in macaroni (Morad *et al.*, 1980). The formulation of spaghetti by blending navy bean and protein isolates of pinto bean with semolina gave inferior color, low cooked weight and high cooking loss compared with 100% durum wheat pasta (Seyam *et al.*, 1983).

Similarly, substituting split pea or faba bean flour and chickpea flour for durum wheat semolina at a high level (35%) requires adapting the pasta-making process at the pilot scale and has a noticeable impact on the cooking quality of pasta, decreasing the optimal cooking time for low-temperature dried pasta and resulting in lower water uptake and higher cooking losses (Wood, 2009; Petitot *et al.*, 2010).

Fortification with legume flours such as navy bean, pinto bean, lentil or green pea protein concentrates causes an increase in firmness, which represents the cutting force required to penetrate product strands compared with 100% durum wheat pasta (Seyam *et al.*, 1983, Bahnassey and Khan, 1986; Zhao *et al.*, 2005).

Wood (2009) reported that increasing chickpea flour (0-30)% into durum wheat semolina to produce spaghetti reduced firmness, improved stickiness and reduced cooking loss of the pasta product. The spaghetti samples supplemented with 15% pea flour showed less elasticity, unpleasant color and higher firmness compared to the control sample (Padalino *et al.*, 2014).

Hager *et al.*(2012a) studied the formulation of egg pasta from wheat, oat and tef flours. The study indicated the optimum response surface methodology (RSM) level of 62.8% tef flour, 25.1% water, 11% egg white powder and 1.1% emulsifier produced gluten free pasta with acceptable texture but with lower stickiness and less elasticity. Similarly, Giuberti *et al.*(2015)

study on the partial substitute of tef with bean flour to produce gluten free "tagliatelle" or pasta. The texture of tef tagliatelle was not affected by the bean flour addition. The increment on the replacement of bean to tef flour from (0 to 40)% showed the tagliatelle product has increased optimal cooking time, similar cooking loss effect and color variation. The texture of spaghetti produced from tef and oat was similar to that of wheat spaghetti except for the lower elasticity.

2.6.3. Effect of the non-traditional ingredients on sensorial quality of pasta

The main sensory attributes of the pasta are appearance, flavor, texture and overall acceptability. Product color is one of the main critical parameters affecting the appearance and overall acceptability of pasta. Product color is one of the main critical parameters affecting the appearance and overall acceptability of pasta. The yellowish color of pasta is mainly due to the degradation of carotenoid pigments in semolina. This pigment degradation is caused by lipoxygenase and manufacturing process (Fua *et al.,* 2013). Generally, consumers prefer a bright yellow color, but fortification with pulse flour significantly decreases brightness because of the higher ash content of legume flours, especially green pea, chickpea, lentil and faba bean flours (Wood, 2009).

The external appearance of pasta and other attributes of sensory quality after cooking are the most important criteria of pasta quality evaluation. The appearance assessment includes: color, specks, surface discoloration and texture (smoothness, white spots, streaks, air bubbles) (Feillet *et al.*, 2000). Pasta and noodles fortified with lupin or chickpea flour up to a 10% substitution level are generally well accepted, and there appears to be no impact on appearance, taste or texture at higher substitution levels (Zhao *et al.,* 2005; Sabanis *et al.,* 2006).

The spaghetti samples supplemented with 15% pea flour into semolina improved the overall sensory quality compared to the control sample (Padalino *et al.,* 2014). Additionally, the inclusion of (5–10)% chickpea flour in pasta products improved organoleptic properties (such as color and flavor) and met the pasta quality criteria in terms of firmness and cooking quality (Sabanis *et al.,* 2006). According to Hager *et al.*(2012a and 2013), tef based spaghetti was inferior overall sensory acceptance compared with wheat and oat spaghetti, but suggesting research opportunities for food technologists to optimize the right recipe and processing parameter.

2.7. Color Measurement

Color is one of the most important physical quality parameter that the consumer perceives and uses as a tool to accept or reject food. Color determination can be carried out by color measuring instrument or by human (visual) inspection. The decision of color in human inspection case is subjective and extremely variable from panelist to panelist. In order to carry out a more objective color analysis, color standards (color spaces and numerical values) are often used as reference material which are used to create, represent and visualize colors in two and three dimensional space (Trusell *et al.*, 2005; León, 2006).

The RGB (red, green, and blue), the CMYK (cyan, magenta, yellow, black), and the L*a*b* color space are the three main color spaces that used to define color. According to Adobe system (2002), the L*a*b* model has the largest range encompassing all colors in the RGB and CMYK gamut.

The L*a*b* values are often used in food research studies. The L*a*b* color space is an international standard for color measurement developed by the Commission Internationale d"Eclairage (CIE) in 1976. The L*a*b* color consists of a luminance or lightness component (L* value, ranging from 0 to 100), a* component (from green to red) and the b* component (from blue to yellow) along with two chromatic components (ranging from -120 to +120). The L*a*b* color is device independent, providing consistent color regardless of the input or output device.

2.8. Optimization

Response surface methodology is a tool to develop and describe relations between a process variable with product quality response statistically (Giovanni, 1983). There are many types of mixture design: simplex-lattice design, simplex-centroid design, axial design, and D-optimal design.

D-optimal mixture design is a type of experimental design which was used in this study. D-optimal mixture design is constructed to minimize the overall variance of the predicted regression coefficient by maximizing the value of determinant of the information matrix (Esbensen *et al.,* 2002); the experimental region is not simplex but it is irregular (NurIzzati *et al.,*2015) and it offers advantages under the condition of limited budget and time and small number of runs as compared with others design (Ruseckaite *et al.,* 2014).

The methodology uses a first degree polynomial model to approximately give response variables (Box and Wilson, 1992). The model has the advantage of being employed with ease and can do approximate estimation of the variables even when the knowledge of process is little. Hence, the method finds frequent use to explore influence of input variable on the response variables of a product or a process. D-optimal design is only an approximation and suggested to use a first-degree polynomial model based on the idea of using designed experiments to optimize responses (Box and Wilson, 1992; Eriksson, 2008).

There are basically three general degrees of freedom to control the final properties of any product manufactured in blending: the properties or selection of raw materials, the ratios in which to blend them and the processing condition to manufacture them (Muteki *et al.,* 2007). This gives us the product development introduce " what raw material properties affect what final product properties".

Previous studies were conducted by applying D-optimal mixture design. For instance, Sirawdink and Ramaswamy (2011) studied on protein-rich extruded products from tef, corn and soy protein isolate blends. The study was conducted with the objective of enriching the protein content of tef products and produces a range of extruded products. The influence of proportion of ingredients (tef, corn and SPI) with three-factor, three-level D-optimal constrained mixture design was employed to quantify the effects on color value, rehydration ratio, water solubility index , expansion ratio and bulk density. Therefore, in the present study also, the RSM with D-optimal mixture design was applied in the formulation of nutritionally enriched macaroni products.

Chapter Three

3. Materials and Methods

Materials

3.1. Grain samples

The durum wheat variety used for this study was 'Utuba'. This variety was selected for the formulation because its higher yield per unit area, popularity among durum wheat farming community. In addition, it has better quality for pasta making and its is well accepted by the local pasta processing industries (Legese, 2017). The Utuba grain sample used for this study was obtained from the Durum Wheat Improvement Program. It was from the lot produced in the 2016/17 main crop production season which was grown in the premises of Debre Zeit Agricultural Research Center (DZARC) using the recommended agronomic practice for optimum production.

Because of its very white color and its acceptability by tef producing farmers, DZ-01-96 ('Magna') was the tef variety type was selected for the formulation (MOA, 2010; Assefa *et al.*, 2013). The DZ-01-96 tef grain sample was taken from the 2016/17 main crop production season produce of the Tef Improvement Research Program of the DZARC. Similarly, because of its seed coat color (white) and preference by farmers, Habru was selected among the released varieties of chickpea (Kinfe *et al.,* 2015). The sample grain of the same was also taken from the lot produced in the 2016/17 main crop production season by the Chickpea Improvement Program of the DZARC.

The sample preparation process were conducted in DebreZeit agricultural research center (DZARC) and Kulmusa agricultural research center (KARC). The pasta extrusion processes, textural analysis and sensory evaluation were done at the Food science and Postharvest Technology of the Hawassa University. Nutritional composition, cooking quality and functional analyses were conducted in the Food Science and Nutritional Analysis Laboratories of

Agricultural and Quality research Laboratory (AQRL) in Ethiopian Institute of Agricultural Research (EIAR). Color and antinutritional factor were done at Addis Ababa University, food science and nutrition laboratory.

3.2. Grain milling processes

3.2.1. Durum wheat milling

3.2.1.1.Cleaning and conditioning

The durum wheat grain was manually cleaned very carefully by winnowing, sifting and sorting with handing picking to remove stones, foreign materials (large chaff, dusts and soils) and other cereals. In order to determine the amount of water, the initial moisture content in wheat grain sample was evaluated before tempering by using Equation 3.1.

The moisture content was determined according to AOAC (2010) ; the official method 925.10 (Equation 3. 1). Approximately 3g of flour sample was weighed (±0.01mg) on analytical balance and the sample was dried in the oven at 130°C for 2 hours.

$$\%Moisture\ content = \frac{Initial\ weight - Final\ weight}{Initial\ weight} \times 100\% \quad \text{(Equation 3.1)}$$

The cleaned wheat grain has been conditioned with adjusted target moisture 17.5% to facilitate tempering and the initial moisture 10.55%. The water toughens outer wheat bran coats for easier separation, softening or mellowing endosperm. The amount of distilled water to be added to increase the grain moisture content to target was calculated using the equation stated below.

$$\text{Water in } \% = \frac{100*(F2-F1)}{100-F2} * \text{amount of wheat grain} \quad \text{(Equation 3.2)}$$

Where: F_1=Initial wheat moisture

F_2= Desired wheat moisture

2526 ml of water was added in the blended container which contained 30 kg wheat grain and mixed well for 15 min by using mixers (Chopin Technology, Type: MR 10L, France). Then the sample was conditioned to 17.5% moisture level with distilled water in plastic container and stored for 24-36 hr to facilitate tempering.

3.2.1.2. Milling

After tempering, the wheat grains were milled into semolina using a Chopin laboratory mill (Moulin CD2 mill, Chopin technology, France) (Appendix I). This CD2 instrument has a simple flow comprising of three break and three reduction passages which set at right and left side position. The three break passages are built on one roll pair and the three reduction passages are built on a second roll pair. The breaker part placed at right side of mill, its aim is to separate the bran from the kernel. Rough semolina and bran was obtained from this breaking operation. The reduction part also equipped with three corrugated rolls placed in left side of mill, their role is to reduce the rough semolina produced previously into coarse semolina, fine semolina and flour. The separation process is ensured by a centrifugal sifting, on each parts of the mill.

The tef and chickpea grain was manually cleaned by winnowing and sifting to remove stones, soils, weeds, large chaff and other unwanted materials. The tef grain was ground into whole flour with a laboratory mill (Perten mill 120, Finland) fitted with a 0.5 mm opening screen size. The chickpea sample was milled by using a Chopin laboratory mill after the removal of the husk with decortications.

3.2.2. Blending

Semolina, tef and chickpea flour was mixed by rotating drum mixer (Chopin MR 10L, France) for each blending proportion according to D-optimal mixture design which ensures uniform blending. The blended flours of 16 run were stored in refrigerator at 5°C after packing in moisture tight polyethylene bags until pasta processing and lab analysis.

3.3. Experimental process and Formulations

The formulation of macaroni with blends of durum wheat semolina (60–100)%, tef (0–40)% and chickpea (0–15)% was conducted by using mixture response surface methodology through D-optimal design. The mixture design with D-optimal which were obtained 16 runs with five replication. The upper and lower limits of the independent variables were selected based on earlier reports and preliminary trial. The independent variables (tef, durum wheat and chickpea) on the dependent variables (nutrient content, cooking quality and sensory features).

Table 3. Blend proportion of semolina, tef and chickpea

Runs	Blend proportion			Amount of water added (ml) (from 100 g flour)
	Semolina (%)	Tef (%)	Chickpea (%)	
Run -1	80.00	20.00	0.00	39.62
Run -2	100.00	0.00	0.00	36.30
Run -3	72.76	12.76	14.48	38.36
Run -4	60.00	32.58	7.42	39.76
Run -5	60.00	40.00	0.00	40.25
Run -6	60.00	25.11	14.89	40.30
Run -7	92.50	0.00	7.50	41.25
Run -8	80.00	20.00	0.00	40.59
Run -9	85.00	0.00	15.00	38.45
Run -10	68.44	28.08	3.48	38.38
Run -11	100.00	0.00	0.00	36.82
Run -12	82.15	9.11	8.74	38.11
Run -13	60.00	40.00	0.00	40.30
Run -14	89.61	10.39	0.00	38.08
Run -15	60.00	25.11	14.89	40.71
Run -16	85.00	0.00	15.00	37.93

Frame work of the study design

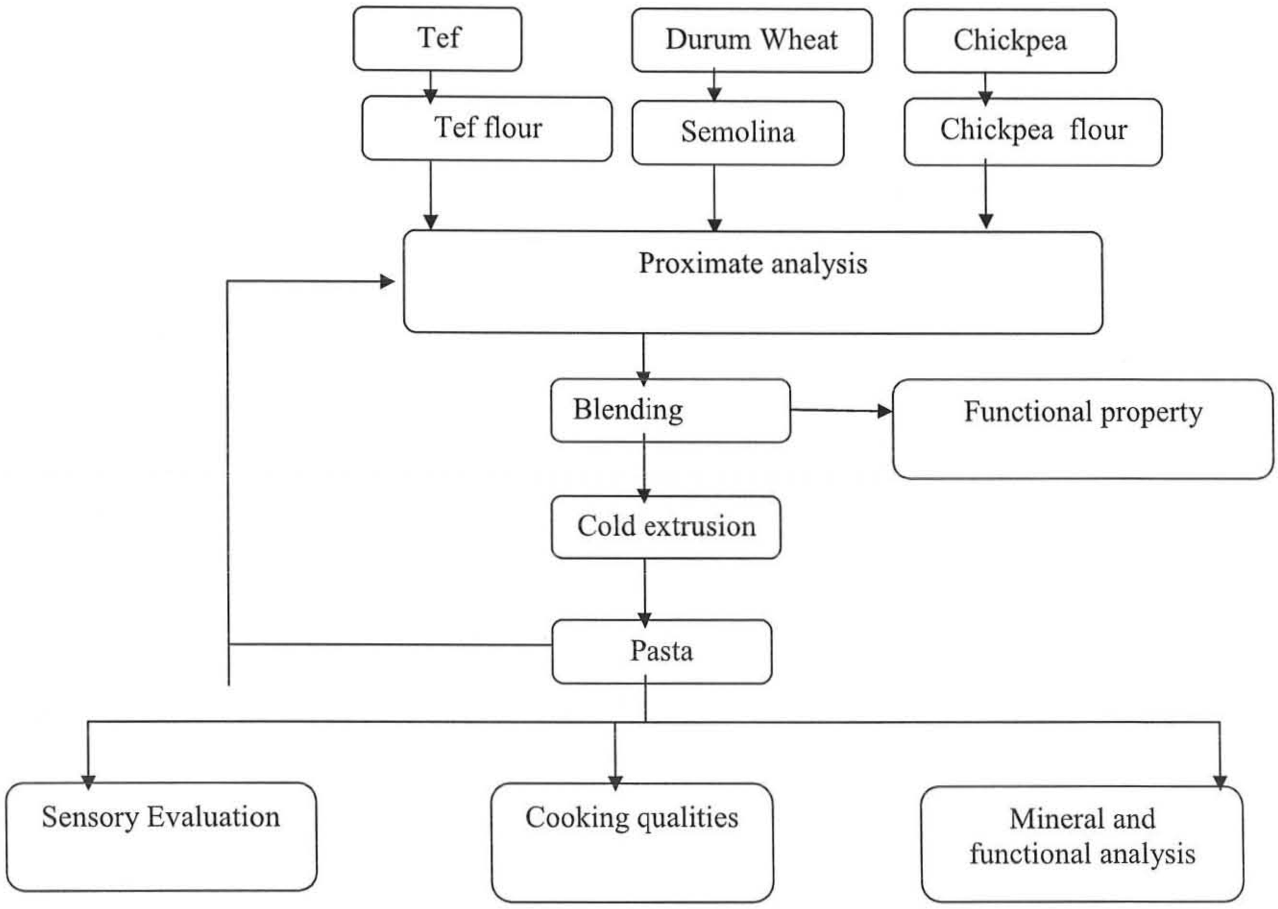


Figure 3: Experimental frame of the research

3.4. Pasta processing

3.4.1. Optimal amount of water for production of semolina macaroni

The optimum level of water for mixing with semolina was determined after several trials. The required amount of water which mixed it with semolina decided for the purpose of uniform granular mixture and free from any spot on the produced macaroni. Care was taken not to add excess or less water which would otherwise have adversely affected the extrusion and drying of the extruded dough. The required amount of water and semolina was calculated for mixing based on the following equation (Mondelli, 2000):

$$A = \frac{Ui * I}{100} \qquad \text{(Equation 3.3)}$$

Where: I = Total weight of dough (g),

Ui = Moisture of dough (%) and

A = Total weight of water in the dough (g)

$$S = (I\text{-}A) + \frac{(I-A)K}{1-K} \qquad \text{(Equation 3.4)}$$

Where: S = Weight of semolina required to make the dough according to desired final moisture of the dough (Ui)

K = Semolina moisture coefficient; $K = \frac{Us}{100}$

Us= Moisture of semolina

$$Aa = A - \frac{(I-A)K}{1-K} \qquad \text{(Equation 3.5)}$$

Where: Aa = Weight of water to be added to semolina to make dough with desired moisture Ui, according to semolina's specific moisture (Us)

Following the above equations, the preparation of a 900 g dough with a final moisture content of 34.5% and made from semolina having 13% moisture has been cited below in Appendix II. 678g semolina and 222.10g water was premixed in manual mixer resulted in a more uniform distribution of water and helped in producing pasta with uniform appearance and without specks.

3.4.2. Water absorption index and optimal water amount for each formulation

The required amount of water for each formulation was determined in semolina and 16 trials that composed in the mixture design according to Anderson *et al.*(1969). Based on the results obtained for WAI, it was possible to obtain the optimal amount of water to be added in each formulation, according to Equation 3.6.

$$WAI(g/g) = \frac{\text{g centrifuge residue}}{\text{unsolubilized dry matter}} \quad \text{(Equation 3.6)}$$

$$\text{Amount of water (\%)} = a * b/c \quad \text{(Equation 3.7)}$$

Where: WAI = Water absorption index

a = WAI of each formulation

b = optimal amount of water added to the base formulation (100% wheat flour and 35% water); and

c = WAI of semolina (g centrifugation residue/ insolubilized dry matter).

3.4.3. Pasta preparation

The extrusion process was performed on laboratory scale single screw extruder (Lanuova Lampa, Model Minilab 305, Italy) (Appendix III) at Hawassa University, Food Science and Post Harvest Technology laboratory. Before extrusion, the blend mixtures from refrigerator were allowed to warm to room temperature and then the blended flour were well mixed and pre-mixed with water according to the recipes and amount of water given in Table 3.

The pre-mixed composite flour and previously determined amount water for each formulation was placed into the feeding hopper of extruder and mixed for 10 min. The mixture was kneaded by the extrusion screw in the pasta machine rotating in opposite direction of extrusion process.

The kneading process imparted continuous pressure on the dough compressing just enough for it to withstand the extrusion and the shaping process. The dough was extruded using a single screw extruder fitted with an adjustable die (diameter 4.2 mm). The extruded product tube type pasta (Macaroni) was cut into pieces of uniform length (3-4 cm) by hand manually with a scissor. The extruded pasta was dried in oven at 60°C for about 4 hour to attain moisture content to about 11% (Mercier *et al.*, 2016).

The process is summarized as follows.

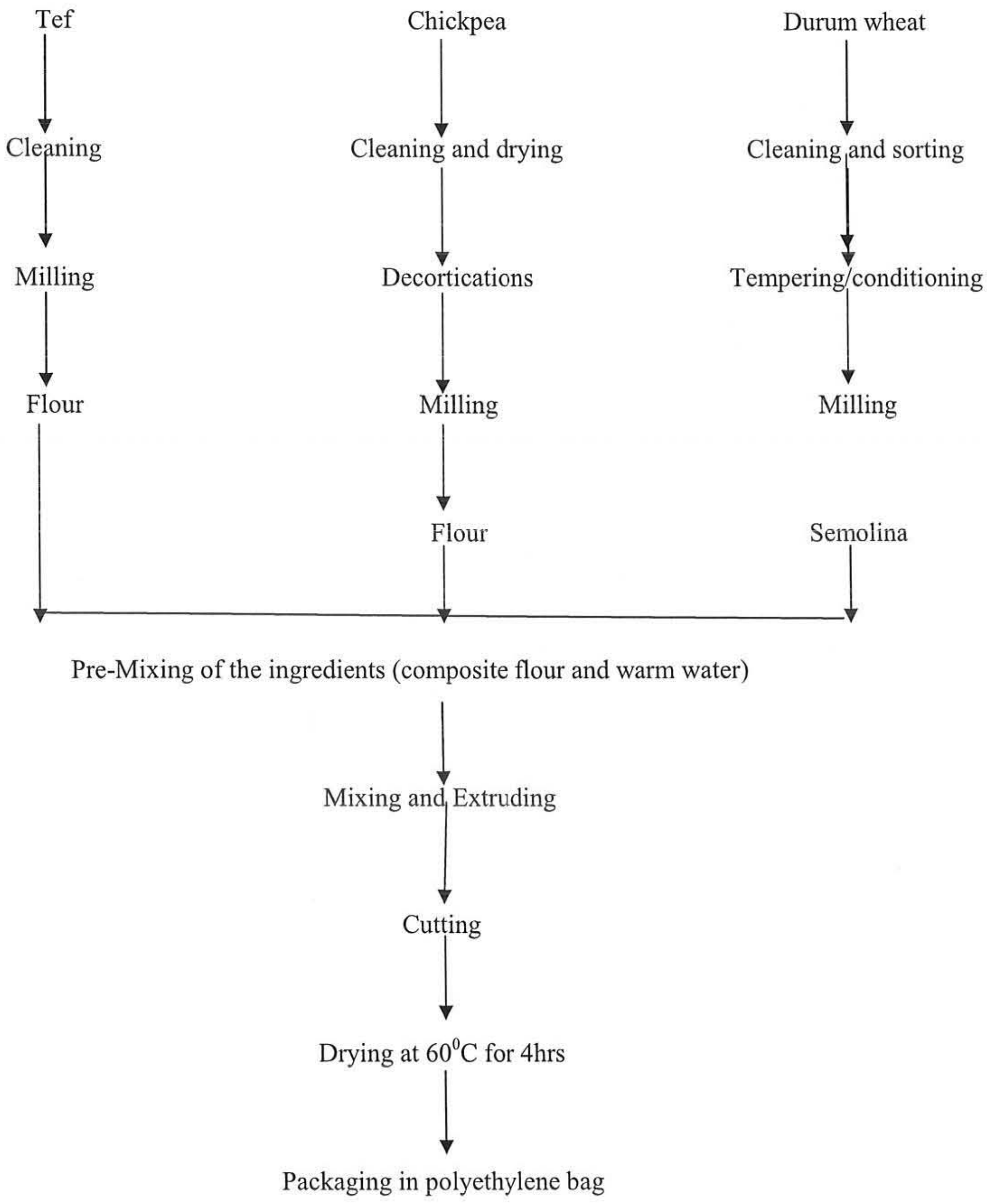


Figure 4: Flow chart for pasta production

3.5. Flour functional properties and nutritional composition

3.4.1. Flour functional properties

Each ingredient (semolina, whole tef flour and chickpea flour) and their composite blend were characterized with the following functional properties:- gluten content, water absorption index and water absorption capacity.

3.4.1.1. Wet gluten content

Wet gluten is a plastic-elastic substance consisting of the proteins gliadin and glutenin, obtained after washing out the starch from wheat flour dough. Ten gram of composite sample was weighed and transferred into the wash chamber. 4.8 ml of the 2% sodium chloride solution was added and allowed for 10 min in the chamber. Wet gluten content was determined by hand washing method. Then mixing and washing procedures were proceeded simultaneously. In the process, starch, water soluble pentosans, water and dilute salt soluble proteins were washed out. Then the gluten was press-dried between hands and rolled in to ball. The total weight of the gluten is defined as gluten quantity. The wet gluten content of the sample was expressed as a percentage of the mass of the original sample (AACC, 2000) and calculated in the following way:

$$\text{Wet gluten content (\%)} = \frac{\text{total gluten (g)}}{\text{Wt of sample}} * 100 = \frac{\text{total gluten}}{10\text{ g}} * 100 = \text{total gluten} * 10 \qquad \text{(Equation 3.8)}$$

3.4.1.2. Water absorption capacity(WAC)

WAC was determined according to the method described by Beuchat (1977). Two grams of composite flour sample (W_0) was mixed with 20 ml of distilled water in 25 ml centrifuge tubes (v1). The dispersed particles were vortexed for 30 sec at room temperature and centrifuged for 30 min at 3000 rpm. WAC was determined by the difference the amount of distilled water before and after centrifuge.

$$\mathbf{WAC(\%)} = \frac{\text{the volume of distilled water before and after centrifuge (V2−V1)}}{\text{weight of sample (Wo)}} * \mathbf{100} \quad \textbf{(Equation 3.9)}$$

3.4.1.3. Water Absorption Index (WAI)

Water absorption index of composite flour was determined according to Anderson et al. (1969). Two gram of composite flour sample was suspended in 25 ml of distilled water in a tarred 50 ml centrifuge tube and shaked (Model AS130.1, IKA, USA) for 30 min. The sample was centrifuged for 10 min at 3000 rpm. The gel remaining in the centrifuge tube was weighed and WAI was calculated as follows:

$$\text{WAI(g/g)} = \frac{\text{Wg}}{\text{Wds}} \qquad \text{(Equation 3.10)}$$

Where: WAI = Water absorption Index

Wg = Weight of the sediment

Wds = Weight of dry sample

3.4.2. Proximate composition of the raw materials and macaroni

The moisture, ash, protein, fat, fiber, carbohydrates and minerals (phosphorus, iron and zinc) content of the raw whole tef, chickpea and semolina were analyzed according to AOAC (2010) protocols.

3.4.2.1. Moisture

Moisture content was determined by heating a flour and pasta sample in an air oven (Model DHG-9123A, Sweden) by using AOAC (2010); the official method 925.10. Three gram of sample was weighed and placed in a moisture dish (M_1). The sample was dried at 130°C for 2 hour and cooled in the desiccator to room temperature until constant mass was attained. Then, the crucible with residue was weighed (M_3). The moisture content was determined using Equation 3.1.

$$\text{Moisture (\%)} = \frac{M2-M3}{\mathbf{M1}} * \mathbf{100} \qquad \text{(Equation 3.1)}$$

Where, M_1 = Weight of sample

M_2= Weight of crucible and sample

M_3= Weight of crucible and sample after oven drying

3.4.2.2. Ash

Ash content was determined by high temperature incineration in an electric muffle furnace according to the AOAC (2010) Method using official method 923.03. Three gram of sample was weighed (M_2) and placed in previously dried and weighed ash cup or porcelain crucible (M_2). The sample was dried at 105 ± 2°C for 2 hour in the air oven (Model DHG-9123A, Sweden) until the contents carbonized and turn to black. The crucible with sample were placed in a muffle furnace (Gallenkamp, Model FSL 340-0100, U.K.) set at 530°C and heated for overnight until its weight was stable. The crucible with its residue was cooled in desiccators and then weighed (M_3). The ash content was expressed as follows:-

$$\text{Ash}\ (\%) = \frac{M3-M2}{M1}*100 \qquad \text{(Equation 3.11)}$$

Where: M_1= Weight of sample

M_2= Weight of crucible

M_3= Weight of crucible and sample after ashing

3.4.2.3. Crude Protein

Crude protein was determined by the method of the AOAC (2001) using Kjeldahl method (Foss Kjeltec 8460, Sweden). Homogenous sample (0.3 g) were weighed into digestion tube. Two kjeltab Cu/3.5 (3.5 g K_2SO_4, 0.4 g $CuSO_4 \times 5H_2O$) and 15 ml of concentrated H_2SO_4 were added and the tube was gently shaken uniformly to wet the sample with the acid. The digestion tube contained rack with exhaust system was loaded on a pre heated digestion block for 45 min and heated to 420°C for an hour allowing digestion. All samples were digested until the solutions turned green and clear.

The distillation cycle was automatically started by using Kjeltec analyzer software 2.2 after sample was cooled. The digestion tube was placed in the distillation unit and closed safety door. Distilled water (80 ml), 30ml of receiver solution (2% boric acid) and 50 ml of 40 % NaOH were added to digestion tubes, respectively. Then, the steam valve of Kjeltec was opened automatically and distilled approximately for 4-7 minutes. The distillate was titrated with standardized 0.1 N HCl until grey end point was achieved. The percent total nitrogen and crude protein were calculated using Equation 3.12.

$$\% \text{ Nitrogen} = \frac{(\text{ml sample} - \text{ml blank}) \times N \times 14.007 \times 100}{\text{mg sample}} \qquad \text{(Equation 3.12)}$$

Where: N= Normality of titrant to 4 places of decimal

$$\% \text{ Recovery} = \frac{\% \text{ Nitrogen}}{21.09} * 100$$

Protein (%,w/w) = % Nitrogen * Conversion factor

3.4.2.4. Crude Fat

The fat content of the samples were measured by AOAC (2010) method by using Soxtec Extraction system (Foss Soxtec ™ 8000 Extraction unit, Sweden). Two gram of the sample was weighed (W_1) into each of the thimbles and then the mass of cooled cups were weighed (W_2). The thimbles with their sample were placed into Soxtec ™ 8000 Extraction system. A 50 ml of petroleum ether was added into each cup by using a dispenser. The extraction process was carried out for 20 min boiling, 30 min rinsing and 10 min recovery. Then the cups with their residue were removed from the Soxtec system and placed in drying oven at 105°C for 30 min. The cups were then cooled in desiccators for an hour. The mass of each cooled cup together with its fat contents were weighed (W_3). The crude fat was calculated by using the formula below (Equation 3.13):

$$\% \text{ Crude fat} = \frac{W3 - W2}{W1} \times 100 \qquad \text{(Equation 3.13)}$$

Where: W_1 = Weight of sample (g)

W_2 = Weight of extraction cup(g)

W_3= Weight of fat residue and extraction cup (g)

3.4.2.5. Crude Fiber

The crude fiber was determined according to AOAC (2010) method. Two gram of sample was weighed in each of crucible (W_1) and inserted with 600 ml beaker. A 200 ml of 1.25% sulfuric acid solution was added to each beaker and allowed to boil on crude fiber apparatus for 30 min by stirring periodically. After 30 min, 20 ml of 28% potassium hydroxide solution was added in to each beaker and again allowed to boil for another 30 min. During boiling the level was kept constant by addition of hot distilled water. The solution in each crucible was then filtered through funnel fitted with rubber stopper. During filtration the sample residue was washed with hot distilled water; with 1% sulphuric acid solution, hot distilled water, 1% sodium hydroxide solution and finally with acetone. Each of the crucibles with their contents was dried at 130^0C for 2 hour and cooled in desiccators and weighed (W_2). Then again they were ashed for 30 min at 550^0C in furnace and were cooled in desiccators. Finally the mass of each crucible was weighed (W_3). The crude fiber was calculated from Equation 3.14:

$$\text{Crude fiber (\%)} = \frac{W2-W3}{W1} * 100 \qquad \text{(Equation 3.14)}$$

Where: W1= Weight of sample

W2 = Weight of crucible and sample after drying

W3= Weight of crucible and sample after ashing

3.4.2.6. Total Carbohydrates

Carbohydrate content was determined by subtracting the sum of the percentages of moisture, ash, protein and lipid content from 100 (Pearson, 1976).

$$\text{Carbohydrate(\%)} = 100 - (\text{\% Moisture} + \text{\% Ash} + \text{\% crude protein} + \text{\% crude fat}) \quad \text{(Equation 3.15)}$$

3.4.2.7. Energy Calculation (kcal/100gm)

Energy was obtained based on the values of crude protein, crude fat and total carbohydrate which were multiplied with factors of 4, 9 and 4 respectively, i.e., was calculated in kilocalories per 100 g sample as reported by Tull (1996) and shown in Equation 3.16 below.

$$\text{Energy (kcal/100 g)} = (4* \%\text{Protein}) + (4*\%\text{CHO}) + (9*\%\text{Fat}) \quad \text{(Equation 3.16)}$$

3.4.3. Mineral content determination

Mineral analysis was determined as described in AOAC (2001) 968.08. Five gram of sample was weighed into crucible and dried in an oven (Model DHG-9123A, Sweden) at 105 ± 2°C and then placed into the muffle furnace (Gallenkamp, Model FSL 340-0100, U.K.) at 550 ± 20°C for 16 hour (overnight) to remove carbonaceous material. The ash was transferred into 250 ml beaker and moistened with distilled water. The crucible was washed with 5 ml of 12 M HCl and carefully transferred into the beaker which may be a vigorous reaction due to CO_2 formation. 12 M HCl was added drop-wise with agitation until all effervescence stopped and then evaporated in hot plate. 15 ml of 6 M HCl and 120 ml of distilled water was added into the beaker and gently boiled which maintained at boiling point until no more ash could be seen to dissolve. The aliquot was filtered on ash-free filter paper and collected the filtrate in a 250 ml volumetric flask. The beaker was washed with 5ml of hot 6M HCl and twice with boiling water and filtered and then made up to the mark with distilled water.

3.4.3.1. Phosphorus

Phosphorus amount was determined according to the method by AOAC (2010), protocol 968.08 using UV-Vis Spectrophotometer (Agilent Technologies, Cary 60 UV-Vis, Malaysia). Phosphorus stock solution (50ppm) was prepared by dissolving 0.2197 g dried KH_2PO_4 into 1 liter distilled water. The standards of concentrations 1, 2, 3, 4, 5 and 6 mg/ml as phosphorus were used. Ammonium molybdate (23 g) and 1.25 g ammonium metavanadate were dissolved into 400 ml and hot 300 ml of distilled water in two beakers, respectively. Concentrated HNO_3 (250 ml) were added into the above mixed solution and bring to 1 l with distilled water. Then, 5 ml of aliquot was taken from sample digested by dry ashing into 100ml volumetric flask and 10ml of ammonium molybdate and metavanadate solution were added to the sample and standards and make up with distilled water. The resulting solution was shaken for uniform mixing and waited for 30 minute to develop color. The absorbance of each sample and standard was determined with a UV-Vis Spectrophotometer at 460nm.

$$P(ppm) = \frac{C*V1*V2*mcf}{S*A} \quad \text{(Equation 3.17)}$$

Where: C = P concentration in sample digest read from the curve, ppm

V_1 = Volume of the digest (100ml)

V_2 = Volume of the dilution

S= Weight of the plant material calcinated in g.

A= Aliquot (5 ml)

mcf= moisture correction factor

3.4.3.2. Iron and Zinc

Iron and zinc contents were determined according to the method by AOAC (2001) using the official method Microwave plasma Atomic emission Spectrophotometry (MP AES, model 4210, Agilent Technologies, USA). Five ml of aliquot was taken from digested sample and diluted with 5 ml of distilled water. The sample was carefully filtered with micro filter (450μm). The solution was sprayed into Atomic emission spectrophotometer at 259.94 nm and 213.857nm to determine the concentration of iron and zinc respectively. The iron standards used were 0 ppm, 0.5 ppm, 1 ppm, 1.5 ppm, 2 ppm and 2.5 ppm. The calibration curve was prepared by plotting the emission values against the metal concentration in mg/100g for all of the above minerals.

$$\text{Metal content (mg/100g)} = \frac{A-B}{10W} *V \quad \text{(Equation 3.18)}$$

Where: W= Weight of sample in (g)

V = Volume of extract (ml)

A = Concentration of sample solution (μg/ml)

3.5. Determination of Antinutritional Factors

3.5.1. Phytate

Phytic acid analysis was determined by using Latta and Eskin method as modified by Vaintraub and Lapteva (1988). A series standard solution was prepared containing 0, 5, 10, 20, and 40 μg/g of phytic acid (analytical grade sodium phytate) in 0.2N HCl. Three ml of each standard was added into 15ml of centrifuge tubes and 3ml of 0.2N HCl were used as a blank. Two ml of Wade reagent was added to each test tube and the solution was mixed on a Vortex mixer for 15 sec. The mixtures were centrifuged for 10 min and the absorbance of the supernatant was read at 500 nm by using distilled water as a blank. A standard curve was developed from absorbance versus concentration graph and the slope and intercept were used for calculation.

About 0.5 mg of dried sample was extracted with 10 ml 0.2 N HCl for 1 hour at an ambient temperature and centrifuged at 3000 rpm for 30 min. The clear supernatant was used for phytate estimation. One ml of wade reagent was added to 3 ml of the supernatant sample solution and homogenize and centrifuged at 3000 rpm for 10min. The absorbance at 500 nm was measured using UV-Vis spectrophotometer (Agilent Technologies, Cary 60 UV-Vis, Malaysia). The phytate concentration was calculated from the difference between the absorbance of the blank (3 ml of 0.2N HCl + 2 ml of wade reagent) and that of assayed sample. The amount of phytic acid was calculated using phytic acid standard curve and result was expressed as phytic acid in μg/g fresh weight.

$$\text{Phytic acid } (\mu g/g) = \frac{[(As-Ab)-\text{Intercept}]*10}{\text{slope}*W*3} \quad \text{(Equation 3.19)}$$

Where: A_S=Absorbance of sample

A_b= Absorbance of blank

W= Weight of sample

3.5.2. Tannin

Tannin content was determined by the modified vanillin with HCl assay (Price *et al.,* 1978) method. One gram composite flour sample was weighed and then extracted with 10 ml of 1% HCl in methanol screw cap test tube and put on the mechanical shaker (model: IKA AS130.1, USA) for 24 hour at room temperature. The mixture was centrifuged for 5 min at 3000 rev/min and then 1 ml of supernatant was taken and mixed with 5 ml of vanillin - HCl reagent.

About 0.04 g of D-Catechin standard was weighed and dissolved in 100 ml of 1 % HCl in methanol. The standard stock solution 0.0, 0.2, 0.4, 0.6, 0.8 and 1ml of D-Catechin was taken and adjusted the volume to 1 ml with 1 % HCl in methanol and then 5 ml of vanillin - HCl reagent was added. After 20 min to complete the reaction, the absorbance of sample solution and the standard solution were measured at 500 nm by using UV-Vis Spectrophotometer (Agilent ,Cary 60 UV-Vis, Malaysia) . A standard curve has been constructed (Absorbance vs Catechin) and the linear portions of the curve were extrapolated to produce the standard curve.

The tannin content was calculated using Equation 3.20 described below:

$$\text{Tannin (mg/g)} = \frac{(As-Ab)-Intercept)}{Slope*d*w}*10 \qquad \text{(Equation 3.20)}$$

Where: A_s= Sample absorbance

A_b = Blank absorbance

d = Density of solution (0.791 g/ml)

W = Weight of sample in gram

3.6. Cooking quality determination

3.6.1. Cooking weight and Water Absorption Capacity

The cooked pasta weight increase was determined by comparing 12 g of the sample before and after cooking, using the optimum cooking time. The obtained weight in comparison with dry macaroni weight which converted into percentage(AACC 2000; 16–50).

$$\text{Water absorption capacity (\%)} = \frac{(\text{weight of cooked \& drained pasta} - \text{wt of raw pasta})}{\text{weight raw pasta}} * 100 \quad \text{(Equation 3.21)}$$

3.6.2. Cooking Loss

Ten gram of pasta sample was cooked in pan which contained 300 ml of boiling water on water bath for optimum cooking time. The sample were taken and pressed between two glass plate during optimum cooking time when non-gelatinized starch in the center were not be found. The cooking water was drained into beaker and 25 ml of the cooking water and the residue were pipetted out and evaporated to dryness in hot air oven at 105°C to determine the solids loss in the gruel and expressed as % cooking loss using method (AACC 2000; 16–50). Dry matter loss was calculated by the following expression:

$$\text{Cooking loss (DL)} = \frac{DM}{Wd} * 100 \qquad \text{(Equation 3.22)}$$

Where: DL= Dry matter loss (%)

DM = Dry matter after oven drying (g)

Wd = Dry weight of uncooked pasta (g)

3.7. Textural Analysis

Texture analysis was performed to analyze firmness and stickiness of the pasta samples using TA plus textural analyzer (LLOYD Instruments, UK 2007) by using AACC 1995 Approved Method 16–50 for pasta with modifications. 10 gram of pasta sample was taken and cooked in 200 ml of distilled water for 10 minute at room temperature. Pasta firmness is defined as the work required to cut a defined amount of pasta. Three cooked pasta strands, at a time, were removed from the water and sheared within 4.5 mm distance from the base plate at a 90° angle using a specially designed aluminum shearing blade with a contact surface of 1 mm. The shear was performed at a cross head speed of 21 mm /min and a load cell of 5 kg. Aluminum shearing blade attached to LLOYDS texture analyzer for measurement of pasta firmness (Appendix Iv). The force (N) required to shear the macaroni was measured in triplicate and the average value was reported. A higher shear value indicates a firmer product.

Stickiness is defined as the maximum peak force to separate the probe from the sample's surface upon probe retraction (the higher the force value, the stickier is the sample). Similar procedures were followed to measure the stickiness of the macaroni except the shearing blade. The special plunger and sample holder were attached with textual analyzer for determining the cooked macaroni stickiness (Appendix v).

3.8. Sensory Evaluation

The sensory evaluation was carried out by twenty semi-trained judges of Food Science and Nutrition Department staff members and post graduate students from Hawassa University. Nine point Hedonic rating scale ranging (1=extremely dislike, 2 = dislike very much, 3= dislike slightly 4 = dislike, 5= neither like nor dislike, 6 = slightly like, 7= like, 8 = like very much and 9= Extremely like) was used for the sensory study. The panelists were asked to score for sensory attributes like color, appearance, flavor, taste, firmness, stickiness and overall acceptability.

3.9. Color Measurement

The color was measured by Digital imaging system includes the capturing, processing and analyzing images, facilitating the objective and nondestructive assessment of visual quality characteristics in food products (Timmermans, 1998). The L*a*b color space was used for determining macaroni colors because color of foods has been measured in L*a*b* color space which gives uniformity in color distribution and closeness to human perception (León *et al.*, 2006).

100 g of macaroni sample were arbitrarily measured and imaged. The light bulb contained chamber was prepared and placed the sample for imaging for purpose of avoiding light reflection in the space and for preventing from fluctuation in imaging. The images were captured by Camera (model: DSC-W610, 16 mega pixels). The camera was fixed parallel to and at a distance of 30 cm from samples. The captured images were cut into 250*250 pixel (Area = 62500 pixels) and saved under JMP format. These images were analyzed in RGB color space, we have to convert it to L*a*b* color spaces by using ImageJ 1.81r software. By aid of the ImageJ package referred to as "Color_Space_Converter".

The converted L*a*b* images were analyzed using ImageJ 1.81r software and the mean value and standard deviation of color intensity in the image pixels was obtained and saved in Microsoft Excel. The total color change, ΔE of the macaroni color from the reference is:

$$\Delta E = ((L_0-L)^2+(a_0-a)^2+(b_0-b)^2)^{1/2} \qquad \text{(Equation 3.23)}$$

Where: L_0, a_0& b_0= control sample

3.10. Statistical analysis

The effect of blending proportion of tef and chickpea with semolina were analyzed by Design expert®, version 7.0.1, Stat-Ease, Inc. (2021 East Hennepin Ave., Suite 480. Minneapolis, MN USA) using D-optimal mixture design. This helps to determine the product analysis on proximate composition, mineral content, cooking quality, textural analysis and sensory scores. A p-value below 0.05 was considered as significant.

Duncan's Multiple Range test (SPSS version 20.0 for Windows, SPSS Inc, Illinois, USA) was carried out to determine level of significance between means. All analyses were conducted in triplicate and the results were expressed as mean ± standard error.

3.11. Optimization of blend proportion

The optimum blend proportion and amounts of water were determined for main pasta quality parameters (nutritional composition, cooking and textural quality, sensory quality) from contour surface overlay plot. The optimum blend proportion were determined for nutritional composition of produced macaroni from contour surface plot, (protein, crude fiber and iron were evaluated or adjusted to be maximum, maximum and maximum respectively). The best composite flour proportion on the basis of cooking and textural property from contour overlay plot (i.e. cooking loss, firmness and stickiness) were considered to be minimum, maximum and minimum, respectively. With regard to sensory score and color value, color, overall acceptability and color change were examined to be maximum, maximum and maximum, respectively. The common optimum were determined from contour surface overlay plot, protein, crude fiber, cooking loss, firmness, stickiness, and overall acceptability. The optimum values for the factor selected are:-

$$Y = \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \beta_{12}X_1X2 + \beta_{13}X_1X_3 + \beta_{23}X_2X_3 + \beta_{123}X_1X_2X_3 \quad \text{(Equation 3.24)}$$

Where: Y-Response

β_{ij}-are regression coefficients

X_1- Semolina (%)

X_2- Tef (%)

X_3- Chickpea (%)

Chapter Four

4. Results and Discussion

In this study, macaroni from different blending ratio of tef, chickpea and semolina was formulated by using mixture response surface methodology (RSM). The proximate and mineral composition of the raw materials and formulated macaroni (protein, fat, carbohydrate, moisture, ash, crude fiber, Fe, Zn and P), functional properties of the composite flour (Wet gluten, WAC and WAI), cooking quality of the macaroni (cooking weight, WAC and cooking loss), macaroni textural analysis (firmness and stickiness) and sensory quality attributes (color, appearance, flavor and taste, firmness, stickiness and overall acceptability) were done. The percentage of semolina, tef and chickpea flours that can influence the chemical composition, textural analysis and cooking quality of macaroni were analyzed using D-optimal mixture design. The detailed results are reported and discussed as follows.

4.1. Proximate and mineral composition of raw materials.

4 .1.1. Proximate composition of the raw materials

Characterization of raw materials is the primary concern in predicting pasta quality. Accordingly, proximate composition of semolina extracted from the durum wheat and whole tef and chickpea flours are presented in Table 4.

Table 4. Proximate composition of semolina, tef and chickpea flours used to formulate macaroni

Raw materials	Composition (g/100g)					
	Moisture	Ash	Protein	Crude fat	Fiber	Carbohydrate
Durum wheat semolina	10.55 ± 0.04^{a}	0.84 ± 0.03^{c}	10.67 ± 0.11^{c}	0.58 ± 0.03^{c}	1.00 ± 0.01^{b}	77.36 ± 0.16^{a}
Chickpea flour	8.37 ± 0.03^{c}	2.94 ± 0.02^{a}	19.04 ± 0.22^{a}	7.66 ± 0.01^{a}	3.30 ± 0.10^{a}	60.99 ± 0.25^{c}
Tef flour	9.91 ± 0.02^{b}	2.36 ± 0.02^{b}	11.63 ± 0.12^{b}	2.67 ± 0.07^{b}	3.32 ± 0.04^{a}	73.46 ± 0.10^{b}

Values followed by different letters with in a column indicate significant difference ($p<0.05$). All values are means ± SE of triplicate analysis. All attributes are expressed on dry matter basis.

As shown in Table 4, there is a significant difference ($p<0.05$) in crude protein, crude ash, crude fat and total carbohydrate contents between semolina, tef and chickpea flours. Protein contributes significantly to texture and flavour of a food products; thus it gets priority in flour quality for pasta product formulation (Hager *et al.,* 2012). Among raw materials, chickpea flour had highest amount of protein followed by tef flour and lower amount in semolina flour (Table 4). The protein content in tef flour was within the range (8.8 to 11.7 g/100g) reported by Bultosa (2007) and Baye (2014). Similarly, the protein content in chickpea was also in the range (17.0–25.1 g/100g) reported by Jukanti *et al.*(2012). This data supports the idea of this study to enrich conventional pasta with chickpea as a means to improve protein content.

Similarly, carbohydrate composition of ingredients plays an important role in determining pasta quality. In this study, the carbohydrate contents of all raw materials varied significantly ($p < 0.05$) (Table 4). Semolina has the highest carbohydrate content followed by tef and chickpea flour respectively. This could be due to semolina extraction that removed the germ in the durum wheat and lowered the fiber content by removing the bran. This helps such lower carbohydrate in the flours selected for blending (tef and chickpea) with durum wheat semolina underlines their potential for decreasing glycemic response of the pasta to be obtained.

In contrast, semolina has lowest fat content than in tef and chickpea flours. Tef was whole milled and retained the lipid content in the germ, hence it has higher fat content than semolina. Among all the raw materials, semolina had the lowest ash content. The ash content of tef in this study is in agreement with the finding of Bultosa (2007) and Hager *et al.*(2012).

4.1.2. Mineral content of the raw materials

Iron, zinc and phosphorus contents of the three raw materials significantly ($p<0.05$) as reported in Table 5. Among which, tef has the highest iron amount, while semolina has the least. Also, tef flour contained the highest zinc and phosphorus contents followed by chickpea flour and semolina. Similar finding were reported by USDA National nutrient data base (2016) on the iron, zinc and phosphorus contents of matured tef grain and chickpea. This supports the hypothesis of this study to select tef as a substituent in fortifying conventional pasta products with essential nutrients.

Table 5. Mineral composition of semolina, chickpea and tef flours used to formulate macaroni

Raw materials	Mineral (mg/100g)		
	Iron	Zinc	Phosphorus
Durum wheat semolina	0.45 ± 0.09^c	1.00 ± 0.00^c	163.27 ± 0.03^c
Chickpea flour	1.80 ± 0.00^b	2.00 ± 0.00^b	192.85 ± 0.94^b
Tef flour	8.75 ± 0.38^a	2.83 ± 0.17^a	206.70 ± 1.27^a

Values followed by different letters with in a column indicate significant difference ($p<0.05$). All values are expressed as mean ± SE in triplicate

4.2. Functional properties of the composite flour

4.2.1. Water absorption index and Water absorption capacity

Water Absorption Capacity (WAC) represents the amount of water that can be absorbed per gram of composite flour sample. The Water Absorption Index (WAI) measures the amount of water absorbed by starch and can be used as an index of gelatinization (Anderson *et al.,* 1969). WAI depends on the availability of hydrophilic groups that bind water molecules.

The blending of durum wheat semolina with tef and chickpea flours significantly increased the WAI (from 1.91 to 2.42)g/g and WAC (88.91 to 172.05)% of the resulting composite flour values between for the 16 runs and raw materials (Table 6). This trend could be due to the higher WAI and WAC scores of tef flours (i.e. tef flour > chickpea flour>semolina) and (i.e. tef flour ≥ chickpea flour>semolina), respectively. The starch in tef flour has higher WAI due to its smaller granule size of starch, the larger the bulk surface area and the higher the water absorption than wheat (Bultossa *et al.,* 2007; Abebe *et al.,* 2015) can support this finding.

Accordingly, the highest WAC was obtained for the highest semolina substitution levels: 138.05% for Run-13 (60% semolina, 40% tef, 0% chickpea) and 130% for Run-6 (60.00% semolina, 25.11% tef, 14.89% chickpea) while the least WAC was obtained in control sample; 88.91% (Run 2-100% semolina)(Table 6). The highest WAI values (2.27 g/g) was found in Run-15 (60% semolina, 25.11% tef, 14.89% chickpea) while the lowest value (2.04 g/g) was obtained in the control sample-

Run 11 (100% semolina). Increasing the proportion of tef and chickpea flour had increased the water absorption index and water absorption capacity of composite flour. Water absorption results in swelling, which is a required factor in determining quality of pasta products. Hummel (1966) mentioned that good quality macaroni products should absorb at least twice their weight after boiling in water. Apparently, in this study also as the amount of water added in the processing of pasta varies with the amount of tef and chickpea flour.

4.2.2. Gluten

Wet gluten content in the composite flours significantly decreased ($p<0.05$) with increasing tef and chickpea flour levels (Table 6). This could be due the decreasing proportion of durum wheat semolina leading dilution of the gluten available in the composite flours. Also, the gluten free nature of both tef and chickpea flour accounted for decreased gluten in the composite. With this regard, the 100% semolina (Run 11) has highest gluten content (35.70%). Meanwhile, the lowest gluten levels were obtained for the highest semolina substitution levels: 14.88% for Run-5 (60%- semolina, 40%-tef and 0%-chickpea); 16.2% for Run-4 (60%- semolina, 32.58%-tef and 7.42%-chickpea) and 16.71% for Run-15 (60%- semolina, 25.11%-tef and 14.89%-chickpea).

Efrem *et al.* (2000) reported the wet gluten content of four durum wheat cultivars between the range (12.6 to 35.8)%. Similar with findings of the present study, Sabanis *et al.* (2006) indicated the increase in the incorporation level of chickpea in durum wheat semolina from 0% to 50% improved protein content and reduced wet gluten content from 35% to 15%. Furthermore, the incorporation of tef and chickpea flours in durum wheat semolina would induce structural changes in the produced macaroni. This is due to their high content of fibers and dilution of gluten proteins by albumins and globulins (Petitot *et al.*, 2010a,b). This will favor higher susceptibility of starch to digestive enzymes due to the disruption of the protein network entrapping starch granules (Tudorica *et al.*, 2002). This supports the idea of the study to enrich pasta with chickpea not only improve protein content but also increased digestibility of protein (Wesche-Ebeling *et al.*,2001).

Table 6. Functional properties and the amount of water added to each formulation of composite flour.

Run	WAC (%)	WAI (g/g)	Amount of water added (%)	Gluten (%)
1	111.91 ± 0.02^{f}	2.19 ± 0.02^{bc}	39.62 ± 0.27^{bc}	26.30 ± 0.48^{c}
2	88.910 ± 0.02^{h}	2.06 ± 0.03^{ef}	37.95 ± 0.21^{d}	34.41 ± 0.51^{a}
3	128.05 ± 0.04^{bcd}	2.12 ± 0.03^{de}	38.36 ± 0.51^{d}	22.20 ± 0.81^{d}
4	122.11 ± 0.04^{cde}	2.20 ± 0.02^{b}	39.76 ± 0.27^{bc}	16.20 ± 0.80^{g}
5	135.92 ± 0.02^{ab}	2.23 ± 0.01^{ab}	40.25 ± 0.14^{bc}	14.88 ± 0.16^{h}
6	130.00 ± 0.01^{abc}	2.23 ±0.02^{ab}	40.33 ± 0.24^{bc}	17.85 ± 0.69^{f}
7	115.02 ± 0.06^{ef}	2.18 ± 0.10^{bcd}	41.25 ± 0.64^{a}	28.75 ± 0.66^{b}
8	119.01 ± 0.03^{def}	2.18 ± 0.04^{bcd}	40.59 ± 0.10^{ab}	25.14 ± 0.23^{c}
9	118.65 ± 0.01^{def}	2.13 ± 0.01^{cde}	38.45 ± 0.12^{d}	25.62 ± 1.21^{c}
10	129.03 ± 0.01^{abc}	2.13 ± 0.01^{cde}	38.30 ± 0.04^{d}	20.89 ± 0.41^{e}
11	98.510 ± 0.04^{g}	2.04 ± 0.02^{f}	37.08 ± 0.18^{e}	35.70 ± 0.44^{a}
12	125.05 ± 0.03^{bcde}	2.11 ± 0.01^{e}	38.11 ± 0.18^{d}	21.34 ± 0.29^{de}
13	138.05 ± 0.02^{a}	2.23 ± 0.01^{ab}	40.30 ± 0.25^{bc}	15.86 ± 0.49^{gh}
14	117.98 ± 0.02^{ef}	2.11 ± 0.01^{e}	38.08 ± 0.07^{d}	30.11 ± 0.42^{b}
15	125.96 ± 0.03^{bcde}	2.27 ± 0.01^{a}	40.64 ± 0.21^{ab}	16.71 ± 0.35^{fg}
16	117.02 ± 0.03^{ef}	2.10 ± 0.02^{e}	37.93 ± 0.39^{d}	25.64 ± 0.61^{c}
Semolina	108.06 ± 0.02^{B}	1.91 ± 0.01^{C}		
Chickpea flour	172.05 ± 0.24^{A}	2.12 ± 0.04^{B}		
Tef flour	170.93 ± 0.05^{A}	2.42 ± 0.01^{A}		

Values followed by different letters with in a column indicate significant difference ($p<0.05$). Lower case letters show comparison between the Runs while the upper case letters show the comparison between the raw materials. All values are expressed as mean ± SE in triplicate; WAC: Water absorption capacity, WAI: Water absorption index

4.3. Proximate and mineral composition of macaroni

4.3.1. Moisture content

Moisture content of the food item is an indicator of product storability (shelf life). Composite flour or macaroni with high moisture content favors the growth of mold and insects, which can cause safety and quality deterioration during storage. Hence, macaroni with low moisture content is more stable during storage.

The moisture content of formulated macaroni ranged from 9.64 - 10.43% (Table 7). The lowest and highest moisture content was observed with Run-9 (85%-semolina, 0%-tef and 15%-chickpea) and Run-13 (60%-semolina, 40%-tef and 0%-chickpea), respectively. This could be due to higher water absorption capacity of tef and chickpea flour (Table 6) (Farooq & boye, 2011; Abebe *et al.,* 2015).

The moisture content from D-optimal design indicated that the quadratic model is significant ($P< 0.01$), $R^2 = 0.9905$ and did not present significant lack of fit ($p > 0.05$). The countour graph and reponse surface plot in Figures 5a and 5b indicated that an increase in the amount of moisture contents in the macaroni enriched with tef and chickpea flour. The following model was developed to predict the moisture content of the product for varying mixing ratio.

$$M = 9.86S + 10.41T + 10.02C - 0.013ST - 1.11SC - 0.12TC \qquad \text{(Equation 4.1)}$$

Where, M : Moisture (%);

S: Durum wheat semolina proportion (%);

T: Tef flour proportion (%), and

C: Chickpea flour proportion (%).

The positive (+) sign shows that moisture increases with the increase of the independent variables (semolina, tef and chickpea) and while the negative (–) sign indicates that the response value decreases with increase of the variables and whether they are linear and binary combinations. The binary interactions are significant models to predict the parameter of macaroni.

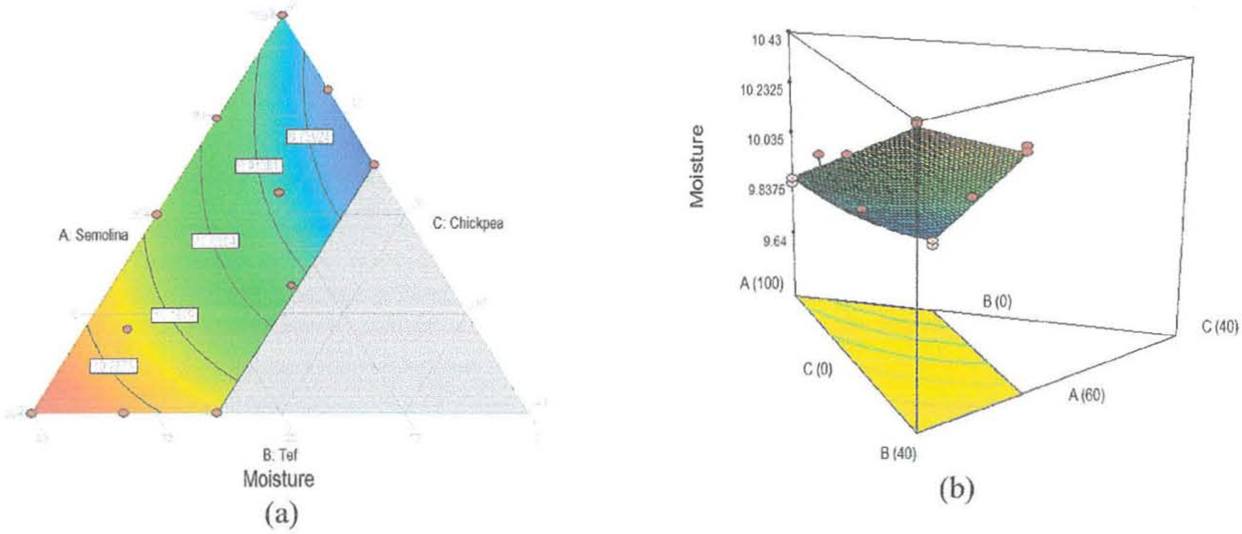


Figure 5: Impacts of tef and chickpea blending with durum wheat semolina on moisture content of macaroni (a) Contour graph and (b) Response surface (3D)

Table 7. Proximate composition of uncooked macaroni samples from 16 runs

Run	Moisture (%)	Ash (g/100g)	Crude protein (g/100g)	Crude fat (g/100g)	Crude fiber (g/100g)	Carbohydrate (g/100g)	Energy (kcal)
1	10.14 ± 0.02^{c}	1.25 ± 0.01^{fg}	12.83 ± 0.06^{fg}	0.90 ± 0.07^{g}	1.44 ± 0.03^{d}	75.88 ± 0.06^{bc}	358.95 ± 0.37^{fg}
2	9.86 ± 0.04^{f}	0.96 ± 0.01^{j}	11.17 ± 0.06^{h}	0.51 ± 0.01^{i}	0.98 ± 0.01^{g}	76.60 ± 0.18^{a}	357.28 ± 0.21^{h}
3	9.96 ± 0.01^{e}	1.60 ± 0.02^{b}	14.10 ± 0.13^{bc}	1.75 ± 0.03^{b}	1.62 ± 0.02^{c}	73.6 ± 0.13^{g}	362.55 ± 0.17^{c}
4	10.28 ± 0.02^{b}	1.56 ± 0.02^{bc}	13.01 ± 0.07^{efg}	1.42 ± 0.05^{cd}	1.98 ± 0.03^{ab}	74.74 ± 0.11^{ef}	359.76 ± 0.23^{f}
5	10.42 ± 0.03^{a}	1.47 ± 0.03^{de}	12.32 ± 0.13^{gh}	1.01 ± 0.02^{fg}	2.12 ± 0.04^{a}	75.91 ± 0.23^{bc}	359.52 ± 0.05^{fg}
6	10.26 ± 0.02^{b}	1.78 ± 0.03^{a}	13.90 ± 0.14^{cd}	1.79 ± 0.02^{b}	1.98 ± 0.03^{ab}	73.28 ± 0.14^{g}	360.79 ± 0.18^{e}
7	9.76 ± 0.02^{g}	1.21 ± 0.01^{hi}	13.25 ± 0.19^{def}	1.16 ± 0.09^{ef}	1.28 ± 0.03^{e}	74.62 ± 0.25^{f}	361.89 ± 0.49^{cd}
8	10.12 ± 0.03^{c}	1.28 ± 0.01^{f}	13.19 ± 0.21^{ef}	0.87 ± 0.02^{g}	1.36 ± 0.03^{de}	75.54 ± 0.25^{cd}	358.78 ± 0.04^{g}
9	9.64 ± 0.02^{h}	1.42 ± 0.03^{de}	14.84 ± 0.08^{a}	1.54 ± 0.07^{c}	1.37 ± 0.02^{de}	73.55 ± 0.10^{g}	363.45 ± 0.46^{b}
10	10.23 ± 0.02^{b}	1.50 ± 0.02^{cd}	13.14 ± 0.04^{ef}	1.19 ± 0.06^{e}	1.44 ± 0.02^{d}	74.95 ± 0.09^{ef}	357.04 ± 0.29^{h}
11	9.84 ± 0.03^{f}	0.98 ± 0.01^{j}	11.11 ± 0.06^{h}	0.62 ± 0.01^{hi}	1.05 ± 0.03^{g}	76.09 ± 0.27^{b}	359.82 ± 0.17^{f}
12	9.89 ± 0.02^{ef}	1.31 ± 0.01^{f}	13.75 ± 0.08^{d}	1.28 ± 0.08^{de}	1.64 ± 0.03^{c}	74.77 ± 0.14^{ef}	361.62 ± 0.50^{d}
13	10.43 ± 0.02^{a}	1.55 ± 0.04^{bc}	12.71 ± 0.02^{g}	1.14 ± 0.02^{ef}	2.17 ± 0.03^{a}	75.17 ± 0.03^{de}	357.78 ± 0.19^{h}
14	10.05 ± 0.02^{d}	1.17 ± 0.02^{i}	13.24 ± 0.05^{e}	0.72 ± 0.02^{h}	1.12 ± 0.02^{f}	75.82 ± 0.07^{bc}	358.75 ± 0.11^{g}
15	10.24 ± 0.03^{b}	1.74 ± 0.02^{a}	13.72 ± 0.03^{d}	2.12 ± 0.05^{a}	2.07 ± 0.02^{a}	73.18 ± 0.04^{g}	362.71 ± 0.39^{bc}
16	9.66 ± 0.02^{h}	1.38 ± 0.02^{e}	14.37 ± 0.08^{b}	2.02 ± 0.04^{a}	1.43 ± 0.01^{d}	73.57 ± 0.14^{g}	365.99 ± 0.12^{a}

Mean values in the same column followed by different superscript letters differ significantly based on Duncan's multiple range test ($p<0.05$. Values are expressed as mean ± SE (n=3)

4.3.2. Crude Ash

The ash content varied between (0.96-1.78) g/100g (Table 7), the highest being in the greatest semolina replacement level: 1.78 g/100g for Run-15 (60.00%-semolina, 25.11%-tef, 14.89%-chickpea) and the lowest in the control sample- Run 2 (100% semolina). Chickpea and tef flour had high ash contents (2.94 and 2.33) g/100g, respectively (Table 4). Thus, ash content significantly increased ($P<0.05$) upon blending semolina with the two flours. Higher ash content in semolina or flour indirectly reveals the presence of higher amount of bran and mineral (NAEGA, 2004). High ash in flour can affect color, imparting a darker color to pasta products. Similarly, Sabanis *et al.*(2006) and Padalino *et al.*(2014) reported increased amount ash content in the spaghetti through the addition of chickpea. Also, the ash content of tef based pasta doubled as high as when compared with oat and wheat based pasta (Hager *et al.*, 2012).

The ash content from D-optimal design indicated that all linear terms of blending ratio showed highly significant ($P< 0.01$) effect on the ash content of the macaroni while the selected model had insignificant lack-of-fit test ($p > 0.05$). Final equation for ash of macaroni is

$$Ash = 0.99S + 1.52T + 2.12\,C \qquad \text{(Equation 4.2)}$$

All the blending components significantly increased the total ash contents. The formula predicted high ash content (1.78 g/100g) was obtained with the macaroni made from lowest level of durum wheat semolina (60%) and highest level of chickpea (14.89%) and tef (25.11%). Since chickpea and tef flour had high ash contents 2.94 g/100g and 2.33 g/100g, respectively (Table 4).

4.3.3. Crude Protein

Protein content in semolina is a key factor for many processing properties such as water absorption and gluten strength during wheat and flour processing. The mean protein content of the macaroni ranged from 11.11- 14.84 g/100g (Table 7). The lowest protein content was obtained in 100% semolina sample (Run 11) while the highest protein levels was obtained at the maximum chickpea replacement levels: 14.84 g/100g for Run-9 (85%- semolina, 0%-tef and 15%-chickpea). All the macaroni formulations had higher protein content than the 100%

semolina macaroni. This is because of high amount of protein in chickpea and tef flour compared to durum wheat semolina (Table 4). Therefore, increased proportion of chickpea and tef in the composite flour improved the protein content of the macaroni significantly ($p<0.05$) (Table 7). Sabanis *et al.*(2006) and Padalino *et al.*(2014) reported also similar finding upon enrichment of durum wheat semolina with chickpea flour. Addition of soy improved both quality and quantity of protein in pasta (Taha *et al.,* 1992). Let alone the leguminous supplements, higher crude protein content of tef pasta than oat and wheat based pasta was reported by Hager *et al.*(2012). The reports from this and previous studies strongly supported our objective of improving protein content of pasta products using legumes.

The crude protein exhibit all quadratic model of blending ratio showed significant ($p< 0.01$) effect on the protein content of the macaroni and the selected model did not present significant lack of fit test ($p > 0.05$) and $R^2 = 0.9721$which demonstrating the adequacy of the model. The fitted model for protein value is shown as Equation 4.3 indicating quadratic effects with all three variables. The following model was developed to predict the protein content.

$$\text{Protein} = 11.21S + 12.68T + 17.16C + 3.76ST + 4.84SC - 2.83TC \quad \text{(Equation 4.3)}$$

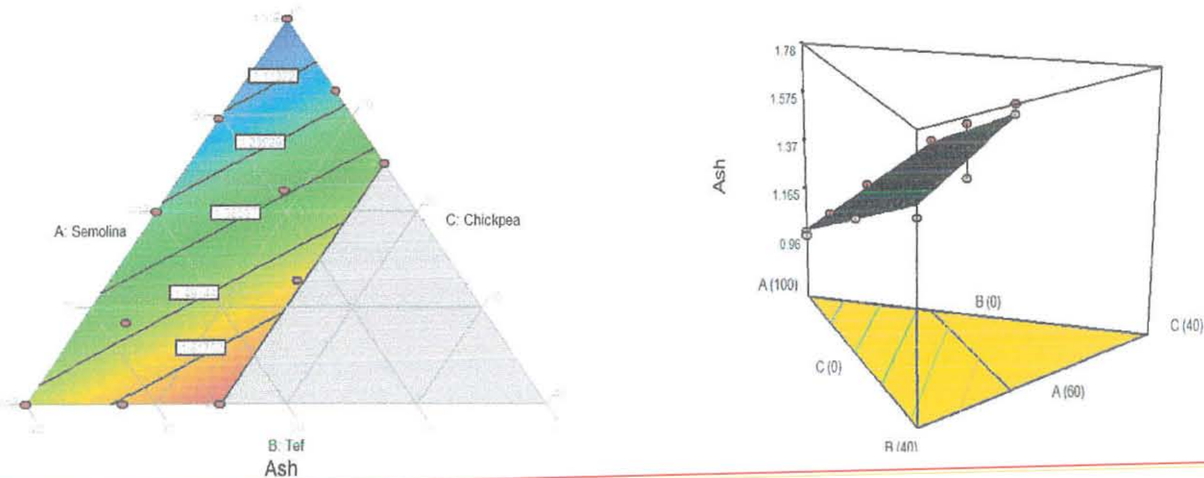
4.3.4. Crude Fat

The fat content of the formulated macaroni varied significantly ($p< 0.05$) from 0.51 - 2.12 g/100g (Table 7) depending on the blending proportion. Control macaroni (Run 2-100% semolina) had the lowest fat content; while highest fat content was observed on macaroni obtained from a blend with maximum chickpea and lowest semolina substitution: in Run-15 (60.00% semolina, 25.11% tef, 14.89% chickpea). This could be due to significantly higher fat content in chickpea and tef flours than semolina (Table 4). Similarly, Flores-Silva *et al.*(2014) and Padalino *et al.*(2014) reported high fat content in pasta formulated with increased levels of chickpea.

The obtained crude fat data from mixture deign which indicates that the linear model is significant ($p<0.01$), and no lack of fit was obtained ($p> 0.05$). Final equation for fat is

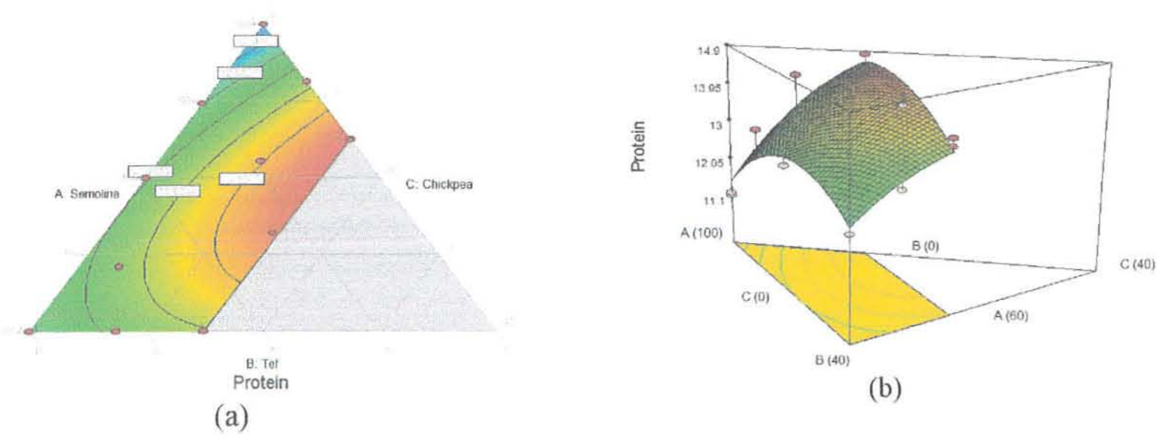
$$\text{Fat} = 0.6S + 1.07T + 3.40C \quad \text{(Equation 4.4)}$$

Similarly the contour and response surface plot Figure 8a & 8b below show that macaroni prepared from composite flours containing chickpea and tef have high content of fat than control samples. The constant value in Equation 4.4 clearly indicate that increase in the proportion of chickpea flour produced higher fat in resulting macaroni than tef flour and this could be due to the fat level in the flours (Table 4).



(a) (b)

Figure 6: Impacts of tef and chickpea blending with durum wheat semolina on ash content of macaroni (a) Contour graph and (b) Response surface (3D)



(a) (b)

Figure 7: Impacts of tef and chickpea blending with durum wheat semolina on protein content of macaroni (a) Contour graph and (b) Response surface (3D)

4.3.5. Carbohydrate

The mean carbohydrate content of the macaroni samples varied between (73.18 -76.60) g/100g. The highest carbohydrate content was found in control samples (Run 2), while the lowest carbohydrate levels were observed from maximum chickpea replacement levels: Run-9 (85%-semolina, 0%-tef and 15%-chickpea) (Table 7). The amount of carbohydrate in the formulated macaroni decreased when the proportion of tef and chickpea in composite flour increased. The reason for such trend could be the low level of carbohydrate in the chickpea flour followed by tef flour as compared to the durum wheat semolina (Table 4). In fact, the carbohydrate content of all the formulations significantly varied ($p<0.05$) compared with semolina based pasta. This is due to higher carbohydrate composition of semolina than tef and chickpea flours. This result corroborates the report by Osorio-díaz *et al.*(2008) where addition of chickpea flour resulted in macaroni with reduced total starch values compared to durum wheat semolina pasta. This lowering carbohydrate in the composite flours selected for blending (tef and chickpea) with durum wheat semolina emphasize decreasing glycemic response of the pasta to be obtained.

The carbohydrate level analysis by D-optimal design showed that the linear model is highly significant ($p< 0.01$), and no lack of fit was obtained ($p > 0.05$). The following model was developed to predict the carbohydrate content of macaroni.

$$\text{Carbohydrate} = 76.13S + 75.54T + 69.44C \qquad \text{(Equation 4.5)}$$

As depicted in the contour and response surface plots (Figure 9a and 9b) macaroni prepared from composite flours containing high semolina had higher carbohydrate content. Equation 4.5 also implies that the contribution carbohydrate in the macaroni samples was more from the semolina than tef flour which in turn had better contribution than the chickpea flour.

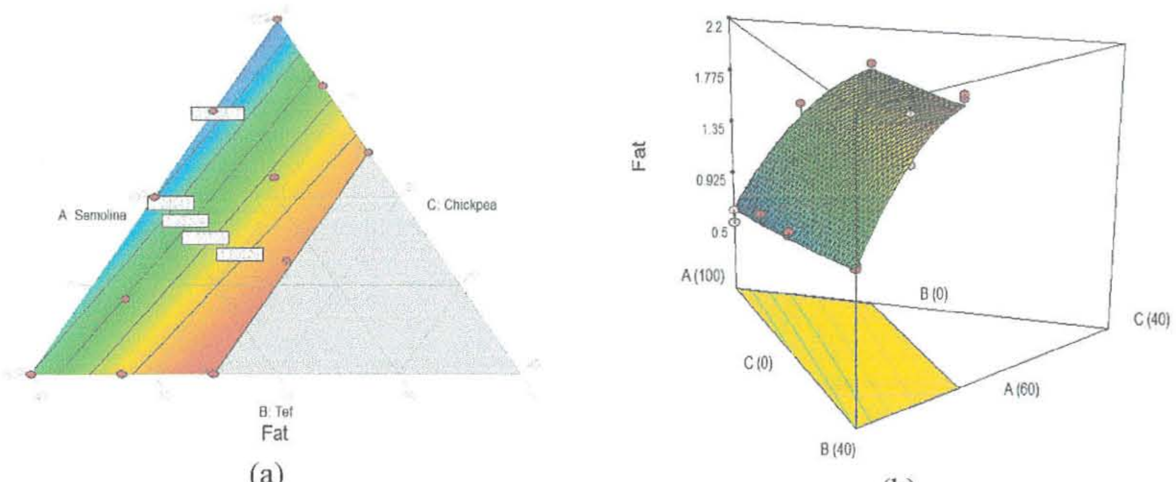
4.3.6. Crude fiber

The fiber content of macaroni was also significantly ($P<0.05$) influenced with the incorporation level of tef and chickpea flours (Table 7). The crude fiber content of the macaroni formulations was between (0.98 to 2.17)g/100g. Run-13 (60%-semolina, 40%-tef and 0%-chickpea) and Run

2 (100% semolina) had the highest and lowest crude fiber amount respectively. Blending ratio had positively influenced on the fiber content of macaroni. Supplementation of the control macaroni with chickpea and tef fiber significantly increased the fiber content of the formulated macaroni. This is due to the fiber content of tef (2.6-3.8 g/100g), which is higher compared with wheat, sorghum, rice and maize (Bultosa, 2007; Kaleab, 2014) due to its small size and whole milled flour. Jayasena and Nasar-Abbas (2011) reported that total dietary fiber in pasta enriched with 50 g/100g lupin kernel fiber increased from 1.5 to 15%. The reports from this and previous studies strongly supported our objective of improving fiber content of pasta products using legumes.

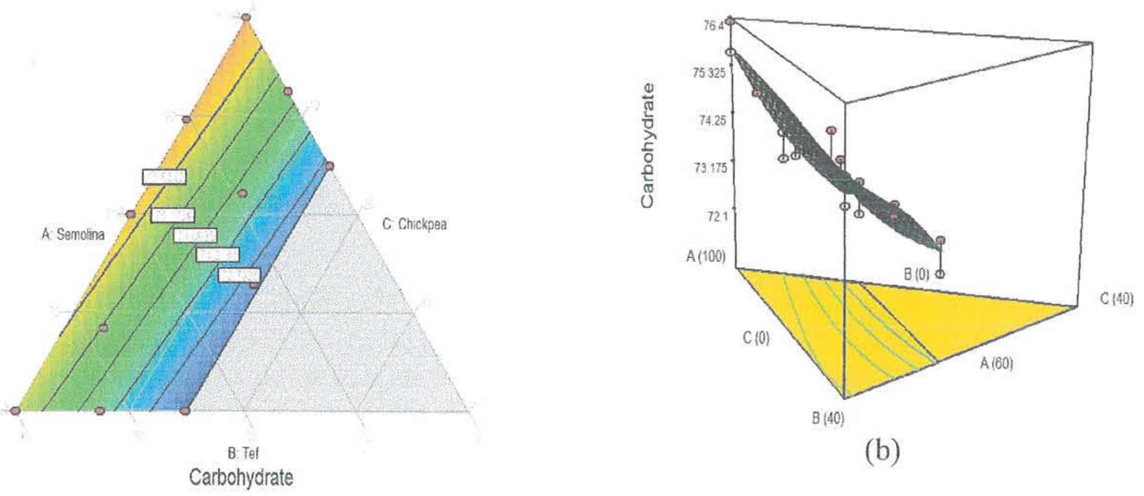
$$\text{Crude fiber} = 1.03S + 6.50T + 1.85C - 4.70ST + 2.41SC - 1.22TC \quad \text{(Equation 4.6)}$$

The coefficients are estimates of the effects. In this finding, the result indicates that addition of more tef and chickpea flour but less semolina proportion will predict higher fiber content. Appendix-VI shows that R^2 value of 0.8853 was in reasonable agreement with the predicted R^2 0.8326. Values of "Prob>F" less than 0.05 indicate quadratic model terms are significant.



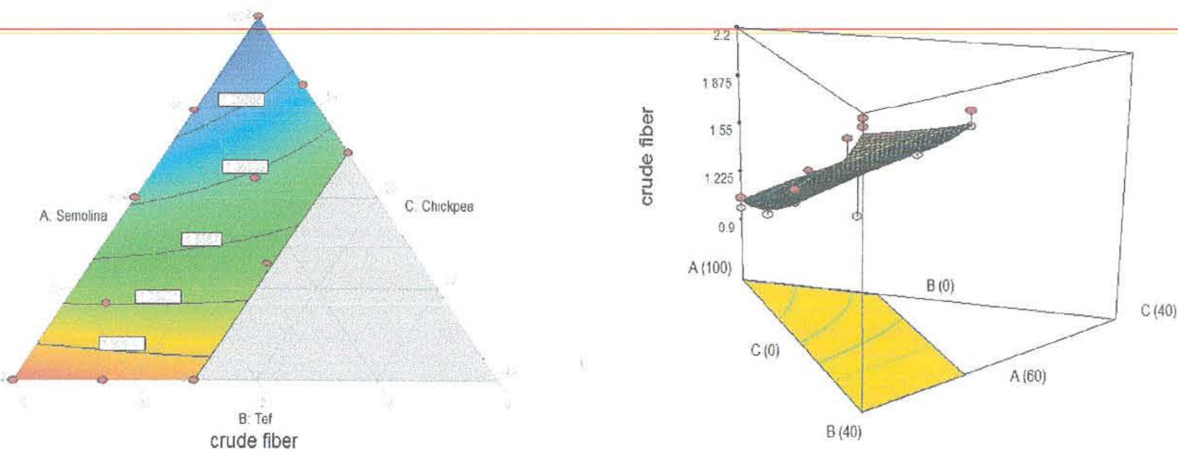
(a) (b)

Figure 8: Impacts of tef and chickpea blending with durum wheat semolina on fat content of macaroni (a) Contour graph and (b) Response surface (3D)



(a)

Figure 9: Impacts of tef and chickpea blending with durum wheat semolina on carbohydrate content of macaroni (a) Contour graph and (b) Response surface (3D)



(a)

(b)

Figure 10: Impacts of tef and chickpea blending with durum wheat semolina on crude fiber content of macaroni (a) Contour graph and (b) Response surface (3D)

4.3.7. Energy

Blending ratio had a significant ($p < 0.05$) effect on the gross energy content of the macaroni (Table 7). The energy of the blended macaroni ranged between (357.28 -365.99) kcal. The lowest energy value was obtained in 100% semolina sample (Run2) while the highest energy value was obtained at the maximum chickpea replacement levels: 366 kcal for Run-9 (85%- semolina, 0%-tef and 15%-chickpea). All the macaroni formulations had higher energy value than the 100% semolina macaroni. This is due to a fortification of the control macaroni with chickpea and tef fiber significantly increased the protein and fat content of the formulated macaroni.

Figure 11a and 11b show the contour graph and response surface of gross energy content. The trend of energy level of macaroni were significantly ($p < 0.05$) influenced by blending proportion (semolina, tef and chickpea) where formulation containing higher chickpea content in combination with lower amounts of tef yield high gross energy content. Analysis of variance (ANOVA) indicated a quadratic model with the lack of fit being not significant($p > 0.05$). The fitted model for gross energy amount is shown in Equation.

$$\text{Gross energy} = 355.03S + 362.53T + 376.61C + 13.66ST + 18.72SC - 9.81TC$$

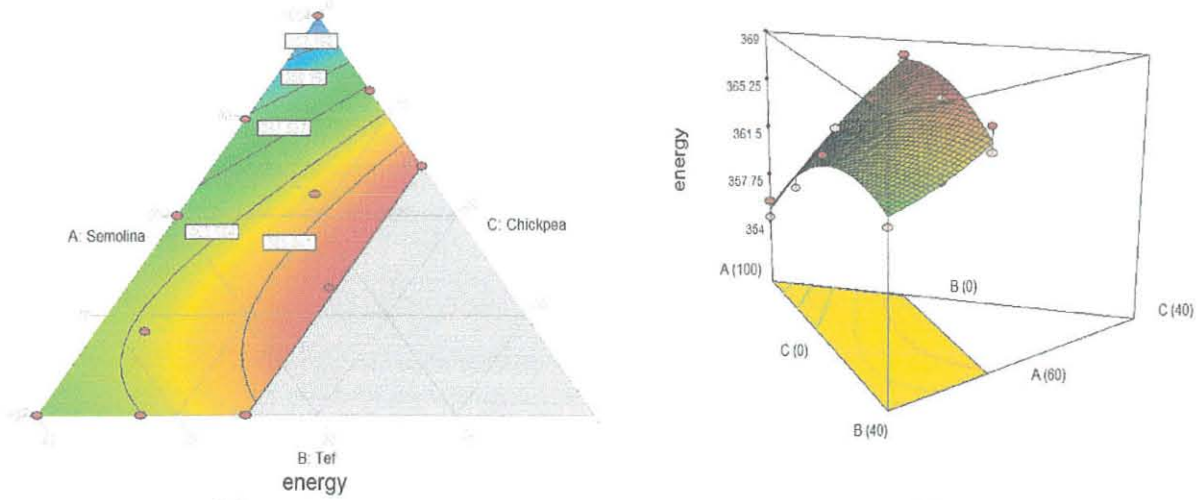


Figure 11: Impacts of tef and chickpea blending with durum wheat semolina on gross energy level of macaroni (a) Contour graph and (b) Response surface (3D)

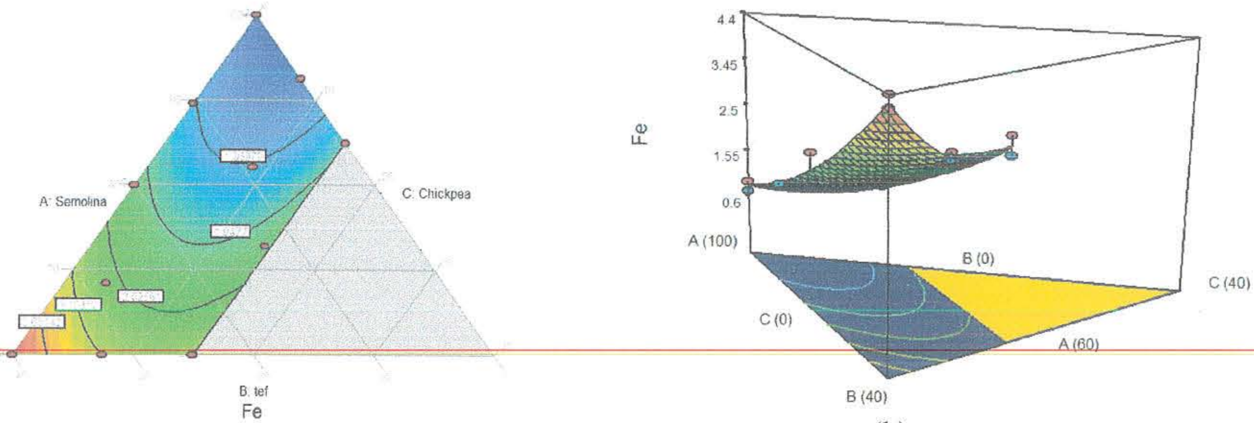
4.4. Mineral content of macaroni

All the blending proportions significantly (P< 0.05) varied the total iron, zinc and phosphorus levels in the macaroni (Table 8). The highest iron, zinc and phosphorus content was obtained for the macaroni with the maximum tef proportion which scored: 4.4 mg/100g, 1.75 mg/100g and 188.13 mg/100g for Run-13 (60%-semolina, 40%-tef and 0%-chickpea), respectively. Meanwhile 100% semolina (Run-11) based macaroni had the lowest iron zinc and phosphorus content 0.7 mg/100g, 1.05 mg/100g and 158.51 mg/100g, respectively. This finding agrees with the earlier result obtained by Hager *et al.* (2012) in which pasta formulated from tef flour scored significantly higher mineral content than wheat and oat pasta. This could be due to the availability of high mineral content in tef flour than the wheat flour (Abebe *et al.*, 2015).

Macaroni iron content trends analyzed using D-optimal mixture response surface application indicated that the quadratic model was highly significant (p< 0.01), and insignificant lack of fit (p>0.05). The obtained zinc and phosphorus data from D-optimal Mixture application showed that the linear model is significant (P < 0.01), and no lack of fit was obtained (p > 0.05). The countor and response surface plots (Figures 11a and 11b-for iron, Figures 12a and 12b-for zinc and Figures 13a and 13b-for phosphorus) show the trend that the level of these minerals in the macaroni increased with the increasing mix proportion of the tef and chickpea flour. The model developed that predict the macaroni iron, zinc and phosphorus for varying durum wheat semolina-tef flour-chickpea flour mix level is depicted in Equations below, respectively.

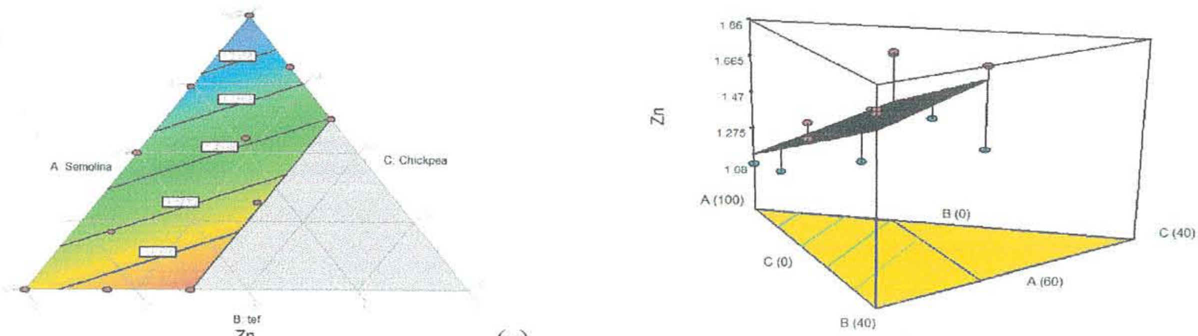
$$Iron = 0.85S + 8.63T + 4.21C - 1.55ST - 9.61SC - 11.98TC \quad \text{(Equation 4.7)}$$

$$Zinc = 1.14S + 1.66T + 2.03C \quad \text{(Equation 4.8)}$$



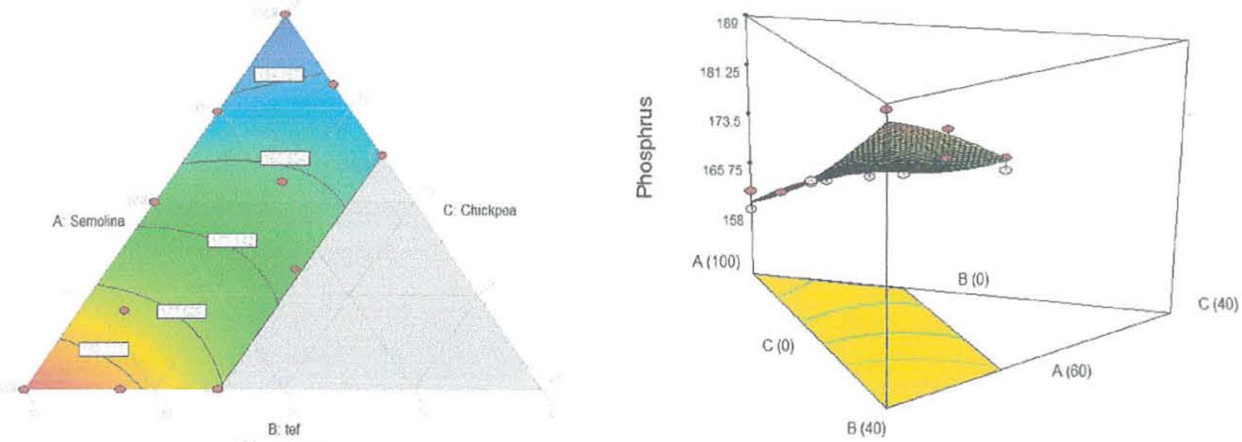
(a) (b)

Figure 12: Impacts of tef and chickpea blending with durum wheat semolina on iron content of macaroni (a) Contour graph and (b) Response surface (3D)



(a) (b)

Figure 13: Impacts of tef and chickpea blending with durum wheat semolina on zinc content of macaroni (a) Contour graph and (b) Response surface (3D)



(a)

(b)

Figure 14: Impacts of tef and chickpea blending with durum wheat semolina on phosphorus content of macaroni (a) Contour graph and (b) Response surface (3D)

Phosphorus = 159.68S + 186.60T + 148.76C - 7.21ST + 46.93TC + 23.47TC (Equation 4.9)

4.5. Tannin and phytate content

The tannin and phytate content of macaroni were below detection limit. The reason for this might be occurrence of complete tannin and phytate reduction and formation of insoluble complexes due to thermal degradation and denaturation during macaroni extrusion and drying processes (Kataria *et al.*, 1989).

Table 8. Mineral composition of the formulated macaroni

Run	Iron (mg/100g)	Zinc (mg/100g)	Phosphorus (mg/100g)
1	2.47 ± 0.26^{c}	1.42 ± 0.08^{def}	171.10 ± 0.26^{cde}
2	0.90 ± 0.06^{g}	1.08 ± 0.08^{g}	161.48 ± 0.22^{f}
3	2.20 ± 0.23^{cd}	1.50 ± 0.00^{bcde}	173.38 ± 0.26^{c}
4	3.20 ± 0.06^{b}	1.75 ± 0.15^{ab}	183.90 ± 0.31^{ab}
5	4.40 ± 0.17^{a}	1.73 ± 0.10^{ab}	188.13 ± 0.28^{a}
6	3.27 ± 0.15^{b}	1.47 ± 0.09^{cde}	178.19 ± 0.22^{b}
7	1.07 ± 0.15^{cde}	1.27 ± 0.09^{efg}	164.09 ± 0.87^{def}
8	2.03 ± 0.12^{cde}	1.50 ± 0.00^{bcde}	170.72 ± 0.31^{cde}
9	1.35 ± 0.06^{ef}	1.72 ± 0.06^{abc}	166.08 ± 0.23^{de}
10	2.30 ± 0.17^{c}	1.65 ± 0.08^{abcd}	179.69 ± 0.12^{b}
11	0.70 ± 0.06^{g}	1.08 ± 0.08^{g}	158.51 ± 0.11^{f}
12	1.47 ± 0.15^{f}	1.22 ± 0.06^{fg}	168.48 ± 0.28^{d}
13	4.17 ± 0.09^{a}	1.75 ± 0.09^{ab}	184.77 ± 0.29^{a}
14	3.17 ± 0.21^{b}	1.15 ± 0.06^{g}	165.46 ± 0.18^{de}
15	2.90 ± 0.06^{b}	1.86 ± 0.07^{a}	176.46 ± 0.04^{bc}
16	1.47 ± 0.03^{def}	1.73 ± 0.73^{ab}	167.11 ± 0.11^{d}

Values followed by different letters with in a column indicate significant difference based on Duncan's multiple range test ($p<0.05$). All values are expressed as mean ± SE in triplicate.

4.6. Cooking quality and textural analysis of Macaroni

4.6.1. Cooking weight

Increase in weight of the cooked macaroni is related with water absorption capacity. The cooking weight in the formulated macaroni significantly increased ($p<0.05$) with increased proportion of tef and chickpea flours incorporation level (Table 9). Evaluation of weight of cooked macaroni indicated that the highest macaroni weight was obtained for maximum semolina substitution levels: 347.67% with Run-10 (68.45%-semolina, 28.08%-tef and 3.49% chickpea flour) while the lowest was in control samples - 271.58% (Run 2 - 100% semolina). This is comparable with the ideal expected cooked weight of semolina spaghetti (i.e. three times the dry weight) (Dick and Youngs, 1988). This could be due to the higher water absorption capacity of tef and chickpea flours and the high level of fiber in them (Bultosa *et al.,* 2004 and Abebe *et al.,* 2015).

In general, pasta samples with light and dark buckwheat gained about three times their weight similar with amaranth and lupin containing samples (Rayas-duarte *et al.,* 1996). Our result is agreed with Rosa *et al.*(2015) who reported the weight gain ranged between 234-344%, with the highest gain for the pasta made from 100% buckwheat flour.

Figures 15a and 15b are the contour graph and response surface plot of cooking weight showing the trend was affected with blending levels. Analysis of variance (ANOVA) indicated a quadratic model with the lack of fit ($p > 0.05$) being not significant. The fitted model for cooking weight is shown in Equation 4.10.

$$\text{Cooking weight} = 32.45S + 37.42T + 38.58C + 6.23ST - 1.07SC + 4.30TC \quad \text{(Equation 4.10)}$$

4.6.2. Water Absorption Capacity

The mean water absorption capacity (WAC) of the formulated macaroni was between (166.53-215.07)% and significant difference ($p<0.05$) was observed due to blending (Table 9). The replacement of tef and chickpea increased in the formulations had shown relatively higher water absorption value while the control samples in the recipe had exhibited minimum water absorption value. Control macaroni (Run 2-100% semolina) was showed the lowest WAC (166.53%) while the highest semolina replacement level: Run-10 (68.44% semolina, 28.08% tef and 3.49% chickpea) had the highest WAC (215.07%). Thus, throughout the formulations as tef and chickpea proportions increased which increased WAC resulted. This could also be due tef flour's water absorption index as its starch has small granule size giving its larger surface area and the presence of high fiber in tef flour favoring water binding (Abebe *et al.,* 2015). In addition, higher WAC results in swelling along with the concentration of protein, starch and fiber. The inherent proteins in raw chickpea flour may also have played some role in the higher water absorption capacity (Esmat *et al.,* 2010).

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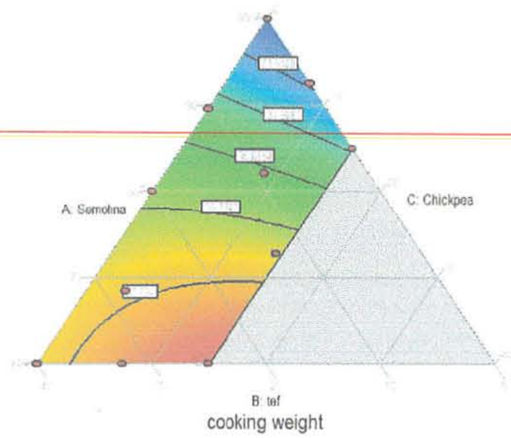
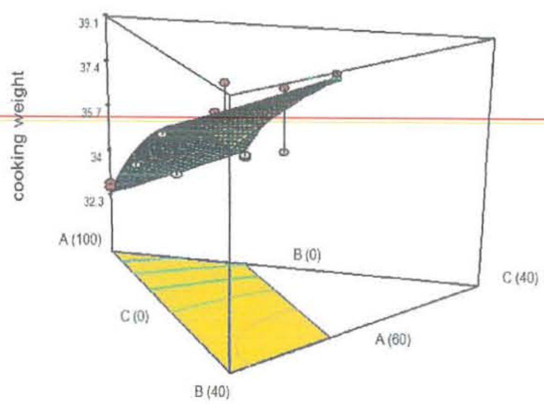
The WAC data from D-optimal mixture response surface application indicated that the quadratic model was significant ($p < 0.05$). The quadratic model showed a significant lack of fit ($p < 0.05$) which indicated that it was not a good indicator of the WAC and could not be used for the prediction. The countor plot and response surface graph below (Figure 16a & 16b) show the increase of WAC of the macaroni was mainly affected with the increase of tef flour proportion. The equation obtained that could predict the WAC of the macaroni depending on the incorporation level of tef and chickpea flours also confirms this (Equation 4.11).

$$WAC = 169.70S + 197.17T + 141.68C + 20.85ST + 203.43SC + 107.20TC \quad \text{(Equation 4.11)}$$

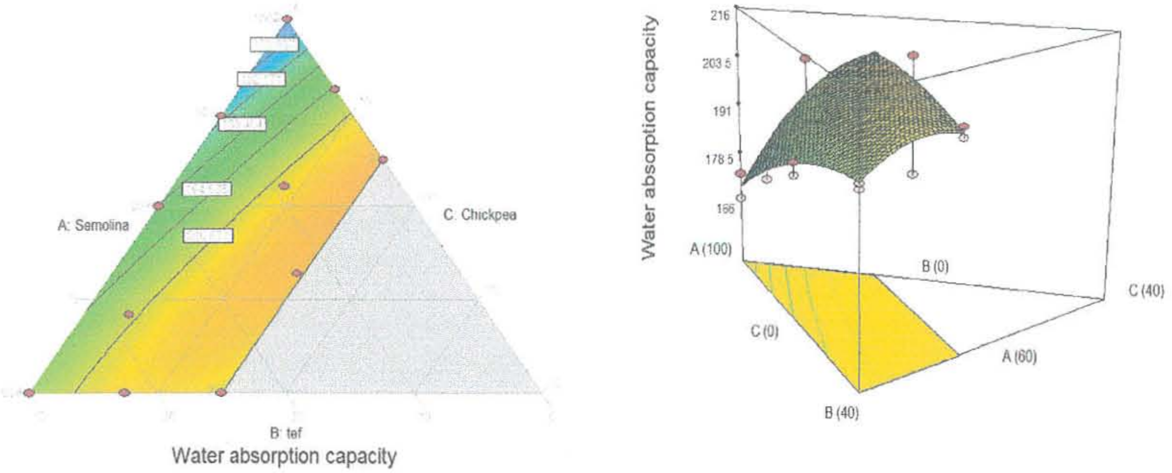


(a)



(b)

Figure 15: Effect of tef and chickpea blending with durum wheat semolina on cooking weight of cooked macaroni (a) Contour graph and (b) Response surface (3D)



(a) (b)

Figure 16: Effect of tef and chickpea blending with durum wheat semolina on WAC of cooked macaroni (a) Contour graph and (b) Response surface (3D)

4.6.3. Cooking loss

Measurement of cooking loss of pasta product is one of the important parameters in assessing overall quality (Mehran, 2006). The amount of residue in the cooking water is widely used as an indicator of cooked macaroni quality. Low amounts of residue indicate high pasta cooking quality. Cooking loss (%) is analyzed as weight of the total solids lost in the cooking water.

In this study, the cooking loss of the formulated macaroni varied from 1.47 to 4.03% (Table 9) and was significantly ($p<0.05$) influenced by the blend proportion. The lowest cooking loss was obtained in control macaroni samples: 1.47% (Run-2; 100%-semolina) and 1.62% (Run-7; 92.5%-semolina, 0%-tef and 7.5%-chickpea). Highest cooking loss of 4.03% was found from the maximum tef level formulation Run-5 (60%-semolina, 40%-tef and 0%-chickpea) and 3.66% for Run-4 (60%-semolina, 32.58%-tef and 7.42%-chickpea). Similarly, tef pasta exhibited higher cooking loss compared with wheat and oat pasta (Hager *et al.*, 2012). Also spaghetti with added buckwheat and bran had cooking loss values inferior to that of spaghetti made only of durum semolina. Yet, these cooking loss values can be acceptable with lower blending proportions (Chilo *et al.*, 2008b). Similarly, increased cooking loss was reported with increased chickpea replacement of semolina spaghetti formulation (Esmat *et al.*, 2010). When semolina was partially substituted with 5 to 25 % legumes (green pea, yellow pea, chickpea, and lentil), cooking loss increased (Zhao *et al.*, 2006; Esmat *et al.,* 2010 and Petitot *et al.,* 2010).

In this study, though all composite-flour macaroni formulations were with higher cooking loss values, still all the values are within acceptable range. In spaghetti made with semolina, cooking loss values not higher than 7 % are expected (Dick and Youngs, 1988). Thus, the composite flour samples in this study can be considered to have acceptable cooking loss levels. The cooking loss values of 8.1, 8.0 and 7.8, and 7.2% were reported in semolina spaghetti containing 30% for amaranth, dark buckwheat, lupin, and light buckwheat, respectively (Rayas-duarte *et al.,* 1996) and 7% cooking loss was obtained in (20%) protein dry bean isolate (Seyam *et al.,* 1983). The reason for such increase of the cooking loss upon the replacement of durum wheat semolina could be related to the dilution of the gluten which is unique to the durum wheat semolina that forms a gluten matrix and holds the starch in the pasta together. In addition, fibrous components in the tef flour could have interrupted and weakened the overall structure of the spaghetti. This may allow leaching of more solids from the spaghetti into the cooking water.

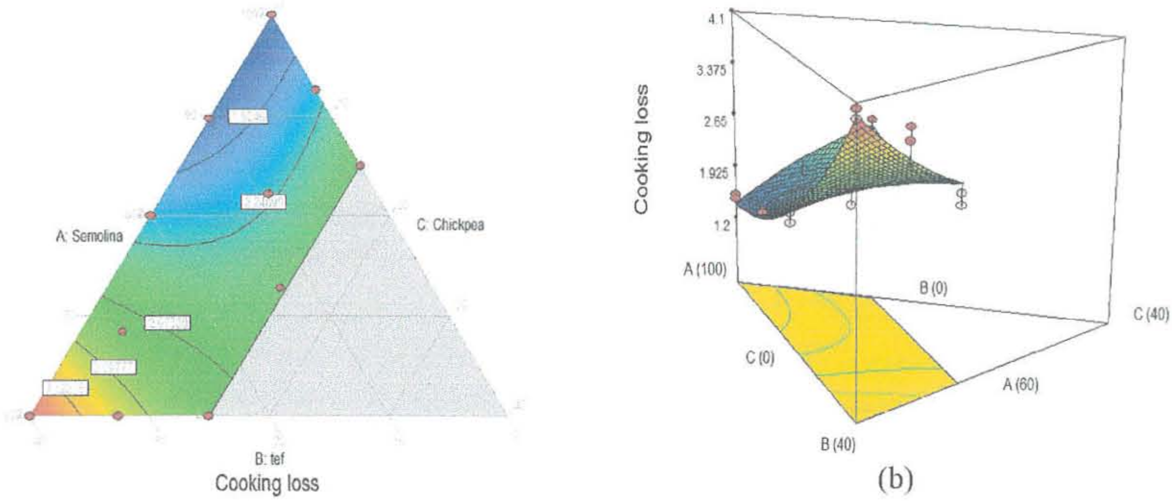
Figure 17a and 17b show the contour graph and response surface of cooking loss. The trend of cooking loss of macaroni were significantly ($p < 0.05$) influenced by blending proportion (semolina, tef and chickpea) where formulation containing higher tef content in combination with lower amounts of semolina and chickpea yield high cooking loss. Analysis of variance (ANOVA) indicated a quadratic model with the lack of fit being not significant($p > 0.05$). The fitted model for cooking loss is shown in Equation 4.12.

$$\text{Cooking loss} = 1.40S + 3.95T + 2.94C - 2.42ST + 2.97SC - 3.23TC \quad \text{(Equation 4.12)}$$

Table 9. Cooking, textural quality and color score of formulated macaroni

Run	Cooking weight (%)	WAC (%)	Cooking loss (%)	Firmness (N)	Stickiness (N)	Color
1	302.42 ± 0.88^{bcd}	188.83 ± 1.68^{fg}	1.91 ± 0.05^{f}	5.21 ± 0.01^{fg}	42.84 ± 0.04^{cde}	6.07 ± 0.04^{h}
2	271.58 ± 1.12^{d}	166.53 ± 3.07^{h}	1.47 ± 0.06^{g}	6.09 ± 0.08^{cd}	41.71 ± 0.23^{e}	10.66 ± 0.09^{c}
3	314.08 ± 1.91^{abc}	212.55 ± 4.65^{ab}	2.90 ± 0.02^{c}	5.96 ± 0.04^{d}	42.69 ± 0.18^{cde}	6.21 ± 0.05^{h}
4	307.75 ± 2.21^{abcd}	195.65 ± 1.55^{ef}	3.66 ± 0.01^{b}	4.80 ± 0.04^{i}	44.24 ± 0.15^{bc}	5.64 ± 0.04^{i}
5	314.33 ± 0.80^{abc}	196.88 ± 2.57^{de}	4.03 ± 0.18^{a}	4.42 ± 0.10^{j}	43.02 ± 0.20^{cde}	4.46 ± 0.08^{k}
6	315.08 ± 1.37^{abc}	200.60 ± 1.50^{cde}	2.8 ± 0.12^{cd}	5.29 ± 0.04^{efg}	43.64 ± 0.41^{cd}	7.56 ± 0.05^{f}
7	319.42 ± 1.80^{ab}	204.23 ± 2.26^{cd}	1.62 ± 0.02^{g}	6.62 ± 0.06^{b}	44.15 ± 0.46^{bc}	10.95 ± 0.04^{b}
8	299.92 ± 0.02^{bcd}	185.62 ± 1.29^{g}	2.05 ± 0.12^{f}	4.95 ± 0.03^{gh}	42.92 ± 0.29^{cde}	6.18 ± 0.04^{h}
9	301.50 ± 0.55^{bcd}	206.31 ± 1.86^{bc}	2.56 ± 0.06^{e}	7.03 ± 0.02^{a}	46.42 ± 0.18^{a}	11.10 ± 0.04^{ab}
10	347.67 ± 1.80^{a}	215.07 ± 1.81^{a}	2.51 ± 0.10^{e}	4.68 ± 0.05^{i}	45.36 ± 1.60^{ab}	5.13 ± 0.05^{j}
11	275.75 ± 0.28^{cd}	173.14 ± 2.77^{h}	1.53 ± 0.04^{g}	6.18 ± 0.04^{c}	42.59 ± 0.41^{cde}	10.66 ± 0.06^{c}
12	303.58 ± 1.29^{bcd}	189.01 ± 1.87^{fg}	2.47 ± 0.06^{e}	5.39 ± 0.05^{e}	42.28 ± 0.23^{de}	6.66 ± 0.05^{g}
13	321.00 ± 1.00^{ab}	195.61 ± 2.36^{de}	3.91 ± 0.02^{a}	4.36 ± 0.05^{j}	43.71 ± 0.25^{bcd}	4.23 ± 0.06^{k}
14	305.83 ± 0.50^{bc}	200.36 ± 1.55^{cde}	1.68 ± 0.01^{fg}	5.50 ± 0.06^{de}	41.95 ± 0.45^{de}	8.15 ± 0.08^{d}
15	327.92 ± 0.94^{ab}	203.12 ± 2.58^{cde}	2.53 ± 0.08^{e}	5.31 ± 0.04^{ef}	42.97 ± 0.04^{cde}	7.85 ± 0.05^{e}
16	296.25 ± 0.30^{bcd}	204.38 ± 3.05^{cd}	2.58 ± 0.11^{de}	6.85 ± 0.05^{a}	46.30 ± 0.95^{a}	11.29 ± 0.05^{a}

Values followed by different letters with in a column indicate significant difference based on Duncan multiple range test ($p<0.05$). All values are expressed mean ± SE in triplicate.WAC: Water Absorption Capacity



(a) (b)

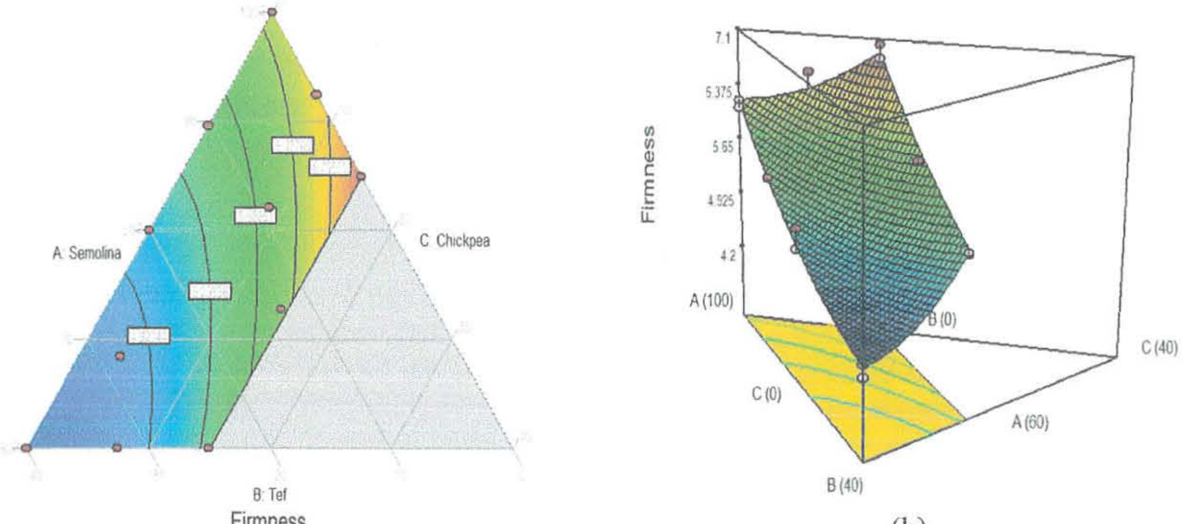
Figure 17: Effect of tef and chickpea blending with durum wheat semolina on cooking loss of cooked macaroni (a) Contour graph and (b) Response surface (3D)

4.6.4. Firmness

Among the blended formulation, Run-9 (85%-semolina, 0%-tef and 15%-chickpea) had significantly the highest firmness (7.03 N) than the other formulations (Table 9). In contrast, Run-13 with the maximum tef amount (60%-semolina, 40%-tef and 0%-chickpea) gave the lowest firmness (4.42 N). Sissons *et al.*(2005) reported a strong correlation between protein content of durum wheat with firmness of spaghetti. This implies the increased firmness of the cooked macaroni with higher chickpea amount (increased protein content). This could be attributed to a significant increase of protein level in obtained from the pea flour (Padalino *et al.*, 2014) while the amount tef increased in the formulations had shown lower firmness value compared with wheat and oat pasta (Hager *et al.*, 2012).

Regression analyses indicated that firmness increased with increasing in semolina and chickpea while it decreased with increasing tef blending proportion (Figures 18a and 18b).The blending ratio have a significant impact ($p<0.05$) on firmness of macaroni. Analysis of variance (ANOVA) for firmness of quadratic model fitted to experimental results showed $p > 0.05$ value for the lack of fit and this implies that it was insignificant. The fitted model for firmness is shown in Equation 4.13.

Firmness = 6.19S +4.40T+10.94C - 1.24ST - 4.50SC - 6.51TC (Equation 4.13)



(a) (b)

Figure 18: Effect of tef and chickpea blending with durum wheat semolina on firmness of cooked macaroni (a) Contour graph and (b) Response surface (3D)

4.6.5. Stickiness

In this study, the mean stickiness of all the formulated cooked macaroni was significantly ($p < 0.05$) affected by the blend ratio and ranged from 41.71 to 46.42N (Table 9). Macaroni formulated from 100% semolina had significantly lower stickiness (41.71N). On the contrary, Run-9 & Run-16 (85%-semolina, 0%-tef and 15%-chickpea) had significantly higher stickiness (46.42N). In fact, all the macaroni formulations had higher stickiness compared with the control. This might be due to the effect of change in surface structure of macaroni strand and starch quality on strand surface during cooking (Dexter *et al.*, 1985). Padalino *et al.*(2014) reported that pea fortified spaghetti had higher adhesiveness compared with control samples . Hence, the highest stickiness of the chickpea -fortified spaghetti in this study might be related with higher protein and higher amylose contents (Sissons *et al.*, 2005).

Analysis of variance (ANOVA) indicated a quadratic model with non significant ($p > 0.05$) lack of fit. As depicted in Figures 19a and 19b with the contour graph and its response surface. The stickiness of macaroni were significantly ($p < 0.05$) affected by different blending ratio (Table 9). The fitted model for stickiness is shown in Equation 4.14

$$\text{Stickiness} = 42.10S + 44.04T + 42.84C - 1.87ST + 13.61SC - 1.59TC \quad \text{(Equation 4.14)}$$

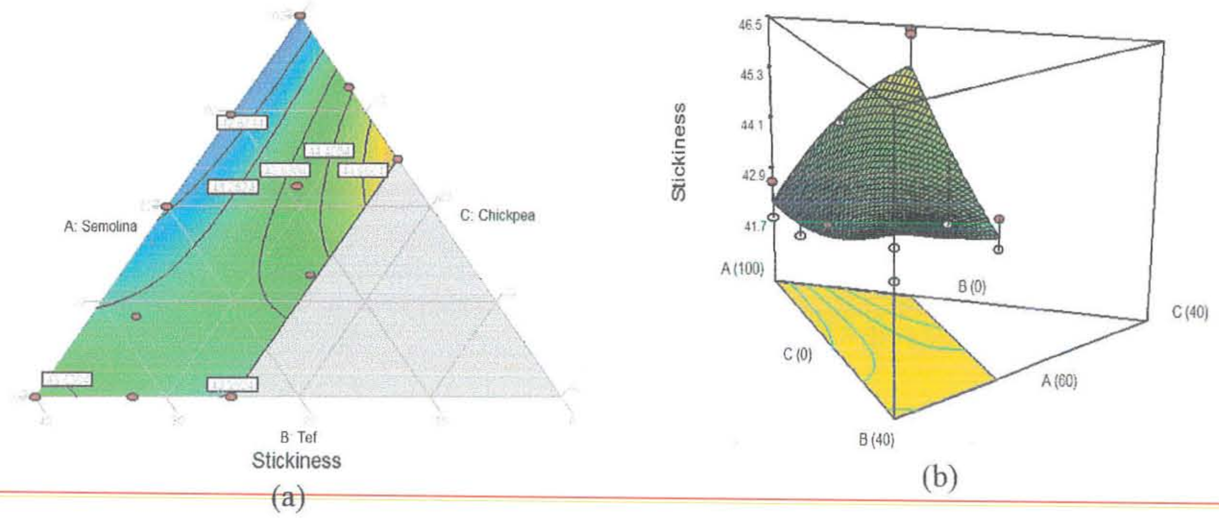


Figure 19: Effect of tef and chickpea blending with durum wheat semolina on stickiness of cooked macaroni (a) Contour graph and (b) Response surface (3D)

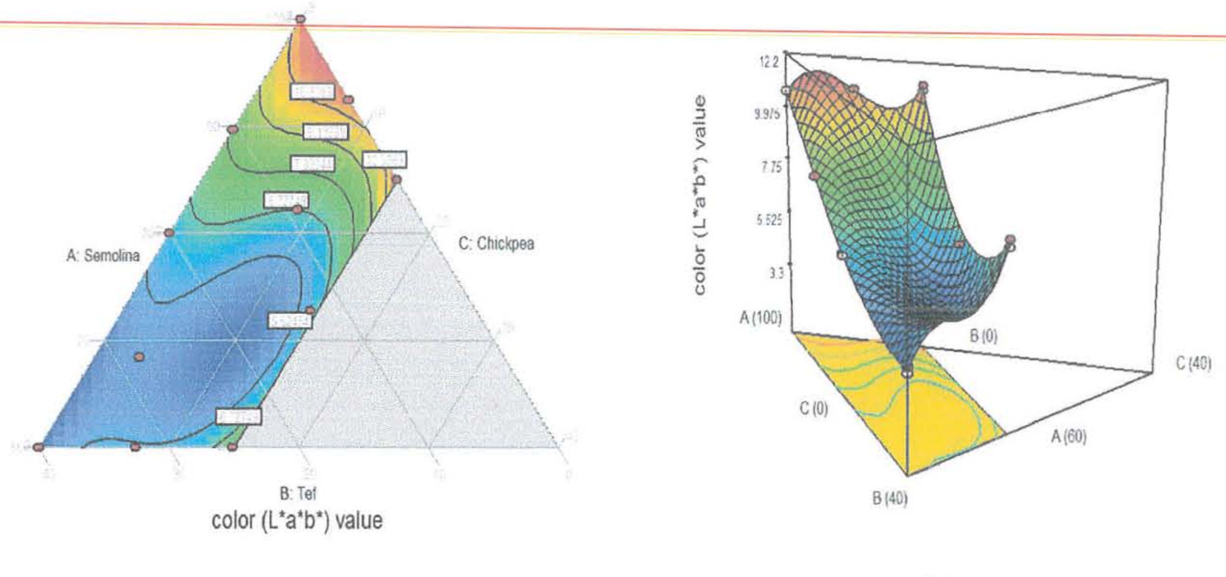
4.7. Color score

Color is an important parameter to determine pasta quality. In pasta products made with semolina, the higher the value, the more desirable the product. Color scores of macaroni samples are shown in Table 9. Compared with 100% semolina macaroni, tef incorporated macaroni showed a significant reduction in color score as the replacement level increased. The macaroni samples made by using higher incorporation (>25%) tef flour had an intense dark brown color while those containing lower amounts of tef flour (≤20%) showed a light brown color in comparison with the bright yellow color of the control sample. On the contrary, the macaroni samples made from durum wheat semolina with small amounts of chickpea flour (up to 15%) appeared to have better for color score compared with control, which indicates good quality.

These results obtained in this study could be considered acceptable when compared to the earlier results reported for spaghetti made from semolina expected 10 average color scores by Rayas-durati *et al.* (1996) and 8.6 average color score by the U.S. durum wheat survey data five-year average (2008-2013 crop years). In addition dried pasta fortified with green pea, chickpea, lentil and tef flour lied in the range reported in this study (Wood, 2009; Petitot *et al.*, 2010a,b; Hager *et al.*, 2012). Seyam *et al.* (1983) obtained color score of 8.5 in spaghetti samples made of semolina mixed with 20% navy bean protein isolates, and 3% gluten reported.

The blending ratio have a significant impact ($p < 0.05$) on color of macaroni. Analysis of variance (ANOVA) of color indicated a special cubic model with non-significant ($p > 0.05$) lack of fit which implies that it was significant. The fitted model for color score is shown in Equation 4.15.

$$\text{Color } (L^*a^*b^*) = 10.67S + 4.35T + 170.64C - 5.54ST - 292.57SC - 287.95TC + 236.25STC \quad \text{(Equation 4.15)}$$



(a) (b)

Figure 20: Effect of tef and chickpea blending with durum wheat semolina on color (L*a*b*) of cooked macaroni (a) Contour graph and (b) Response surface (3D)

4.8. Sensory Quality

The sensory evaluation on the quality characteristics of macaroni is an important step in product development and optimization. Data showing the scores for different sensory attributes of macaroni are given in Table 10. The sensory attributes were evaluated by twenty semi-trained panel members. The data reported are mean of twenty observations and the analysis was performed using SPSS 20 and design expert 7.0.1 (Design Expert ®, version 7.0.1, Stat-Ease, Inc., Minneapolis, MN). As shown in Table 10, it was observed that blend ratio had significantly ($p<0.05$) affected all the characteristics of the sensory attributes of the macaroni.

4.8.1. Color

Color is essential parameter for assessing pasta quality. Generally, consumers prefer pasta with a bright yellow color (Debbouz *et al.*,1995). Blend ratio had a significant impact ($p < 0.05$) on the color and appearance of the macaroni among the 16 experimental formulations based on panelist preference. The color of the macaroni varied from 3.74 to 7.89. The lowest color score (3.74) was obtained for Run 13 (with maximum tef proportion levels, i.e., 60%-semolina, 40%-tef and 0%-chickpea) blend while highest color scores (7.89) was obtained for Run 16 (with the maximum chickpea proportion levels, i.e., 85%-semolina, 0%-tef and 15%-chickpea). Formulations with 100% semolina and high chickpea in the formulated macaroni had exhibited relatively maximum color value.

The fact that the detrimental effect of addition of tef flour which also increases addition level with progressively decreases macaroni color. This is due to high ash content of tef and use a form of whole floured (Bultosa, 2007). Similar effect was reported in different works done earlier (Sirawdink & Ramaswamy, 2011; Hager *et al.*, 2012 and Abebe *et al.*, 2015). Study made by Padalino *et al.*(2014) shows the color of the spaghetti made exclusively from 100% semolina or containing small amounts of pea flour (up to 15% w/w) appeared to have a pleasant yellow color, which indicates good quality. In addition, this results are in agreement with those of (Goni & Valentin-Gamazo, 2003; Zhao *et al.*, 2005 and Wood, 2009) who reported that pasta fortified up to a 10-15% substitution level with chickpea flour is generally well accepted sensory quality.

As shown in response surface and contour plots (Figures 21a and 21b) the control sample (100% semolina) and the formulation with high chickpea blend proportion exhibited relatively maximum color value. This result is in agreement with the results measured using Digital imaging system reported earlier in this study.

Analysis of variance (ANOVA) was used for evaluation of the quadratic model for color data was significant ($p < 0.01$) and the lack of fit test was not significant ($p > 0.05$) for the fitted model and this indicated that the model is suitable for prediction purposes (Equation 4.16).

$$\text{Color} = 7.51S + 4.24T + 24.34C - 1.04ST - 25.83SC - 29.13TC \quad \text{(Equation 4.16)}$$

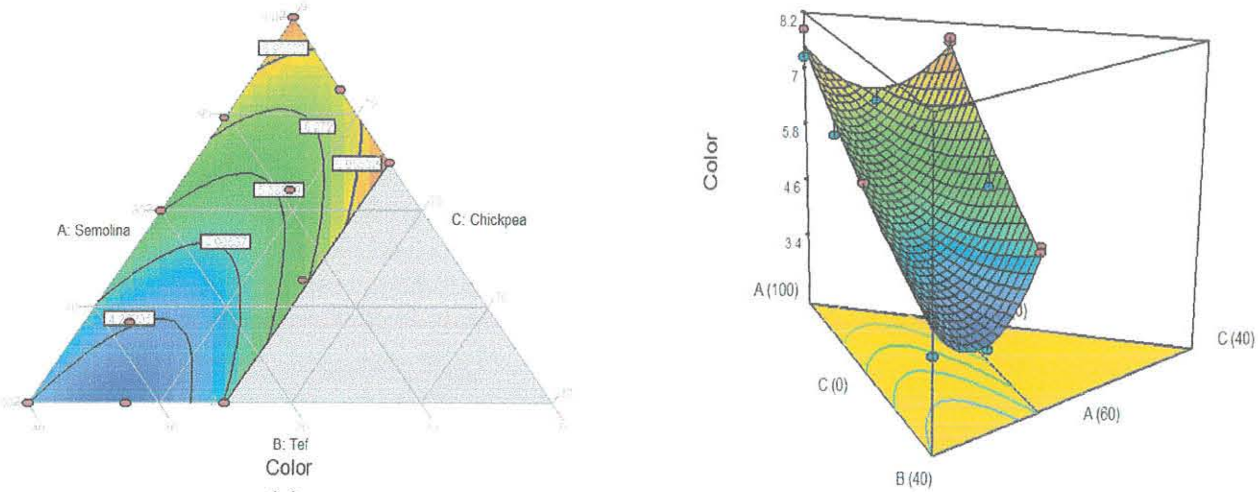
4.8.2. Appereance

The appearance of the macaroni a significantly ($p < 0.05$) difference on the appearance scores of the macaroni and ranged from 3.74 to 7.53 (Table 10). The lowest (3.74) and highest (7.53) mean appearance score of macaroni were obtained at Run 4 (60%-semolina with 32.58%-tef and 7.42%-chickpea) and Run 16 (85%-semolina with 0%-tef and 15%-chickpea) blend, respectively. Response surface and contour plots (Figures 22a & 22b) obtained by fitting a quadratic model to appearance show the formulation having high chickpea and 100 % semolina in mixture had a maximum appearance value. However, with the increasing proportion of tef in the formulation, the appearance score gets lower. Probably this could also due the high amount fiber in whole floured tef and the less composite homogeneity; thus result in minimum appearance score split pea also had an impact on surface appearance of cooked pasta due to the presence large fiber fragment and probably less homogeneity (Petitot *et al.,* 2010b). On the contrary, pasta and noodles fortified with lupin or chickpea flour up to 10% substitution are generally well accepted, and there appeared to be no impact on appearance at higher substitution levels too (Farooq and Boye (2011).

Analysis of variance (ANOVA) was used for evaluation of the quadratic model for appearance score was highly significant ($p < 0.01$) and the lack of fit test was not significant ($p > 0.05$) for the fitted model. This indicated that the model (Equation 4.17) is suitable for prediction purpose.

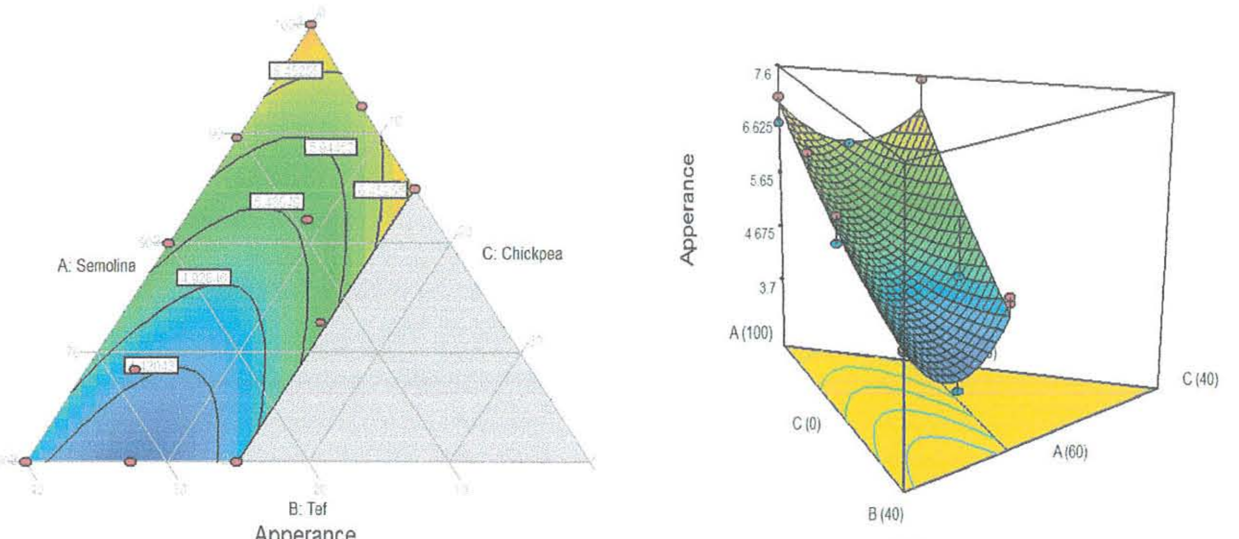
$$\text{Appearance} = 6.96S + 4.70T + 18.69C - 0.99ST - 18.43SC - 22.40TC \quad \text{(Equation 4.17)}$$

Therefore, with increasing the addition of chickpea and semolina in the formulation favoured both the color and appearance while the incorporation level of tef had deleterious effect on the color and appearance the macaroni formulated.



(a) (b)

Figure 21: Influence of tef and chickpea blending with durum wheat semolina on cooked macaroni color (a) Contour graph and (b) Response surface plots (3D)



(a) (b)

Figure 22: Influence of tef and chickpea blending with durum wheat semolina on cooked macaroni appearance (a) Contour graph and (b) Response surface plots (3D)

Table 10. Sensory evaluation of macaroni formulated with durum wheat semolina, chickpea and tef flours

Run	Color	Appearance	Flavor	Taste	Firmness	Stickiness	Overall acceptability
1	5.74 ± 0.29^{cdef}	5.84 ± 0.43^{bcde}	5.95 ± 0.44^{abcd}	5.84 ± 0.5^{abc}	6.00 ± 0.42^{abc}	6.16 ± 0.49^{abcde}	5.74 ± 0.42^{cdef}
2	7.84 ± 0.23^{a}	7.05 ± 0.40^{ab}	7.21 ± 0.27^{a}	6.68 ± 0.35^{a}	7.11 ± 0.32^{a}	6.95 ± 0.26^{ab}	7.53 ± 0.33^{a}
3	5.53 ± 0.42^{cdef}	4.68 ± 0.51^{efg}	4.84 ± 0.44^{ef}	4.63 ± 0.44^{bc}	5.42 ± 0.49^{cde}	5.58 ± 0.45^{bcdef}	5.16 ± 0.42^{efg}
4	3.97 ± 0.44^{hi}	3.74 ± 0.45^{g}	4.47 ± 0.44^{f}	4.53 ± 0.44^{c}	4.74 ± 0.46^{e}	4.47 ± 0.39^{f}	4.72 ± 0.41^{g}
5	4.79 ± 0.31^{fgh}	4.74 ± 0.4^{efg}	5.32 ± 0.40^{cdef}	5.16 ± 0.49^{bc}	5.00 ± 0.42^{de}	4.95 ± 0.40^{ef}	5.11 ± 0.25^{efg}
6	5.11 ± 0.36^{defg}	4.89 ± 0.45^{efg}	4.89 ±0.46^{ef}	5.16 ± 0.40^{bc}	5.11 ± 0.47^{cde}	5.47 ± 0.47^{cdef}	5.47 ± 0.37^{defg}
7	6.47 ± 0.44^{bc}	6.32 ± 0.59^{abcd}	6.63 ± 0.36^{ab}	6.58 ± 0.34^{a}	5.84 ± 0.39^{bcd}	5.58 ± 0.48^{bcdef}	6.82 ± 0.41^{ab}
8	6.00 ± 0.33^{bcdef}	5.58 ± 0.45^{cdef}	5.63 ± 0.34^{bcde}	5.68 ± 0.34^{abc}	6.05 ± 0.35^{abc}	6.42 ± 0.35^{abcd}	6.25 ± 0.36^{bcde}
9	7.79 ± 0.24^{a}	6.84 ± 0.47^{abc}	6.53 ± 0.47^{abc}	6.84 ± 0.24^{a}	6.68 ± 0.38^{ab}	6.89 ± 0.46^{abc}	6.84 ± 0.25^{ab}
10	4.00 ± 0.48^{ghi}	4.37 ± 0.44^{fg}	4.63 ± 0.40^{ef}	4.58 ± 0.45^{bc}	4.79 ± 0.43^{de}	5.26 ± 0.46^{def}	4.63 ±0.36^{fg}
11	7.26 ± 0.37^{ab}	6.58 ± 0.39^{abc}	6.84 ± 0.43^{ab}	6.63 ±0.41^{a}	6.84 ± 0.33^{a}	6.84 ± 0.34^{abc}	7.26 ± 0.3^{ab}
12	6.37 ± 0.43^{bcd}	6.00 ± 0.41^{bcde}	6.26 ± 0.42^{abcd}	5.89 ± 0.45^{ab}	6.21 ± 0.41^{abc}	6.47 ± 0.38^{abcd}	6.58 ± 0.43^{abcd}
13	3.74 ± 0.46^{hi}	4.68 ± 0.46^{efg}	5.16 ± 0.43^{def}	4.89 ± 0.40^{bc}	4.79 ± 0.39^{e}	5.21 ± 0.51^{def}	5.37 ± 0.38^{efg}
14	6.16 ± 0.43^{bcde}	6.47 ± 0.45^{abc}	6.42 ± 0.44^{abcd}	6.58 ± 0.40^{a}	6.50 ± 0.43^{ab}	6.05 ± 0.49^{abcde}	6.81 ± 0.43^{abcd}
15	5.00 ± 0.53^{efgh}	5.00 ± 0.44^{defg}	5.21 ± 0.40^{def}	5.16 ± 0.47^{bc}	5.42 ± 0.35^{cde}	5.53 ± 0.50^{bcdef}	5.67 ± 0.46^{defg}
16	7.89 ± 0.32^{a}	7.53 ± 0.21^{a}	7.16 ± 0.34^{a}	6.74 ± 0.34^{a}	7.00 ± 0.29^{a}	7.42 ± 0.25^{a}	7.37 ± 0.29^{a}

Mean values in the same column followed by different superscript letters differ significantly based on Duncan's multiple range test ($p < 0.05$). All values are expressed in mean ± SE in triplicate

4.8.3. Flavor and Taste

As it is presented in Table 10, blending caused a significant ($p < 0.05$) difference on the flavor scores of the macaroni which ranged between 4.47 (Run-4: 60%-semolina, 32.58%-tef and 7.42%-chickpea) and 7.21 (Control: 100% semolina). The incorporation of tef and chickpea increased in the formulations had shown relatively lower flavor score while the control samples (100 % semolina) in the recipe had exhibited higher flavor score. Increased incorporation of tef and chickpea reduced the flavor score as compared with the 100% semolina macaroni.

Analysis of variance (ANOVA) indicated a linear model for the flavor score was significant ($p < 0.01$) with the non-significant ($p > 0.05$) lack of fit which proved the suitability of the model (Equation 4.18).

$$\text{Flavor} = 7.02S + 4.72T + 5.35C \qquad \text{(Equation 4.18)}$$

The other sensory attribute was taste that the value varied significantly ($p < 0.05$) and the scores ranged from 4.52 to 6.85 (Table 10). The blending ratio have a significant impact on taste sensory score of macaroni. The highest mean taste score (6.85) was obtained in highest chickpea blend proportion of Run 9 (85%-semolina, 0%-tef and 15%-chickpea) while the lowest (4.52) was obtained at 60%-semolina, 33%-tef and 7%-chickpea. Formulations with high chickpea and 100% semolina in the mixture had a maximum taste sensory value. In contrast, with increased proportion of tef, the taste score of the cooked macaroni product became lower.

Analysis of variance (ANOVA) of taste indicated a special cubic model with non-significant ($p > 0.05$) lack of fit which implies that it was significant. The fitted model for taste score is shown in Equation 4.19. As depicted in contour graph and response surface plot (Figure 24a & 24b) the formulation with high chickpea blend ratio and the control (100% semolina) had a maximum taste sensory value, while increasing detrimental effect was observed with the increase in the proportion of tef flour in the formulation.

$$\text{Taste} = 6.74S + 4.92T + 9.46C - 0.033ST - 4.01SC - 6.73TC - 26.46STC \qquad \text{(Equation 4.19)}$$

Spaghetti enriched with higher amounts of pea flour had taste and odour very intense as compared to the samples enriched with lower percentage of pea flour and control (Sabanis *et al.*, 2006). Pasta fortified with chickpea flour up to a 10% substitution level led to generally well accepted, and significant impact was observed on taste at higher substitution levels (Farooq and Boye, 2011). However, Zhao *et al.*(2005) reported that increasing the substitution level of chickpea lowered the taste score. Lorenz *et al.*(1979) were able to use up to 20% faba bean concentrates in noodle products which showed acceptable flavor of the cooked product.

This again supports the hypothesis of this research to incorporate legumes (chickpea) to improve protein quality of pasta products without compromising the important sensory attributes.

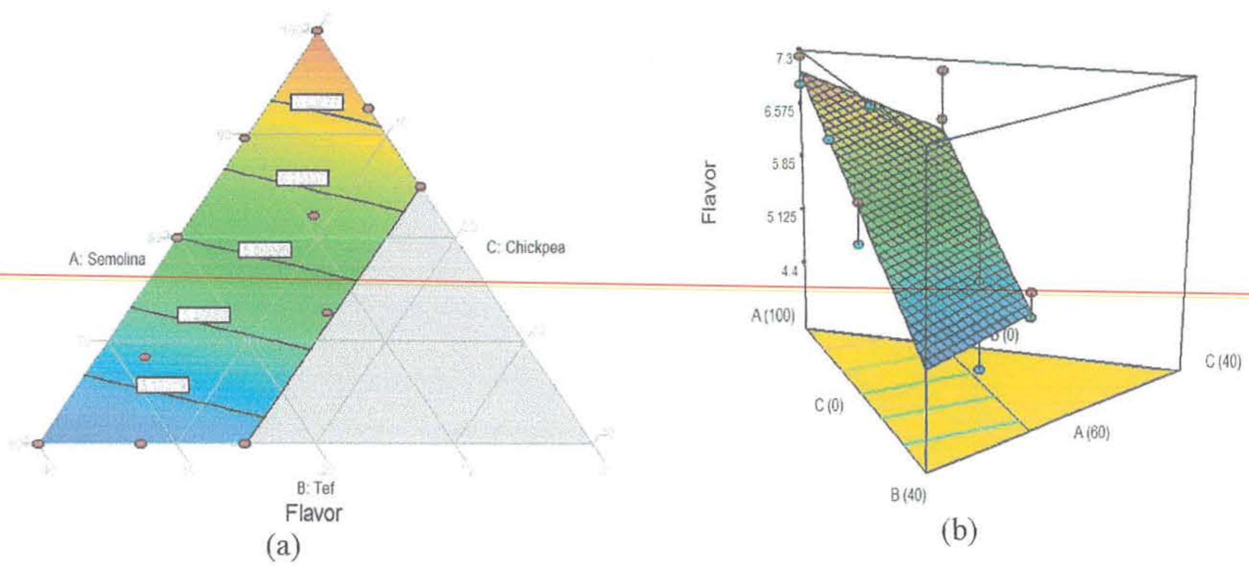


Figure 23: Influence of tef and chickpea blending with durum wheat semolina on cooked macaroni flavor (a) Contour graph and (b) Response surface plots (3D)

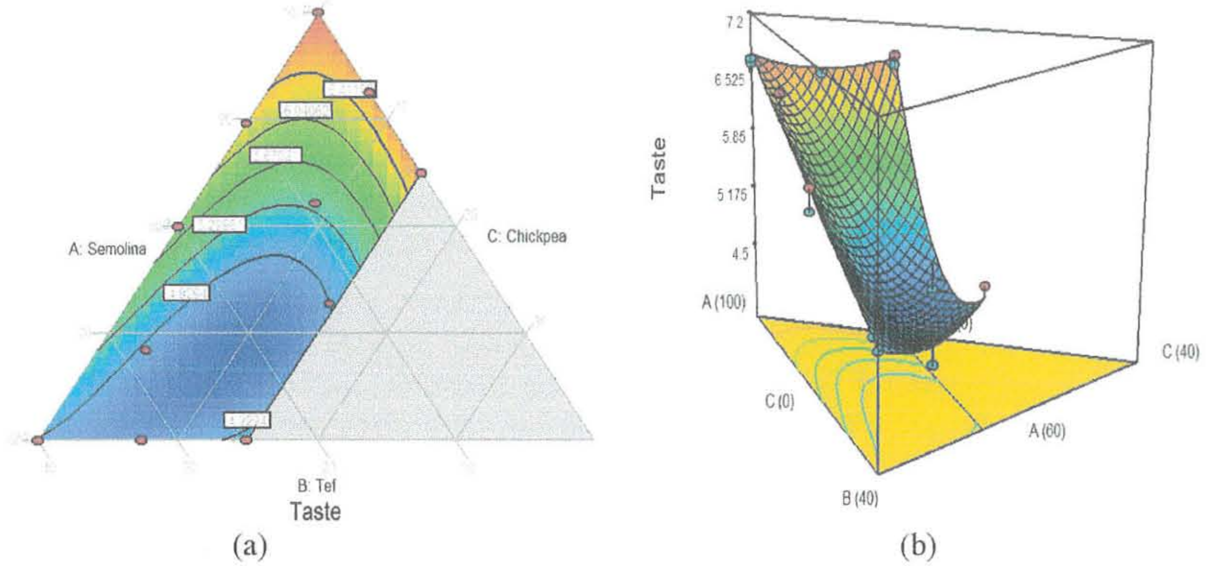


Figure 24: Influence of tef and chickpea blending with durum wheat semolina on cooked macaroni taste (a) Contour graph and (b) Response surface plots (3D)

4.8.4. Firmness and Stickiness

The sensory firmness score in this study varied between (4.74-7.11) (Table 10). There was a significant difference ($p < 0.05$) between all macaroni formulations in firmness scores. The 100% semolina macaroni (Run 2) gave the maximum (7.11) firmness score, followed by Run 16 (highest chickpea) (85%-semolina, 0%-tef and 15%-chickpea) with score of 7.00. The minimum score (4.74) was obtained with the highest tef Run-4 (60%-semolina, 32.58%-tef and 7.42%-chickpea) and Run-5 (60%-semolina, 40%-tef and 0%-chickpea). At higher substitution level of chickpea led to macaroni with firmness more or less close to the control, while higher tef flour incorporation decreased the macaroni firmness. This could be attributed to the dilution of protein due to the added tef flour and the increase of the same because of the addition of chickpea flour. These results are in line with the trend reported by Seyam *et al.* (1983) for semolina spaghetti containing navy and pinto protein isolates and the finding by Rayas-duarte *et al.*(1996) on spaghetti formulated from buck wheat, amaranth and lupin flours.

The contour graph and response surface plot (Figure 25a & 25b) indicate that macaroni prepared from composite flours containing exclusively durum wheat semolina and chickpea- durum wheat semolina blend had higher firmness than tef flour included formulations. The analysis of variance (ANOVA) of firmness indicated that the blending ratio had a significant ($p < 0.05$) impact and depicted quadratic model with R^2=0.9705. The following model, with non-significant ($p > 0.05$) lack of fit, was developed to predict the firmness score. The fitted model for firmness is shown below.

$$\text{Firmness} = 6.88S + 4.94T + 15.65C - 0.22ST - 14.8SC - 15.79TC \quad \text{(Equation 4.20)}$$

The firmness data and trend obtained using the sensorial analysis in agreement with the results firmness test conducted using TA plus textural analyzer described earlier in this study. According to Tina Fuad and Prabhasankar (2010) the inclusion of dietary fiber (pea fiber and inulin) interfered with the structure of pasta, disruption in the protein matrix, lowered the continuity of the protein-starch matrix and lowers the firmness and this corroborates the finding in this study. On the other hand, firmness was found to increase in pasta fortified with 5% of chickpea flour (Zhao *et al.,* 2005).

The stickiness of the macaroni varied significantly ($p < 0.05$) and the scores between (4.47 to 7.42) (Table 10). Macaroni made from the different blend ratio with the most liked 7.42 (Run 16: 85%-semolina, 0%-tef and 15%-chickpea) and 6.95 (control sample) to less liked 4.42 (Run 4: 60%-semolina, 32.58%-tef and 7.42%-chickpea). Increasing proportion of tef flour in the composite had decreased the stickiness sensory score which implies good quality of pasta products.

$$\text{Stickness} = 6.74S + 5.12T + 19.89C + 0.97ST - 20.01SC - 22.27TC \quad \text{(Equation 4.21)}$$

The stickiness data and trend obtained using the sensorial analysis in agreement with the results stickiness test conducted using TA plus textural analyzer described earlier in this study. The results obtained were also had similar trend with report by Sabanis *et al.*(2006) where the incorporation of chickpea up to 10% to 15% gave lasagna optimum firmness and helped to reduce stickiness.

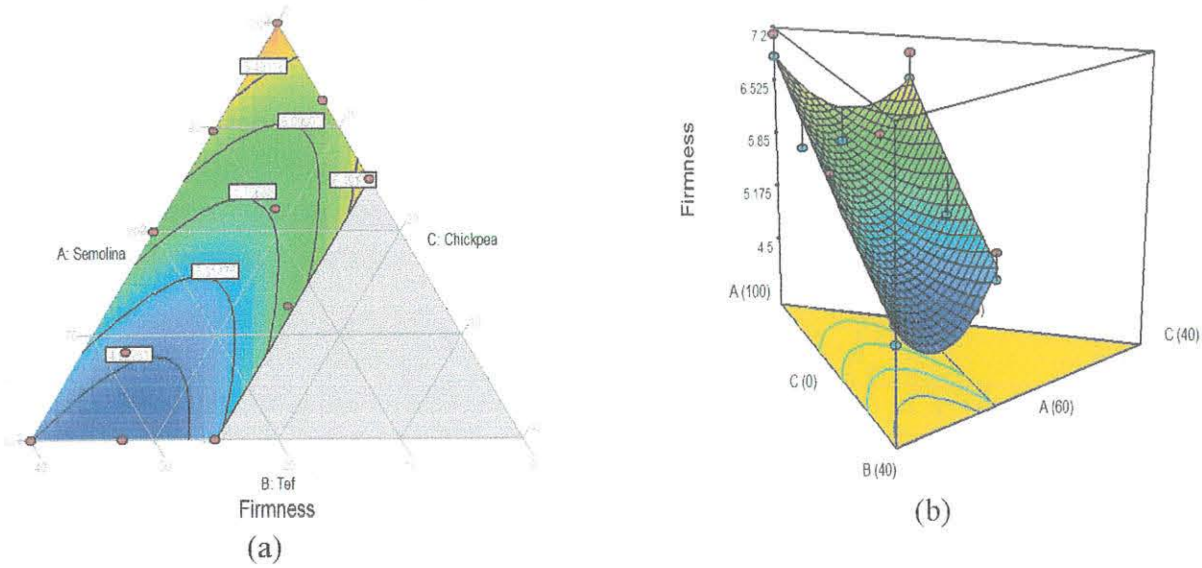


Figure 25: Influence of tef and chickpea blending with durum wheat semolina on cooked macaroni firmness (a) Contour graph and (b) Response surface plots (3D)

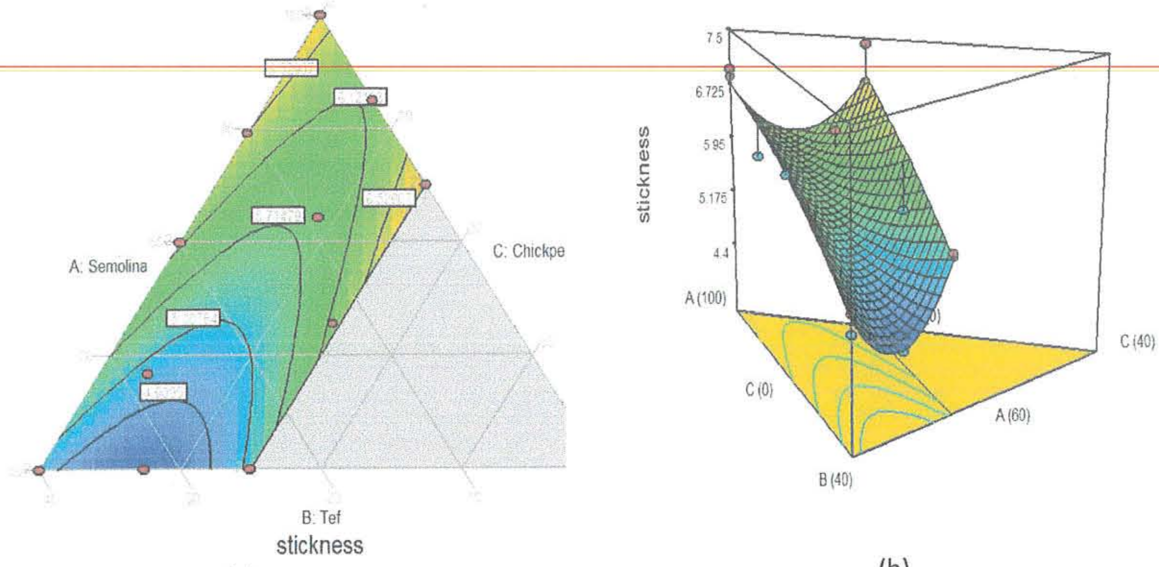


Figure 26: Influence of tef and chickpea blending with durum wheat semolina on cooked macaroni stickiness (a) Contour graph and (b) Response surface plots (3D)

4.8.5. Overall acceptability

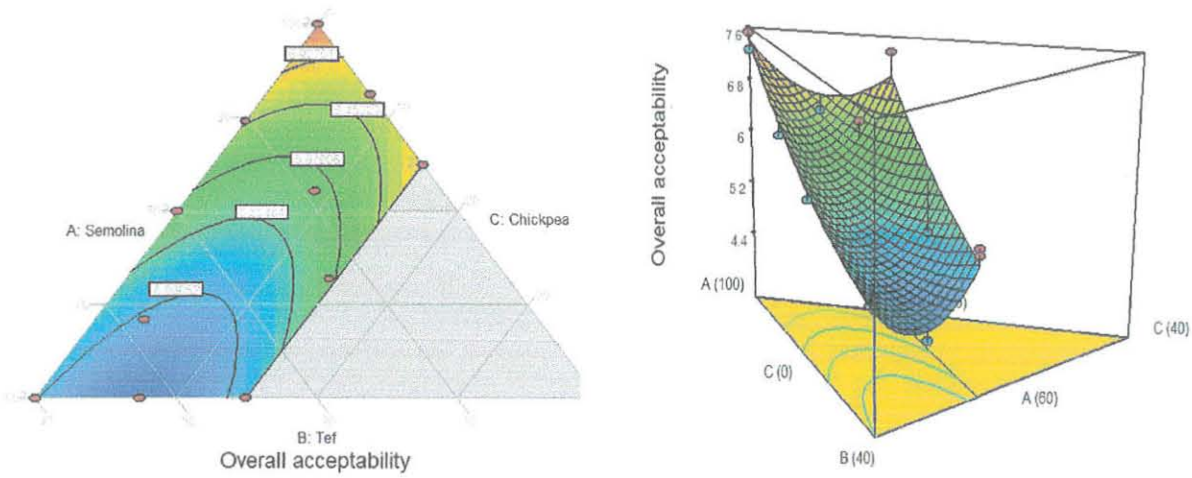
Blending ratio had a significant ($p < 0.05$) effect on the overall acceptability of the blend macaroni (Table 10). The overall acceptability score of the blended macaroni ranged from 4.42 to 7.53. The highest sensory score was recorded from control Run-2 (100 % semolina) (7.53) and maximum chickpea incorporated macaroni samples Run-16 (85%-semolina, 0%-tef flour and 15%-chickpea flour) (7.37), respectively. Run-4 (60%-semolina, 32.58%-tef and 7.42%-chickpea) and Run-10 (68.4%-semolina, 28.1%-tef and 7.00%-chickpea), were the least accepted macaroni products with respective scores of 4.42 and 5.10.

Addition of more proportion of semolina exclusively or semolina with only chickpea flour produced a macaroni with the highest overall acceptability. In contrast, tef based macaroni had less overall acceptability. Most studies on the sensorial evaluation of fortified pasta focused on the overall product acceptability. No significant difference observed between the control macaroni and semolina-chickpea macaroni blend. These results were in line with the trend of pasta fortified up to a 10-15% substitution with chickpea flour were generally well accepted (Goni and Valentin-Gamazo, 2003; Zhao *et al.,* 2005; Wood, 2009 and Petitot *et al.,* 2010). Taha *et al.*(1992) reported that pasta containing up to 5 percent soy flour were comparable in overall acceptability (based on appearance, color, surface case, odour, taste and mouth feel) with 100% durum semolina pasta.

In this study, the overall sensory acceptability score in blend macaroni appeared to be lower than the value in the control sample. Figure 27a and 27b show the contour graph and response surface of overall acceptability. The trend of overall acceptability of macaroni were significantly ($p < 0.05$) influenced by blending ratio. Analysis of variance (ANOVA) indicated a quadratic model with the lack of fit being not significant($p > 0.05$). The following model (Equation 4.22) was developed to predict the overall acceptability.

$$\text{Overall acceptability} = 7.4S + 5.06T + 16.11C - 1.56ST - 15.56SC - 16.89TC \quad \text{(Equation 4.22)}$$

The predicted value of the blend macaroni made by taking exclusively semolina and the proportion 85% semolina, 0% tef and 15% chickpea was obtained from the formula by substituting the proportion. The result indicated that the actual overall acceptability score obtained from the experiment was approximately equal to the predicted value with a small residual value. This indicates that the data was good enough to describe the model.



(a) (b)

Figure 27: Influence of tef and chickpea blending with Durum wheat semolina on macaroni overall acceptability (a) Contour graph and (b) Response surface plots (3D)

4.9. Optimization

A numerical multi-response optimization technique of RSM was applied to determine the optimum combination of semolina, tef and chickpea for the production of nutrient rich and functional pasta. The criteria for optimization were nutritional content (crude protein, crude fiber and iron were maximum target); cooking and textural quality (firmness, stickiness and cooking loss were maximum, minimum and minimum, respectively); sensory score (color, overall acceptability) and color (L*a*b*) value.

Based on macaroni nutritional composition (protein, crude fiber and iron), the formula that could be selected is optimum blend is 60 g/100g semolina, 25 g/100g tef and 15 g/100g chickpea flour with 13.71 g/100g protein, 1.99 g/100g crude fiber and 3.06 mg/100g iron having desirability of

0.782. The white region in contour overlay plot (Figure 28) showed the optimum option for producing macaroni with maximum nutrient.

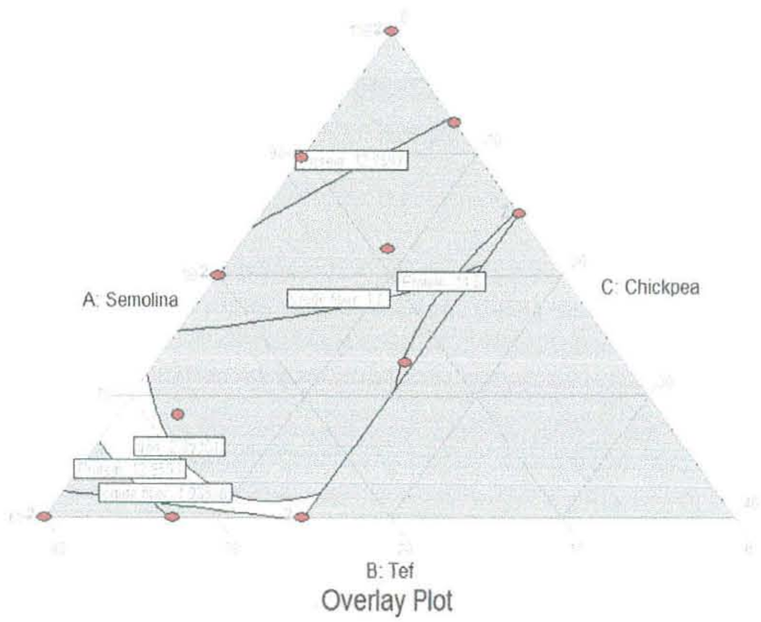


Figure 28: Contour plots explaining optimum responses for nutritional content using graphical optimization

Interms of cooking and textural analysis, which considered stickiness, cooking loss and firmness the optimum blend was found to be 67.08 g/100g semolina, 17.93 g/100g tef flour and 15 g/100g chickpea flour were obtained with the target of minimize, minimize and maximize, respectively. The white region in the contour overlay plot shown in Figure 29 could be consudered as the best option for producing macaroni ().

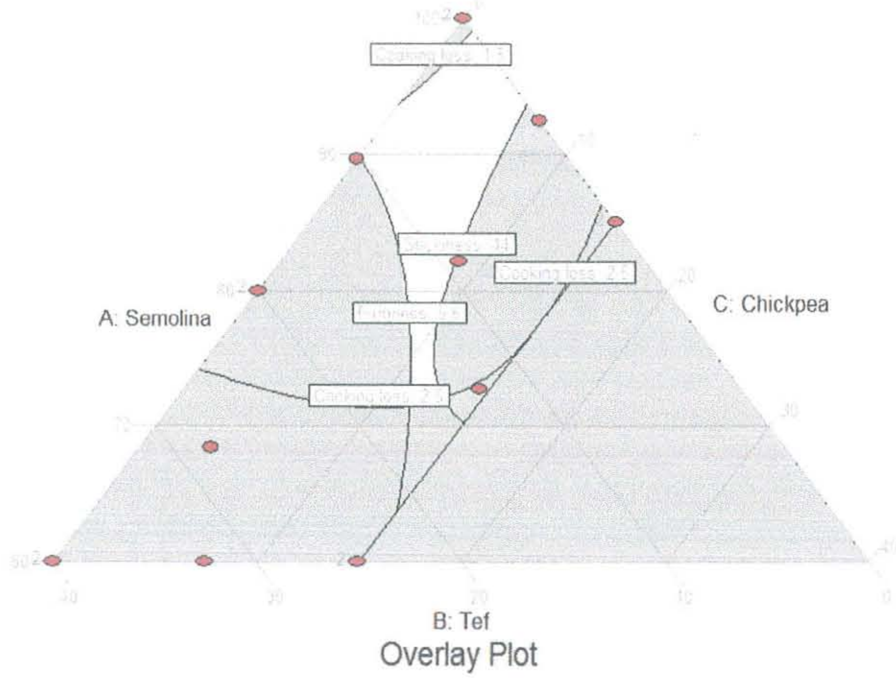


Figure 29: Contour plots illustrating optimization responses for cooking and textural quality using graphical optimization.

Since the target for sensory score and color (L*a*b*) value is the maximum level, the best mix ratio for producing macaroni from durum wheat semolina, tef flour and chickpea flour was found to be the mix with maximum chickpea flour i.e., 15 g/100g chickpea flour and 85 g/100g semolina. As shown Figure 30 below, the color, overall acceptability and color (L*a*b*) of this formulation were 7.77, 6.74 and 10.73, respectively with at desirability of 0.612.

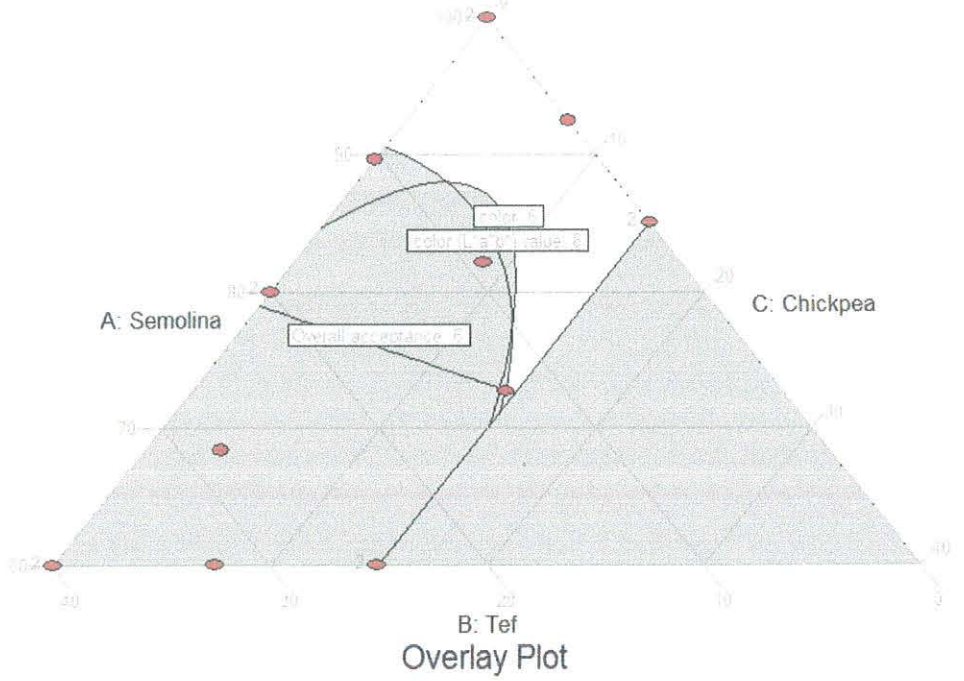


Figure 30: Contour plots illustrating optimum sensory responses using graphical optimization.

The common optimum macaroni formulation for excellent quality with maximum (protein, firmness and overall acceptability) and minimum (stickiness and cooking loss) could be made from ratio of combination of three independent variables at 73.46 g durum wheat semolina, 11.55 g tef flour and 15 g/100g chickpea flour. For optimum formulation for parameter which include protein, crude fiber, stickiness, cooking loss and firmness were obtained by simultaneously maximizing the dependent variables and minimizing durum wheat semolina keeping the tef and chickpea flour in ranges. From numerical optimizatiom was 14.62 g/100g protein, 1.63 g/100g crude fiber, 44.30 N stickiness, 6.06 N firmness, 2.55% cooking loss and 6.04 overall acceptability.

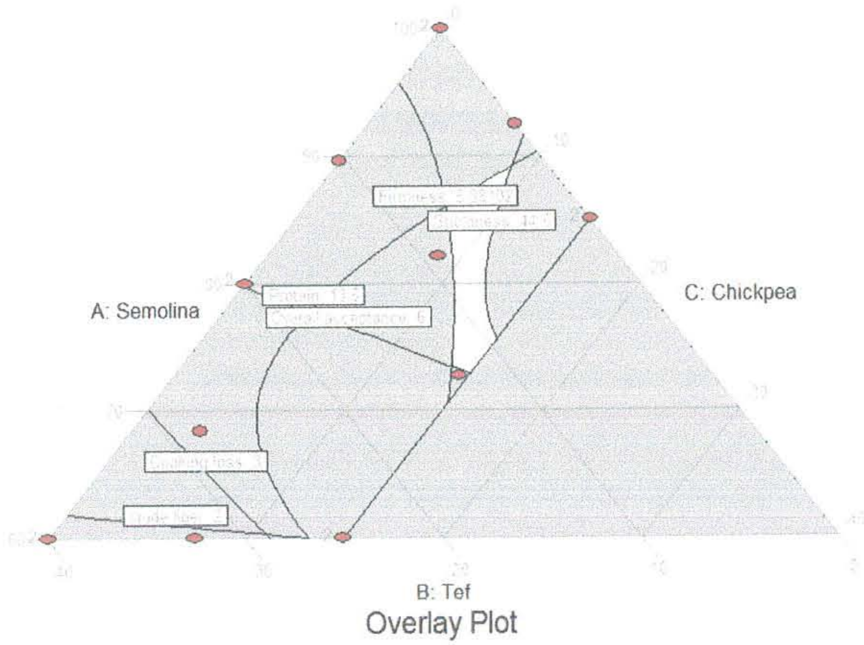


Figure 31: Contour plots explaining common optimum responses for nutritional, sensory, cooking and textural quality using graphical optimization.

Chapter Five

5. Conclusions and Recommendations

5.1. Conclusions

This study was conducted with the broad intention of enhancing the nutritional contents and functional properties of macaroni from durum wheat semolina with incorporation of tef and chickpea flours. Accordingly, the study explored the impact of tef and chickpea flour addition on durum wheat semolina in terms of nutritional composition, cooking, textural and sensory quality of the formulated macaroni. Response Surface Methodology (RSM) was applied as an effective tool to indicate the optimum conditions obtained for the development of durum wheat semolina based tef and chickpea fortified macaroni.

Accordingly, fortification of durum wheat semolina with tef and chickpea flour considerably increased the level of protein, ash, fat, dietary fiber, iron and zinc contents in the macaroni. Exclusively chickpea fortified with incorporation level up to 15% with semolina produced a macaroni comparable sensory quality with durum wheat semolina macaroni. Similarly, though the addition of tef flour considerably increased the cooking loss and it also considerably improved the water absorption capacity/index of the macaroni.

The optimum formulation with durum wheat semolina (85%), tef (0%) and chickpea (15%), a macaroni with color, overall acceptability and color (L*a*b*) of 7.77, 6.74 and 10.73, respectively was obtained. Similarly, the optimum blending proportion the produced quality macaroni with optimum cooking loss, firmness and stickiness was 67.08% semolina, 17.93% tef and 15% chickpea. Numeric and graphic optimization results showed that common optimum values for macaroni were (73.46%) semolina, (11.55%) tef and (15%) chickpea were produced with better quality macaroni with higher for crude protein, crude fiber, overall acceptability, firmness and lower for stickiness and cooking loss.

The outputs of this study can provide the industry with useful information on the potential utilization of tef and chickpea flour in macaroni formulations. This will ultimately help consumers with improved nutritional quality of widely consumed pasta products; thus expanding the opportunity on product development for new functional foods.

5.2. Recommendations

- The following further studies are recommended to optimize the processing condition, product utilization and economic feasibility:
    - Study on dough rheological properties, processing conditions and macaroni drying temperature for process optimization.
    - Study on impact of tef and chickpea blend on improvement of the shelf life of macaroni and their nutritional status would help to promote the product utilization.
    - Economic feasibility for production of tef based macaroni in small and medium scale industries.
- Promotion of the results obtained so that the usage of tef and chickpea by pasta producing industries is encouraged and the utilization of the product designed is promoted to enhance the nutrition security of the society.
    - Commercialize the enriched tef based macaroni and community awareness must be created to use products.

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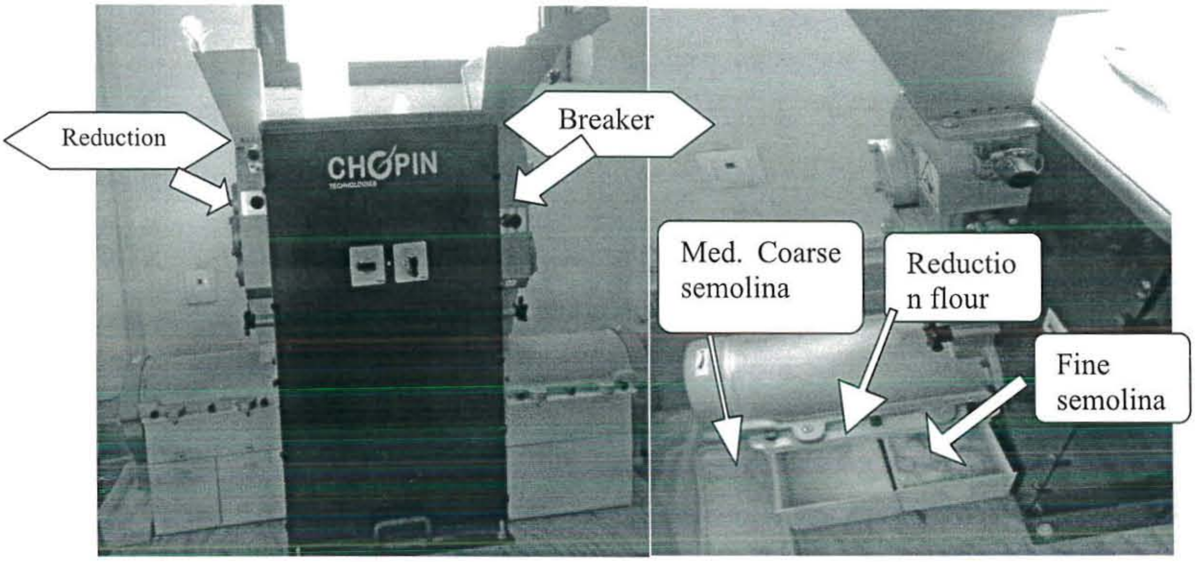
Appendix

Appendix i: Durum wheat milling process: semolina extraction process.



Chopin laboratory mill

Appendix ii: Determination of the amount of water and semolina in control sample

Following the above equations, the preparation of a 900 g dough with a final moisture content of 34.5%, and made from semolina having 13% moisture has been cited below:

Total weight of water in the dough ; $A = \frac{Ui*I}{100} = \frac{34.5*900}{100} = 310.5$ g

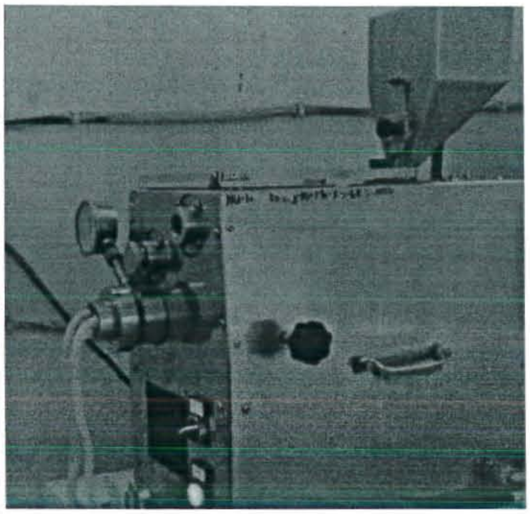
Semolina moisture coefficient; $K = \frac{Us}{100} = \frac{13}{100} = 0.13$

Required Semolina; $S = (I-A) + \frac{(I-A)K}{1-K} = (900-310.5) + \frac{(900-310.5)*0.13}{1-0.13} = 589.5 + \frac{76.64}{0.87} = \underline{678\text{ g}}$

Required amount of water; $Aa = A - \frac{(I-A)K}{1-K} = 310.5 - \frac{(900-310.5)*0.13}{1-0.13} = 310.5 - 88.09 = \underline{222.1\text{g}}$

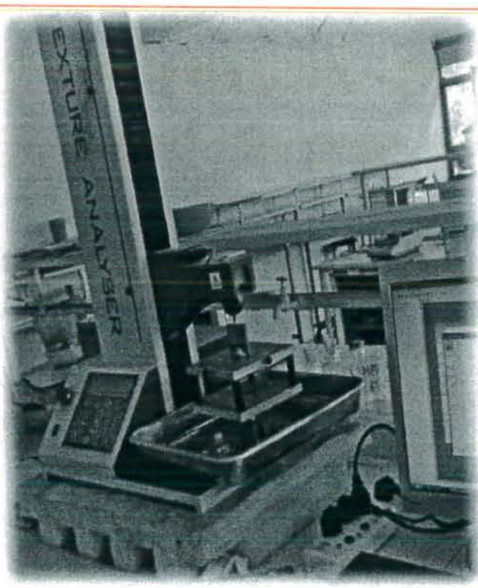
678 g semolina and 222.1g water was premixed in manual mixer resulted in a more uniform distribution of water and helped in producing pasta with uniform appearance and without specks.

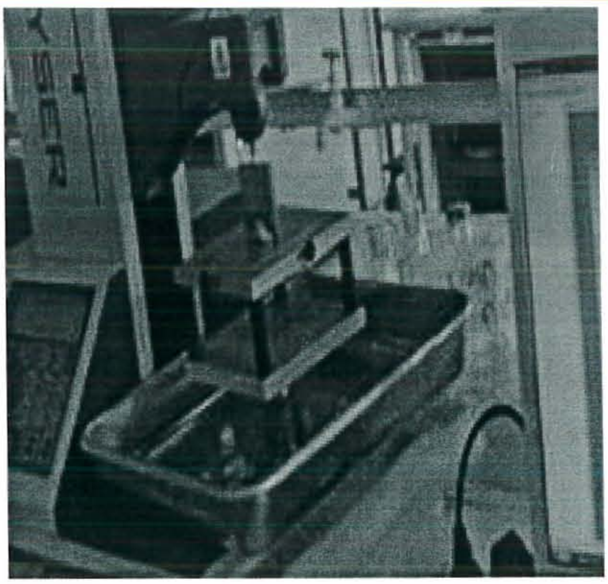
Appendix iii: Macaroni Extrusion process



Laboratory scale single screw extruder

Appendix iv: Textural analyzer with aluminum shearing blade for measuring pasta firmness





Aluminum shearing blade attached to LLOYDS texture analyzer for measurement of pasta firmness

Appendix v: Textural analyzer with special plunger for measuring pasta stickiness

Texture analyzer with special plunger and sample holder for instrumental assessment of cooked macaroni stickiness

Appendix vi: Coefficient estimates, model significance, adjusted regression coefficient (adj R^2) and lack of fit values for proximate composition of macaroni produced from semolina, tef and chickpea.

Predictive model		Proximate composition						Mineral content		
		Moisture	Ash	Protein	Fat	Carbohydrate	Fiber	Fe	Zn	P
$Yi=\beta_1S+\beta_2T+\beta_3C+\beta_4ST+\beta_5SC+\beta_6TC+\beta_7STC+\beta_8ST(S-T)+\beta_9SC(S-C)+\beta_{11}TC(T-C)$	β_1	9.86	0.99	11.21	0.60	76.13	1.03	0.85	1.14	159.96
	β_2	10.41	1.52	12.68	1.07	75.54	2.08	8.63	1.66	181.85
	β_3	10.02	2.12	17.16	3.40	69.44	1.96	4.21	2.03	172.68
	β_4	- 0.013ns	-	3.76*	-	-	- 0.80*	-9.61*	-	-
	β_5	- 1.11*	-	4.84*	-	-	0.31ns	-1.55*	-	-
	β_6	- 0.12*	-	- 2.83*	-	-	-0.20*	-11.98*	-	-
	Adj R^2	0.9858	0.9742	0.9582	0.9580	0.9441	0.9235	0.9561	0.7209	0.8250
	R^2	0.9905	0.9777	0.9721	0.9636	0.9516	0.8853	0.9707	0.8140	0.8483
	Pred R^2	0.9756	0.9666	0.9326	0.9399	0.9223	0.8326	0.9312	0.5147	0.7752
	Mean	10.05	1.38	13.12	1.24	74.83	1.57	2.20	1.49	170.97
	C.v.%	0.30	2.78	1.61	7.73	0.35	8.47	10.74	11.16	2.05
	(Prob> F)	< 0.0001	< 0.0001	<0.0001	<0.0001	< 0.0001	< 0.0001	< 0.0001	0.0010	< 0.0001
	Lack fit	0.082	0.3165	0.4026	0.9957	0.768	0.071	0.3181	0.1988	0.3910

* significant at $p < 0.05$; ** highly significant at $p < 0.001$ and ns-not significant

Appendix vii: Coefficient estimates, model significance, adjusted regression coefficient (adj R2) and lack of fit values for sensory evaluation of pasta produced from semolina, tef and chickpea.

Predictive model		Cooking and textural analysis				
		Cooking weight	WAC	Cooking loss	Firmness	Stickiness
$Yi=\beta_1S+\beta_2T+\beta_3C+\beta_4ST+\beta_5SC+\beta_6TC+\beta_7STC+\beta_8ST(S-T)+\beta_9SC(S-C)+\beta_{10}TC(T-C)$	β_1	32.80	171.13	1.52	6.19	42.15
	β_2	38.12	196.55	3.97	4.40	43.37
	β_3	1395.41	7478.27	67.62	10.94	367.92
	β_4	2.77ns	12.37ns	-3.07**	-1. 24*	0.49 ns
	β_5	-2501.74**	-13352.66*	-114.52 ns	-4.50ns	-580.26*
	β_6	-2490.09**	-13348.59*	-124.95 ns	-6.51ns	-602.55*
	Adj R^2	0.97	0.73	0.98	0.95	0.93
	R^2	0.99	0.89	0.99	0.97	0.97
	Lack of fit	0.27	0.002	0.13	0.07	0.98
	C.v.%	1.16	3.48	4.80	3.35	0.87
	Model (Prob>F)	< 0.0001	< 0.0255	< 0.0001	< 0.0001	0.0006

* significant at $p < 0.05$; ** highly significant at $p < 0.001$ and ns-not significant

Appendix viii: Coefficient estimates, model significance, adjusted regression coefficient (adj R^2) and lack of fit values for sensory evaluation of pasta produced from semolina, tef and chickpea.

Predictive model		Sensory Evaluation							
		Color	Appearance	Flavor	Taste	Firmness	Stickiness	Bulkiness	Overall acceptability
$Yi=\beta_1 S+\beta_2 T+\beta_3 C+\beta_4 ST+\beta_5 SC+\beta_6 TC+\beta_7 STC$	β_1	7.51	6.96	7.02	6.74	6.88	6.74	6.58	7.40
	β_2	4.24	4.7	4.72	4.92	4.94	5.12	5.15	5.06
	β_3	24.34	18.69	5.35	9.46	15.65	19.89	5.94	16.11
	β_4	- 1.01ns	- 0.99ns	-	- 0.033ns	- 0.22ns	0.97ns	-	- 1.56ns
	β_5	- 25.83**	- 18.43*	-	- 4.01ns	- 14.80*	- 20.01*	-	-15.56ns
	β_6	- 29.13**	- 22.4*	-	- 6.73ns	- 15.79*	- 22.27*	-	- 16.89*
	β_7	-	-	-	- 26.46**	-	-	-	
	Adj R^2	0.9117	0.8317	0.7512	0.8847	0.8354	0.7507	0.5620	0.8231
	R^2	0.9411	0.8878	0.7844	0.9308	0.8903	0.8338	0.6204	0.8820
	Lack of fit	0.3427	0.1031	0.1181	0.0098	0.077	0.063	0.1121	0.0525
	C.v.%	7.31	8.01	7.92	5.12	5.67	6.94	7.19	6.94
Model	Type	Quadratic	Quadratic	Linear	Quadratic	Quadratic	Quadratic	Linear	Quadratic
	(Prob>F)	< 0.0001	0.0002	< 0.0001	< 0.0001	0.0002	< 0.0012	0.0018	0.0002

* significant at $p < 0.05$; ** highly significant at $p < 0.001$ and ns-not significant