EVALUATION OF THE QUALITY CHARACTERISTICS OF WHEAT - PLANTAIN COMPOSITE FLOUR BREAD CONTAINING GUM ARABIC FROM *Acacia Senegal var Kerensis*

LILIAN GESARE SOIBE

A thesis submitted to the Graduate school in the partial fulfillment for the requirements of the Master of Science Degree in Food Science of Egerton University

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DECLARATION

I declare that this thesis is my original work and has not been previously presented in this or any other University for any degree.

Signature ………………………………………… Date………………………….

Lilian Gesare Soibe

Reg No. KM16 /2855 /10

Email: lilsoibe08@yahoo.com

RECOMMENDATION/ APPROVAL BY SUPERVISORS

This thesis has been submitted with our approval as university supervisors

Signature …………………………………... Date……………………………..

Professor Anakalo Shitandi

Registrar – Division of Research, Extension and Linkages, Kisii University,

P.O. Box 408 – 40200, KISII – KENYA

Email: anakalos@gmail.com

Signature……………………………………… Date……………………………..

Dr. Ben N. Chikamai

Analytical Chemist and Director, Kenya Forestry Research Institute

P. O. Box 20412 – 00200, NAIROBI, KENYA

Email: bnchikamai@gmail.com

Signature…………………………………… Date………………………………

Professor Symon Mahungu, PhD

Professor of Food Chemistry, Department of Dairy and Food Science

Egerton University P.O. Box 536- 20115, EGERTON

Email: smahungu@yahoo.com

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ABSTRACT

The uses of composite flour in bread making are becoming more important as people become health conscious and accept the role of functional foods globally. The effect of partial replacement of wheat with 10% to 40% plantain flour and the subsequent effect of 1% to 3% gum arabic addition on composite bread quality attributes was investigated. It was hypothesized that wheat- plantain flour physicochemical properties did not differ from the control (100% wheat); and that neither substitution of 10% to 40% plantain in wheat nor incorporation of 1% to 3% gum arabic had an effect on quality attributes of wheat –plantain composite bread quality attributes. To test these hypotheses, several tests were done namely: proximate and mineral content analysis, farinograph test, analysis of other physical properties, specific loaf volume determination, pasting and texture profile analysis (TPA). The results indicated that the Kenyan plantain under study had noticeably higher protein (5.84±0.22%) and ash content (3.80± 1.42%) and a lower crude fat content (0.31± 0.01%) on dry basis. Moisture content, crude protein (CP) and crude fat (CF) decreased while carbohydrate content, crude fiber and ash content increased as the level of plantain substitution increased from 0 to 40%. Plantain substitution in wheat did not adversely alter the mineral content except for potassium which was significantly higher in the composites than the control at $P \leq 0.05$.The potassium levels in the wheat- plantain composite flour ranged between 29.74±3.53 to 62.59± 6.69 mg/ 100g compared to the control which had 17.17±0.39 mg/ 100g. The difference between the control and the composites was statistically significant ($P \leq 0.05$) at all levels of plantain incorporation for water-holding capacity (WHC), foaming capacity (FC), Emulsion capacity (EC) and bulk density (BD). All the four composites differed significantly from the control ($P \leq 0.05$) with respect to farinograph parameters namely: water absorption (WA), dough stability (DS), departure time (DT) and peak time (PT). Wheat-plantain composites produced dough that took longer than the control to breakdown thus stronger dough. Plantain composites had a higher peak viscosity which indicated that the composites had a higher swelling index than the wheat (control). The results indicated that low levels of plantain substitution may have no adverse effect on gluten functionality since composite’s bread volume did not differ significantly from the control ($P > 0.05$). Gum Arabic as used in this study was found to improve the bread’s textural qualities such as reducing bread hardness and chewiness and increasing bread springiness.

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LIST OF ACRONYMS

AACC-	American Association of Cereal Chemists
AOAC-	Association of Official Analytical Chemists
ANOVA -	Analysis Of Variance
AT	Arrival Time
BD	Bulk Density
BU-	Brabender Unit
BV	Breakdown Viscosity
CF	Crude fibre
CP	Crude Protein
DS	Dough Stability
DT	Departure Time
EC	Emulsion Capacity
ES	Emulsion Stability
FC	Foaming Capacity
FS	Foaming Stability
FV	Final Viscosity
GA	Gum Arabic
KALRO	Kenya Agricultural and Livestock Research Institute
KIRDI	Kenya Industrial Research and Development Institute
MTI	Mechanical Tolerance Index

NCD	Non Communicable Diseases
OAC	Oil Absorption Capacity
PT	Peak time
PV	Peak Viscosity
SCFA	Short Chain Fatty Acids
SV	Setback Viscosity
TPV	Time to Peak Viscosity
USDA	United States Department of Agriculture
WHC	Water Holding Capacity
SSL	Sodium Steroyl Lactylate

CHAPTER ONE: INTRODUCTION

1.1 Background of the problem

There are several nutrition related challenges worldwide including non-communicable (NCD) diseases like diabetes, hypertension and conditions such as cancer. This has created a need for the development of functional and nutritionally beneficial foods (Angioloni and Collar, 2011). This together with the emergence of a trend towards healthy eating has made people to be more receptive to plantain because of its functional and nutritional benefits (Singh, 2008). Plantain is rich in resistant starch and essential minerals like potassium, phosphorous and magnesium (Krishnan and Prabhasankar, 2010; Daniells, 2003). It is also considered to be rich source of polyphenols with antioxidant effects (Ovando-Martinez *et al*, 2008).

The importance of various bakery products including bread in the current eating habits suggests that they can serve as vehicles for important nutritional components (Ivanovski *et al*, 2012; Mashayekh *et al*, 2008).Traditionally, bread is made from wheat but the use of other non-wheat flours such as barley, pea, spelt, rye, buckwheat, soy bean, brown rice, chestnut, Moringa seed fenugreek and oat flour have been reported. (Alasino *et al*, 2011; Angioloni and Collar, 2011; Demirkesen *et al,* 2011; Yamsaengsung *et al,* 2010; Finocchiaro *et al,* 2010; Renzetti and Arendt *et al*, 2009; Mariotti *et al,* 2006; Shalini and Sudesh, 2003; Shogren *et al*,2003). Hence, enrichment of bread with plantain flour seems to be a viable option in the attempt to curb some nutrition related challenges.

The use of non-wheat flours like plantain flour in making composite bread is constrained by a number of challenges. It has been reported in most literature on composite bread that as the level of substitution with other flours in wheat flour increased, bread quality progressively reduced (Yaseen *et al,* 2010; Conforti and Davis ,2006; Dhingra and Jood, 2004). The reduction in quality attributes has been attributed to gluten dilution leading to reduction of flour strength and gas retention capacity (Muranga *et al,* 2010; Dhingra and Jood, 2004). This situation ultimately leads to reduced sensory appeal for most composite breads necessitating the use of bread improvers and dough strengtheners like gums. Gum Arabic in particular is an example of bread improvers and dough strengthener (Yaseen *et al,* 2010). Studies have shown that incorporation of gum arabic in both wheat bread and composite bread significantly improved bread quality attributes such as dough water absorption and improved mechanical tolerance (Yaseen *et al*, 2010; Asghar *et al*, 2005; Toufeli *et al*, 1994). It also resulted in stronger dough (Yaseen *et al*, 2010). The resultant bread had improved loaf volume, improved specific volume, better sensory attributes, improved moisture retention and it exhibited a longer shelf-life (Yaseen *et al,* 2010; Asghar *et al*, 2005).

The use of plantain flour and green banana flour in making weaning food, snacks, pasta/ noodles, cake and chips has been intensively investigated (Choo and Aziz, 2010; Bukusuba *et al*, 2007; Otegbayo *et al,* 2002; Yomeni *et al,* 2004). Howhever, reports on the quality characteristics of bread baked using wheat – plantain composite flours fortified with gum Arabic are almost non-existent. Thus, the objective of the current work was to study the effect of gum arabic on the quality characteristics of composite bread prepared from wheat - plantain flour. The information obtained from the current study will be important especially in functional foods formulation and preparation; ultimately promoting industrial utilization of both plantain and gum Arabic.

1.2 The statement of the problem

Although plantain is produced in significant amounts in Kenya and in the world; its industrial use is underdeveloped despite studies suggesting its importance as a functional food due to its resistant starch and high fiber content. Consequently, plantain farmers and traders have had to contend with immense losses during commercial handling. In addition, a recent trend towards healthy eating and development of functional foods has been observed. Bread enrichment is a viable option to solve this problem since bread is a common staple food in many households. Developing nutritionally beneficial bread that is attractive to the consumers and endorsed by both the health and food safety authorities has been a challenge. This is because of the deterioration of bread quality following the addition of non-wheat flour to wheat flour bread.

1.3 Objectives

1.3.1 General Objective

To investigate the effect of gum arabic on the quality characteristics of composite bread prepared from wheat - plantain flour.

1.3.2 Specific Objectives

i. To analyse the physicochemical properties of wheat- plantain composite containing 0 - 40% plantain substituted in wheat flour.

ii. To determine the effect of partial replacement of wheat flour with plantain from 0 % to 40% on the bread's quality characteristics (that is physicochemical, rheological and bread attributes).

iii. To determine the effect of gum arabic on quality attributes of the wheat- plantain composite flour bread containing 0% to 40% plantain flour.

1.4 Hypotheses

i. The wheat- plantain composite flour's physicochemical properties did not differ from the control (100% wheat).

ii. The substitution of plantain flour (0% to 40%) in wheat will have no effect on wheat - plantain bread quality attributes.

iii. The incorporation of gum arabic (1% to 3%) will have no effect on the quality attributes of wheat - plantain composite flour bread.

1.5 Justification of the study

Although bread is an important breakfast item, improving its nutrient density without significantly altering its quality attributes has been a challenge. The proposed enrichment of bread with plantain flour while attempting to improve the composite bread's quality attributes using gum arabic is expected to not only produce acceptable and nutritious bread with functional properties but it will also promote the industrial production and utilization of plantain flour and gum arabic in Kenya and other developing countries. This study used gum arabic to improve bread quality attributes and therefore generated information on the effect of gum arabic on quality attributes of plantain-wheat composite bread containing 10% to 40% plantain flour. The information so generated will be useful in promoting and enhancing the potential of commercial utilization of these two locally available materials (plantain and gum Arabic).

CHAPTER TWO: LITERATURE REVIEW

2.1 Plantain flour

A trend towards healthy eating has been witnessed (Singh *et al*, 2008). Therefore, food components that were once thought to be non-nutritive have since been found to be the key in disease prevention and overall maintenance of good health (Conforti and Davis, 2006). Considerable effort has been put into developing bread that has both health benefits and good sensory properties (Ivanovski *et al*, 2012). One strategy to achieve this is by enriching bread with plantain flour. Plantain (*Musa Spp*.) is a climacteric plant and it is extensively grown in the tropical and subtropical regions (Daniells, 2003). It is a good source of carbohydrates and nutritionally interesting bioactive compounds, fibre, resistant starch, vitamin A, B, C as well as calcium and iron (Kolawole and Ayojesuomi, 2010; Daniells, 2003). There is great interest in green bananas and plantain because of their functional components i.e. resistant starch and dietary fiber. The name plantain refers to the species that requires cooking (Adegunwa, 2011). Plantain is usually harvested when it is mature but unripe. It is highly perishable since it ripens within 2- 7 days when stored under normal conditions (Kolawole and Ayojesuomi, 2010; Muranga *et al,* 2010). Plantains are produced in excess in plantain producing regions leading to large quantities being lost during commercial handling (Ovando- Martinez *et* al, 2009). In tropical regions, postharvest losses are estimated to be about 300 g/ kg of produce (Yomeni *et al*, 2004). This situation is exacerbated by the fact that, the industrial utilization of plantain is underdeveloped. Plantain flour contains a high amount of indigestible compounds such as resistant starch and dietary fiber which have been reported to possess beneficial effects on human health (Bello-Pérez *et al,* 2011; Rabbani *et al* ,2010).Unripe banana flour has also been considered as a source of polyphenols with antioxidant effects (Ovando-Martinez *et al,* 2008). Banana and plantain contain various antioxidants namely catechin, epicatechin, and gallocatechin (Krishnan and Prabhasankar, 2010).

It has been reported in most literature on fortified bread that incorporation of non-wheat components diminished bread quality notably the bread volume, crumb texture, moisture retention and reduction in dough mechanical tolerance (Conforti and Davis , 2006).This has been attributed to the low-gluten content of the non-wheat components (Conforti and Davis, 2006; Dhingra and Jood, 2004). Gluten quantity and quality imparts such attributes as better gas production and retention capacity in dough's and it forms a cellular network of crumb, which imparts desirable characteristics to bread (Muranga *et al,* 2010; Dhingra and Jood, 2004). The non-wheat components cause a dilution and/ or weakening of wheat gluten matrix which results in diminished bread quality (Muranga *et al,* 2010). It is therefore crucial to remedy this problem to produce a functional, nutritious, yet acceptable bread product. Studies have shown that dough strengthening treatments such as the addition of gluten, hydrocolloids such as gum arabic, oxidants such as bromate or ascorbic acid, surfactants such as Sodium Steroyl Lactylate (SSL) as well as water addition give a larger volume (Alasino *et al,* 2011; Hemeda and Mohamed, 2010; Mohammed *et al*, 2010; Muranga *et al*, 2010; Shogren *et al*, 2003).

2.2 Health benefits of plantain in the diet

Mature green plantain is rich in resistant starch. This starch is resistant to α-amylase and glucoamylase; the resistance is attributed to its high degree of crystalline intrinsic structure (Krishnan and Prabhasankar, 2010). Funtes- Zaragoza *et al* (2011) define resistant starch as a portion of starch that can resist digestion in the small intestine by human pancreatic amylase, therefore reaching the colon undigested .The functional benefits of resistant starch are similar to those of soluble , fermentable fibre in that they increase fecal bulk, lower colonic pH, improve glycemic control, enhance bowel health and reduce the risk factors for cardiovascular diseases (Funtes- Zaragoza *et al*, 2011; Mitcheff and O' Neal, 2009). In addition green bananas contain a high amount of total dietary fiber content, especially hemicellulose (Bello-Pérez *et al,* 2011). Resistant starch and dietary fiber are of great interest because they are fermented in the large intestine, producing short-chain fatty acids, that are associated with the prevention of colon cancer and cardiovascular diseases (Bello-Pérez *et al,* 2011; Muranga *et al,* 2010). Uzomah and Ofuya (2009) reported the principle end products of matured green plantain fibre (among other dietary fibre) fermentation to be short chain fatty acids (SCFA). These short chain fatty acids have an acidifying effect on the caecum thus inhibiting the growth of bacteria responsible for producing enzymes that have carcinogenic or mutagenic effect since their optimum pH is 7 or above (Uzomah and Ofuya, 2009). The soluble and insoluble fiber fractions in banana have been reported to have blood pressure lowering effects, reduction of salt sensitivity and reduction of susceptibility to kidney stones (Mohamed *et al,* 2010). In addition bananas contain high amounts of essential minerals such as potassium, phosphorous, chlorine and magnesium and vitamins A, B1, B2, and ascorbic acid. (Krishnan and Prabhasankar, 2010 ; Daniells, 2003). Potassium, which is one of the major mineral in plantain, is the third most abundant mineral in the human body and plays a crucial role in regulating not only blood pressure, but also water retention and muscle activity (Mohamed *et al*, 2010).

Green bananas have been recognized for the important role they play in the management of diarrhea. A study carried out in rural Bangladesh reported that plantain played a key role in hastening the recovery of both acute and prolonged childhood diarrhea managed at home. This is attributed to the high content of amylase- resistant starch which is fermented into short- chain fatty acids thus stimulating colonic salt absorption and hence water absorption (Rabbani *et al*, 2010). It has also been reported in literature that Green, unripe plantains have a protective capacity against acute aspirin-induced gastric mucosal injury. They are effective in healing of ulcers as well as having protective effect on the gastric mucosa against an acid insult in rats. This is attributed to the presence of water-soluble polysaccharides and surface-active phospholipids in unripe plantains. These water soluble polysaccharides and surface active phospolipids increase the resistance of the gastric mucosa and promote healing of the ulcers (Dunjic`*et al*, 1993).

2.3 Effect of plantain flour addition on composite and bread quality attributes

2.3.1 Effect of plantain flour incorporation on nutrient composition

a) Flour composition

Muranga *et al* (2010) observed higher levels of ash and starch, and lower levels of moisture in banana flour when compared to the control, which comprised of 100% wheat flour. Bhargava *et al* (2011) , while studying the effect of replacement of whole wheat flour with a blend containing barley, banana and soy protein isolate up to 60% on North Indian Parrotta (a type of flat bread), reported low protein content in banana flour, about 3.5 g/ 100 g. The protein in banana flour had lower digestibility than whole wheat protein. The banana however was high in dietary fiber (that is 13.9 g/ 100 g) and high total starch of about 78.2 g/100 g of which 25.1 g was resistant starch and the rest was soluble starch.

b) Composite bread and other Composite food commodities

Mepba *et al* (2007) reported that incorporation of plantain flour in composite bread was not significantly different from the control in nutrient composition at 5% level of incorporation. Further increase in plantain flour levels (up to 30%) led to a decrease in protein, fat and moisture content from 10.2 to 5.6%, 1.7 to 0.6% and 12.6 to 8.2% respectively and an increase in carbohydrate content. A similar trend was reported by Ovando- Martinez *et al* (2009) while working with unripe banana flour as a raw material to increase the indigestible carbohydrates of pasta. Similarly, a comparative study on plantain containing wheat bread and whole wheat bread reported an increase in ash content as plantain level increased progressively from 0 to 15 % with the highest quantity reported for 15% plantain substitution level (Olaoye *et al,* 2006). In Nigeria a combination of soy and plantain flour was used to make extruded snacks. The snacks had a low fat content, high protein, carbohydrate and ash content; the high protein content could have been due to the presence of soy in the snack. In addition, the snack had high digestibility (Otegbayo *et al*, 2002). A similar low fat content was reported in other studies such as a study carried out to investigate the influence of finger millet and banana flours on pasta quality (Krishnan and Prabhasankar, 2010). Choo and Aziz (2010) observed higher fiber content and ash content in noodles following plantain substitution.

2.3.2 Effect of plantain flour incorporation on rheological properties of the dough

Farinograph tool is one of the appropriate tool in testing dough rheology (Mohamed *et al*, 2010; Xu *et al,* 2014). Dough rheology has an influence on both the end product's quality and dough machinability (Xu *et al,* 2014). Farinograph parameters of any dough are beneficial in determining its response to mechanical mixing because of the dough's interaction with water; it mimics the shearing that takes place during dough mixing in bakeries (Shittu *et al*, 2013).Mohamed *et al* (2010) reported that the presence of banana flour increased the farinograph water absorption, decreased the dough mixing tolerance and dough stability. These researchers attempted to explain this phenomenon. In their opinion the presence of banana fiber dilutes wheat gluten functionally. This is due to its lack of viscoelasticity and a heightened water holding capacity. This increases dough mixing time because it will take longer for gluten to form disulphide bonds between its fractions. This is important in forming the film required to hold the dough components together (Mohamed *et al*, 2010). Other studies have reported similar results, for example Bhargava *et al* (2011) reported an increase in the farinograph water absorption and dough development time with an increase in the level of substitution of a combination of barley, banana and soy protein isolate from 0 to 60%. The extensograph resistance to extension also increased and the extensibility decreased. This is indicative of an increase in elasticity and a decrease in extensibility. The opposite is true for native wheat. Foreign flours alter the elasticity and extensibility properties of wheat flour dough that are characteristic of the presence of gluten in it (Bhargava *et al*, 2011). In the recent past, a study carried out to investigate the effect of two variables – tooke (Ugandan for cooking banana flour) and vital gluten on physicochemical and dough rheological properties reported a similar increase in water absorption with the increase in both variables. On the contrary, dough stability to mixing reduced with the increase in raw tooke flour and increased with the increase in vital wheat gluten (Muranga *et al*, 2010). The researchers also reported that as the level of raw tooke flour increased, the degree of dough softening increased. This was according to farinograph reading. The extensograph revealed a destabilization of resistance to extension and an increase in extensibility which is characteristic of weak gluten. On the contrary, the control (100% wheat flour) had a higher resistance to extension and a reduction in extensibility (Muranga *et al*, 2010).

2.3.3 Effect of plantain flour incorporation on bread attributes

2.3.3.1 Loaf volume and specific loaf volume

Various studies have reported that as non-wheat flour levels increased, the loaf volume decreased while the loaf weight increased (Conforti and Davis, 2006; Ribbota *et al*, 2005; Dhingra and Jood, 2004). Mepba *et al* (2007) observed a decrease in loaf specific volume from 5.3cc/g to 4.2 cc/g and oven spring from 2.1 to 1.0 as the level of plantain substitution increased from 0 to 30 %.

Mohamed *et al* (2010) prepared different wheat- plantain composite bread formulations containing 10%, 15%, 20%, 25%, and 30% banana powder and maintained vital wheat gluten at 25% in all blends including the control which had 0% plantain. Unlike other studies, the researchers reported that the 10%, 15%, 20%, and 25% blends exhibited considerably higher loaf volume compared to the control (0% plantain); the 30% blend's loaf volume was the most comparable to the control (Mohamed *et al, 2010*). The increase in loaf volume was due to incorporation of vital wheat gluten which lacked in the other studies that reported a reduction of loaf volume. The study shows that vital wheat gluten addition had positive effect on loaf volume only at low levels of non-wheat flour substitution (i.e. up to 25%) and the researchers also had to make a number of recipe modification namely omission of sugar and salt and the dough was proofed in a pan without punching. The researchers reported an increase in unfreezable water in the presence of banana flour and a 50% reduction in bread stalling.

Mitcheff and O'Neal (2009) reported an increase in the force required to compress a slice of bread using a texture analyser as the level of plantain flour substitution in wheat flour bread increased from 0 to 50% and finally to 100%. This suggests that the bread increased in firmness. This is an important factor in bakery products because it strongly correlates with consumers' perception of bread freshness (Sabanis *et al,* 2009). Although Mitcheff and O' Neal (2009) did not investigate the effect of plantain flour substitution on loaf volume, the results indicate that there must have been a reduction in loaf volume, as one study has shown that there is an inverse relationship between bread loaf volume and firmness (Ribotta *et al,* 2005). In addition as the level of substitution increased the color became darker in the resultant product with the control having the lightest colour and 100% plantain having the darkest colour (Mitcheff and O, Neal 2009).

Bhargava *et al* (2011) reported a progressive decrease in texture as was indicated by a decrease in shear force in North Indian Parrotta (a type of flat bread) in which a blend of barley, plantain and soy protein isolates had been incorporated from 0 to 60%. The shear force decreased from 1400g to 1100g. The resultant North Indian Parrotta had a darker colour, that is; it changed in colour from light brown to dark brown; the color intensified with the increase in the level of substitution from 0 to 60%.

2.3.3.2 Sensory attributes

Olaoye and others (2006) after comparing wheat- plantain composite bread and whole wheat added bread (up to 15% of each added flour level) gave an interesting report. They reported that there were no significant differences in sensory characteristics at all levels of plantain substitution indicating that whole wheat flour is similar to plantain in sensory characteristics at the 15% level of substitution and below (Olaoye *et al,* 2006). This was different from a study carried out by Bhargava *et al* (2011) on North Indian Parrotta (a type of flat bread) in which a blend of barley, banana and soy protein isolates had been incorporated from 0 to 60%. A decrease in sensory scores (such as pliability, eating quality and appearance) with the increase in the level of barley, banana and soy protein isolate blend substitution was reported (Bhargava *et al, 2011*). In their study, the resultant bread was reported to be thick, it had a dominating foreign taste and it increased in residue formation in the mouth. Nonetheless, it is not clear which component contributed the most to the foreign taste and residue formation since soy protein isolate; banana and barley were used in combination and not in isolation. The difference could also have been due to the difference in sensory attributes tested because North Indian Parrotta is not pan bread per se (Bhargava *et al, 2011*).

Another study carried out with 0%, 50% and 100% plantain flour substitution in wheat bread reported an increase in bread darkness, moistness and softness with the increase in level of substitution; the panelists preferred the control bread (0 % plantain) over the other two bread (Mitcheff and O'Neal, 2009). This indicated that the acceptability of plantain bread was poor. This could have been due to the high levels of plantain used without any form of bread improver to improve the bread attributes thus improve the bread's acceptability.

2.3.4 Effect of incorporation of plantain on other flour attributes

Mepba *et al* (2007) reported an increase in water absorption, oil absorption and foam capacity with the increase in plantain flour content in the composite flour blends. There was no significant difference in foam stability between the composite flours and the control. A decrease in the energy in the flour samples was reported as the levels of substitution with plantain flour increased (Mepba *et al*, 2007).

2.4 Gum Arabic

The traditional definition of gum arabic is a substance which exudes from Acacia Senegal or related species (Diallo *et al*, 2015). Unlike other vegetable gums it has a high solubility in water i.e. up to 50%, forming a colourless, tasteless solution. In addition, its interaction with other chemical compounds is minimal (Salif, 2008). Gum arabic is a slightly acidic complex compound composed of glycoprotein and polysaccharides and their calcium, magnesium and potassium salts (Salif, 2008). Gum arabic is mainly galactane polymer with side chains of galactose and/ or arabinose and ultimately ending in side chains of rhamnose or glucoronic acid (Salif, 2008). The human digestive system is incapable of synthesizing and secreting enzymes capable of hydrolyzing this polysaccharide (Salif, 2008). It therefore travels through the digestive system undigested and it only gets fermented completely in the large intestine such that there is no detectable amount excreted in faeces (Salif, 2008). The end products of this breakdown are gases that are excreted during respiration or absorbed in the mucus membranes in the form of short chain fatty acids (Salif, 2008).

Most of gum arabic is produced from Africa, Kenya being among the top 17 gum arabic producing countries (Salif, 2008). It is used in the food industry not only to set flavours, but also as an emulsifying agent, to prevent recrystallization of sugar in confectionary and as a stabilizing agent in frozen dairy products (Hemeda and Mohamed, 2010; Salif, 2008). Its viscous and adhesive properties are of importance in the bakery industry especially where non-wheat flours are used. This is because such bakery products require polymeric substances that mimic the viscoelastic properties of gluten in the dough (Toufeili *et al*, 1994). Gums have other important properties such as controlling the pasting properties of food and improving the moisture content. They also maintain overall product quality during storage (Hemeda and Mohamed, 2010).

2.4.1 Effect of incorporation of gum arabic on wheat – plantain composite bread quality

2.4.1.1 Rheological properties of the dough

Yaseen *et al* (2010) carried out a study to investigate the effects of hydrocolloids i.e. pectin and gum arabic on corn-wheat pan bread .They reported that, although corn flour addition reduced water absorption from 68.5% to 66.5%, gum arabic addition in wheat- corn flour increased dough water absorption from 66.5 to 67.4%. This is because gums have a high water holding capacity and in addition they retard moisture migration in the dough (Asghar *et al,* 2005). The dough development time and dough stability that had decreased on addition of corn flour increased with the incorporation of gum arabic (Yaseen *et al*, 2010).Addition of corn flour progressively increased dough weakening, reduced the extensibility, resistance to extension and energy, these attributes significantly improved following the incorporation of gum arabic (Yaseen *et al*, 2010).

2.4.1.2 Bread and Sensory attributes

According to Yaseen *et al* (2010) loaf volume, specific loaf volume and crumb moisture that had reduced in composite flour bread following the incorporation of corn flour into wheat was significantly improved by incorporation of 1- 3% gum arabic. These researchers concluded that 2% was the best level of gum arabic to use in bread making. The effect of gum arabic on bread attributes was in agreement with another study carried out by Asghar *et al* (2005) while investigating whether gums improved quality characteristics of frozen dough, this researchers reported improvement in loaf volume , internal and external appearance (according to their sensory panel) following the incorporation of gum arabic.

Hemeda and Mohamed (2010) reported that gum arabic and locust bead gum improved moisture retention and maintained the overall bread quality after storage. Unlike the other studies, these researchers replaced wheat flour with 5 and 10% gum arabic itself and not non-wheat flours (Hemeda and Mohamed, 2010). In addition they reported an increase in mineral content i.e. sodium, calcium, magnesium and potassium following the incorporation of gum arabic into wheat bread when compared to the control which was 100% wheat flour.

Yaseen *et al* (2010) reported that sensory attributes like symmetry of shape, crust colour, break and shred, crumb texture, crumb colour, aroma, taste and mouth feel significantly improved in wheat- corn flour pan bread on addition of gum arabic. Similarly, Toufeli *et al* (1994) reported that gluten free pocket type bread baked from pre-gelatinized rice flour and pre-gelatinized corn starch with corn flour, in which gum arabic had been incorporated was similar to the control in sensory attributes .The control was baked from the commercial baker's flour. The presence of gum arabic in the non-wheat flour imparted dough strength and improved its tolerance to mechanical handling.

Elsewhere, researchers have reported that a combination of additives (i.e. 5% dry gluten powder + 0.5% Sodium Steroyl Lactylate and 0.5 % hydroxyl propyl methyl cellulose), increased the farinograph water absorption and dough development time. The combination of additives imparted a positive effect since they had a restorative ability on the dough's elasticity and extensibility at 40% barley, banana and soy protein isolate substitution level which had otherwise been destabilized by the addition of barley, banana and soy protein isolate blend to wheat flour. The combination of additives decreased the resistance to extension from 900 to 570 Brabender Units (BU) and an increase in extensibility value from 38 to 50 mm extensograph reading (Alasino *et al*, 2011).

There are reports in literature that bread improving additives such as hydroxyl propyl methyl cellulose enhance water retention and interfacial activity within the dough system during proofing and the formation of gel network on heating in the bread making process (Bell, 1990; Bhargava *et al*, 2011).

CHAPTER THREE: MATERIALS AND METHODS

3.1 Flours

Njoro BW II wheat was purposely picked because of its strong glutein. About 40 kg of wheat was randomly drawn from KARI pool storage and milled to provide wheat flour. The plantain bunches were systematically sampled from Nyamache- Kisii farmer where every 10th mature bunch of banana was picked. Ng'ombe plantain cultivar (genome AAA) were obtained at stage 1-2 (i.e. entirely green) (Yomeni *et al,* 2004) from Kisii. Plantain was processed into flour following the procedure of Yomeni *et al* (2004). The plantain fingers were separated, washed and peeled. The peeled plantains were immersed in water immediately in order to limit air – peeled plantain contact which favors enzymatic browning (Yomeni *et al,* 2004). The peeled plantain were cut into slices of about 3- 4 mm thick and blanched at 80 ºC for 15 minutes. This treatment was meant to inhibit the action of the polyphenol oxidase which was responsible for the enzymatic browning. The samples were dried in an oven set at 65 ºC for 48 hours. The dried slices of plantain were ground using a mill - UTL USCH/UZ mill (Bauermeister GmbH, Hamburg, Germany) with a mesh size of 0.8 mm. The flour obtained was stored hermetically in polyethylene bags awaiting subsequent use (Yomeni *et al*, 2004).

3.1.3 Formulation of composite flours

Composite flours were prepared by substituting wheat flour with plantain flour in the following proportions; 100:0, 90:10, 80:20, 70:30 and 60:40 wheat flour to plantain flour on w/ w basis. A second set of composite flours were prepared as described but now containing 1%, 2% and 3% gum arabic (*Acacia Senegal var Kerensis)* per every composite flour proportion and treated like the previous set of composite flour. The composite flours were blended to obtain a homogenous mixture using a manual rotary blender, crafted in 'jua kali'- Kenya.

3.2 Physicochemical properties of the flours

3.2.1 Moisture content

Moisture content of the samples was determined using Method 14.004 (AOAC, 1984). Approximately 5 g of the wheat- plantain composite flour samples were dried in a hot air oven at

105°C until constant weight was achieved (about 5- 6 hours). Moisture content was calculated as a percentage of the total dry matter in the sample.

3.2.2 Crude protein

Crude protein content was determined using the improved Kjeldahl method (Method 46-12A; AACC, 2000). About 0.2 g flour samples of known dry matter content were weighed accurately in a nitrogen free-filter paper, folded carefully and placed in a Kjeldhal flask. One tablet of Kjeldhal catalyst and 5 ml concentrated sulphuric acid were added to the flask. The mixture was digested alongside a blank sample consisting of only a filter paper, Kjeldhal catalyst and sulphuric acid in a fume cupboard for about 2 h until a clear solution was obtained. After cooling, enough distilled water was added to increase the volume of the mixture to three-quarters of the flask. The flask was connected to the distillation unit after adding 1 ml phenolphthalein and 10 ml 40% sodium hydroxide solution. Distillation was carried out until there was no reaction between a drop of the distillate with Nessler's reagent placed in a test tube. The distillate was collected in a 400 ml conical flask containing 50 ml boric acid solution and 2-3 drops bromocresol blue indicator. The excess hydrochloric acid solution in the distillate was back titrated with 0.1 mol/l sodium hydroxide. The percent nitrogen was calculated as follows:

$$\%\ \text{nitrogen} = C_{HCl} \times \frac{(V_{HCl(s)} - V_{HCl(b)}) \times 14.007}{S} \qquad (3.1)$$

Where: C_{HCl} = normality of hydrochloric acid

$V_{HCl(s)}$ = volume of hydrochloric used to titrate the sample in ml

$V_{HCl(b)}$= volume of hydrochloric used to titrate the blank in ml

S = sample weight in g

Protein content was calculated as percent nitrogen multiplied by 6.25.

3.2.3. Crude fibre

Crude fibre determination was done according to AOAC standard methods of analysis (AOAC, 1984). Approximately 2 g flour sample of known dry matter content was accurately weighed into a graduated 600 ml beaker and about 100 ml boiling distilled water and 2.04 mol/l sulphuric acid solution added. The volume of the mixture were made up to 200 ml with boiling distilled water and maintained at this volume whilst boiling for 30 min on a hot plate. The mixture was filtered using a Buchner funnel lightly packed with glass wool. The residue was washed three times with boiling distilled water. The residue and the glass wool were transferred quantitatively back to the beaker and about 100 ml of boiling distilled water and 25 ml of 1.73 mol/l potassium hydroxide solution added. The volume was made up to 200 ml with boiling distilled water and this volume maintained whilst boiling on a hot plate for 30 min. The mixture was filtered again using glass wool and it was washed three times with boiling distilled water. The residue was further washed three times with small amounts of ethanol. The residue and glass wool were transferred quantitatively to a porcelain dish and dried in an air oven at 105^0C for 2 h. The sample was cooled and weighed in the porcelain dish before igniting at 550^0C in a muffle furnace to constant weight after which the sample was cooled in the dish and weighed. The crude fibre content were calculated and expressed as a percentage of the sample's dry matter content.

3.2.4. Total ash

The ash content of the flours was determined using AOAC Method 942.05 (AOAC, 1984) in triplicates. Approximately 2 g of each sample was weighed into a platinum crucible and placed in a temperature controlled furnace preheated to 550 °C. The samples were held at this temperature for 2 hours. The crucible was then transferred directly to a desiccator, cooled and weighed. Ash content was reported as a percentage of the whole sample.

3.2.5 Mineral profile

For mineral profiling of the samples, the ash from 3.2.4 above was added to 10 ml 50% hydrochloric acid and heated until a yellow colour was observed. This was made up to 100 ml using distilled water. The concentrations of calcium, iron, zinc, magnesium, manganese, copper, sodium and potassium were determined using an AA-6300 atomic absorbance spectrophotometer (Shimadzu Scientific Instruments, Kyoto Japan). To determine phosphorus; 20 ml of the above solution was placed in a 50ml volumetric flask. 10 ml of ammonium molybdate metavanadate reagent was added and the mixture diluted with distilled water to the 50 ml mark. The absorbance of the sample versus a blank at a wavelength of 430nm was measured after 10 minutes, using a UV-Visible spectrophotometer (Varian Carry win 50 UV-Visible spectrophotometer model, From Australia, year 2002).

3.2.6 Crude fat

Crude fat was determined according to AOAC approved method 24.005; (AOAC, 1984). Approximately 5g ground sample of known dry matter content was weighed accurately into an extraction thimble and covered with cotton wool. The thimble was placed into the soxhlet extractor and the fat extracted into a tared flask for 6 h using petroleum ether (boiling point, 40-60^{0}C). The solvent was then evaporated in a rotary evaporator and the residue dried in an air oven at 105^{0}C for 1 h before weighing. The crude fat content was expressed as percentage of the sample's dry matter content.

3.2.7 Carbohydrate content

The carbohydrate content was obtained by finding the difference as described by Tekle *et al* (2009) and Yomeni *et al* (2004).

The calculation was performed using the following expression.

$$\% \text{ Carbohydrate} = 100 - [\text{Protein} + \text{fat} + \text{ash} + \text{moisture}] \qquad (3.2)$$

3.2.8 Water-holding capacity

The water-holding capacity for the different flour mixtures were determined using the method described by Vittadini and Vodovotz (2003). About 5g of each composite flour was weighed into a 50-mL centrifuge tube and 30 mL water was added to the tube. The slurry was stirred for 5 minutes and allowed to stand for 30 minutes at ambient conditions. The flour mixture was centrifuged at 4500 revolutions per minute for 25 minutes and the volume of free liquid recorded. The water holding capacity was expressed as the amount of water absorbed per gram of sample on dry weight basis, water density was assumed to be 1g/ml (Mebpa *et al*, 2007)

3.2.9 Oil absorption capacity

Oil absorption properties of the composite flour were determined using the method described by Mebpa *et al* (2007) with minor modifications. About 0.1g flour sample was mixed with 1 ml of oil in a calibrated centrifuge tube. The samples were mixed thoroughly with Janke and Kenkel mixer and allowed to stand at 30 °C for 30 minutes. The samples were centrifuged at 10,000 revolutions per minute for 30 min and the volume of supernatant in a graduated tube determined. The oil density was determined by weighing a known volume of oil and expressing it in g/ml. The oil absorption capacity was expressed as percentage of the amount of oil absorbed (in grams) per gram of sample on dry weight basis.

3.2.10 Foaming capacity and stability

Foaming capacity and stability were determined using the method described by Mebpa *et al* (2007). About 0.5 g flour sample were blended for 30 min with 40 ml distilled water at the highest speed in a blender. The mixture was transferred into a 100 ml graduated cylinder. The blender was rinsed with 10 ml distilled water which was added gently into the graduated cylinder. The foam volume in the cylinder was recorded per sample after 30 min standing. The ***foam capacity*** was expressed as a percentage increase in volume. The foam volume was recorded 1 h after standing the whipped mixture to determine the ***foaming stability*** as a percentage of the initial foam volume.

3.2.11 Emulsion capacity and stability

Emulsion capacity and stability were determined using the method described by Mebpa *et al* (2007). ***Emulsion capacity:*** A flour sample weighing about 2 g was blended with 100 mL distilled water for 30 seconds in a blender at high speed. After complete dispersion, about 5 ml sunflower oil was added from a burette and the mixture blended, this was repeated until phase separation occurred. The volume of oil used (volume of oil emulsified) was determined. Emulsion capacity was expressed as grams of oil emulsified by 1g flour.

Emulsion stability: About 4 g flour sample was dispersed in 100 mL distilled water. To the dispersed sample, 100 mL of sunflower oil was added drop wise while blending. Each sample was blended in a blender at high speed for 60 seconds. The blended sample was transferred into a 250 ml graduated cylinder. The volumetric changes in foam, oil and aqueous layers were recorded after 3 hours. The emulsion stability was expressed as percentage and it was calculated as the ratio of the height of emulsified layer to the total height of the mixture.

3.2.12 Bulk density

Bulk density of samples was determined by the method described by Mebpa *et al* (2007). About 50 g sample was weighed into a 100 ml graduated cylinder. The cylinder was tapped ten times against the palm of the hand and the final volume expressed as g/ml.

3.2.13 Pasting properties of the flours

AACC method 22-12 (2000) was used to determine the wheat pasting properties. About 65 g flour sample was completely dispersed in 450 ml distilled water. The suspension was heated from 30˚C to 93˚C at a rate of 1.5˚C/ min. The sample was cooled to 30˚C at a rate of 1.5˚C/ min after keeping it at 93˚C for 15 min. For the wheat: plantain composites flours, minor modifications were made to the method. Instead of using a 65 g sample, a 49 g sample was used and instead of dispersing the sample in 450 ml water it was dispersed in 338 ml water. A Brabender Viscograph-E (Brabender GmbH and Co. KG, Duisburg, Germany) was used in characterizing the composite flours. The parameters recorded were: paste temperature (˚C) and peak viscosity in Brabender units and time to peak viscosity in minutes.

3.3 Rheological property of the dough

3.3.1 Farinograph test

This test was used to determine flour water absorption and dough strength. The farinograph test results were thus used to determine the effects of gum arabic and plantain flour on the dough mixing properties of the composite flours. AACC method 54- 21 was used. A flour sample weighing 50 g on a 14% moisture basis was placed in a farinograph mixing bowl. Water from a burette was added to the flour and mixed to form dough. The farinograph recorded a curve on graph paper as the dough was mixed. The volume of water that was absorbed by the flour while making the dough affected the position of the curve on the graph paper. The curve was centered on the 500-Brabender Unit (BU) line ±20 BU (AACC, 2000). From the farinograms, water absorption, arrival time, peak time, departure time, mixing tolerance index (MTI) and stability profiles were calculated as per the description in AACC methods, 2000 and Xu, 2014.Water absorption (WA) is the amount of water required to center the farinograph curve on 500 Brabender Unit (BU), therefore it is the amount of water required to optimally prepare the dough

(Wheat Marketing Center, 2004; Xu 2014). Dough development time was defined as the time between the first addition of the water and the development of the maximum dough consistency (peak time).The mixing tolerance index (MTI) was calculated as the difference in BU between the top of the curve at the peak time and the top of the curve measured 5 minutes after the peak time. The time between the point at which the top of the curve peak first intercepts the 500-BU line (arrival time) and the point at which the top of the curve leaves the 500-BU line (departure time) was defined as stability (AACC, 2000).

3.4 Bread characteristics

3.4.1 Baking process

The procedure that was used for making pan bread was as is described by Abdelghafor *et al*, 2011. The ingredients were: 300 g flour, 1-3 g gum Arabic (sourced from Kenya Forestry Research Institute), 4.5 g yeast (active dry yeast from Agro chemicals and Food company limited, Kenya), 4.5 g salt (Kensalt- Kenya), 9 g shortening (Kimbo from Bidco Afrika), 9 g sugar (Mumias sugar- Kenya), and water added as per the farinograph findings (table 4.5). All dry ingredients were weighed and placed in a mixer for 5 sec; yeast suspension in water was then added to the mixture (table 4.5). The mixture was further run at high speed for 92 sec. Water was added to the mixture as indicated by the farinograph results. Dough was transferred onto a clean work-top, divided into three equal portions, rounded into balls by hand and then placed in lightly greased pans and proofed at 30ºC and 85% relative humidity for 20 min. The dough was sheeted and molded by hand, placed in lightly greased pans and finally returned to the proofing cabinet for a final proofing for 50 min. When the height of dough had risen to about 1 - 2 cm above the pans, the pans were placed in a preheated convection oven and baked at 212.8ºC for 18 min. Loaves were cooled on racks before being weighed and the volume was recorded.

3.4.2 Specific volume

The rapeseed displacement method as was described by USDA (2008) was used to determine the specific volume of the bread. The cooled loaf of bread was placed in a container which was higher and greater in perimeter than the bread. The void space in the container containing the product was filled with rapeseed so that the rapeseed was level with the top edge of the container. The amount of rapeseed used was measured in whole milliliters using a graduated cylinder; the volume was recorded as V2. The product was removed from the container and weighed. The weight was recorded in whole grams. The empty container was again filled with rapeseed so that the rapeseed was level with the top edge of the container.

The amount of rapeseed was measured using a graduated cylinder as was described above; the volume was recorded as V1.

Specific volume was calculated as follows:

$$\text{Specific Volume} = \frac{V1 - V2}{W} \quad (3.4)$$

Where V1 referred to the volume of rapeseed in the empty container, while V2 referred to the volume of the rapeseed in the void space in the container that contained the product and W referred to the weight of product (USDA, 2008).

3.4.3 Texture Profile Analysis of bread

The loaves of bread were sliced into 10 mm thick slices using a bread slicer (Mac Adams Baking Systems, Cape Town, South Africa). Two slices were taken from the centre of the bread after 24h. A 30 mm diameter ring was punched out from the slices. Texture Profile Analysis of the slices of bread was done using a TA.XT.*plus* Texture Analyzer (Stable Microsystems, Surrey, United Kingdom), equipped with a 50 kg load cell; figure 3.1. The settings of the instruments were: Pre-test speed 5.0 mm/s; post-test speed 5.0 mm/s; distance 10 mm (i.e. 50% compression); trigger type auto force 5g; data acquisition rate 200pps, 75mm aluminium probe. The waiting time between the first and second compression cycle was 5 seconds. The average temperature and humidity while running the test was; 28˚C and 40% respectively.

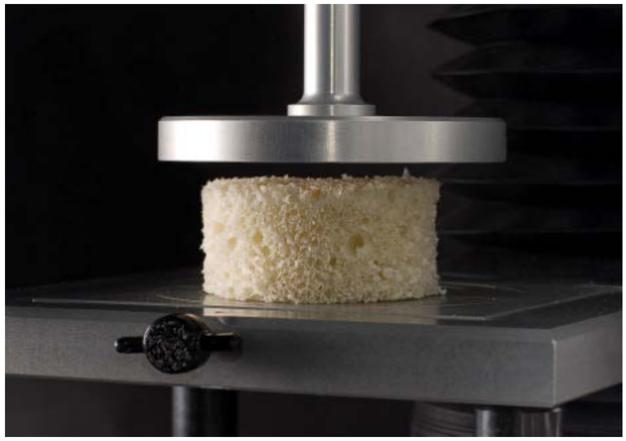

Figure 3.1: Front view of TA.XT.plus Texture Analyser showing the mechanism of compression.

Hardness, cohesiveness, springiness, gumminess and resilience were calculated from the Texture Profile Analysis graph (figure 3.2).

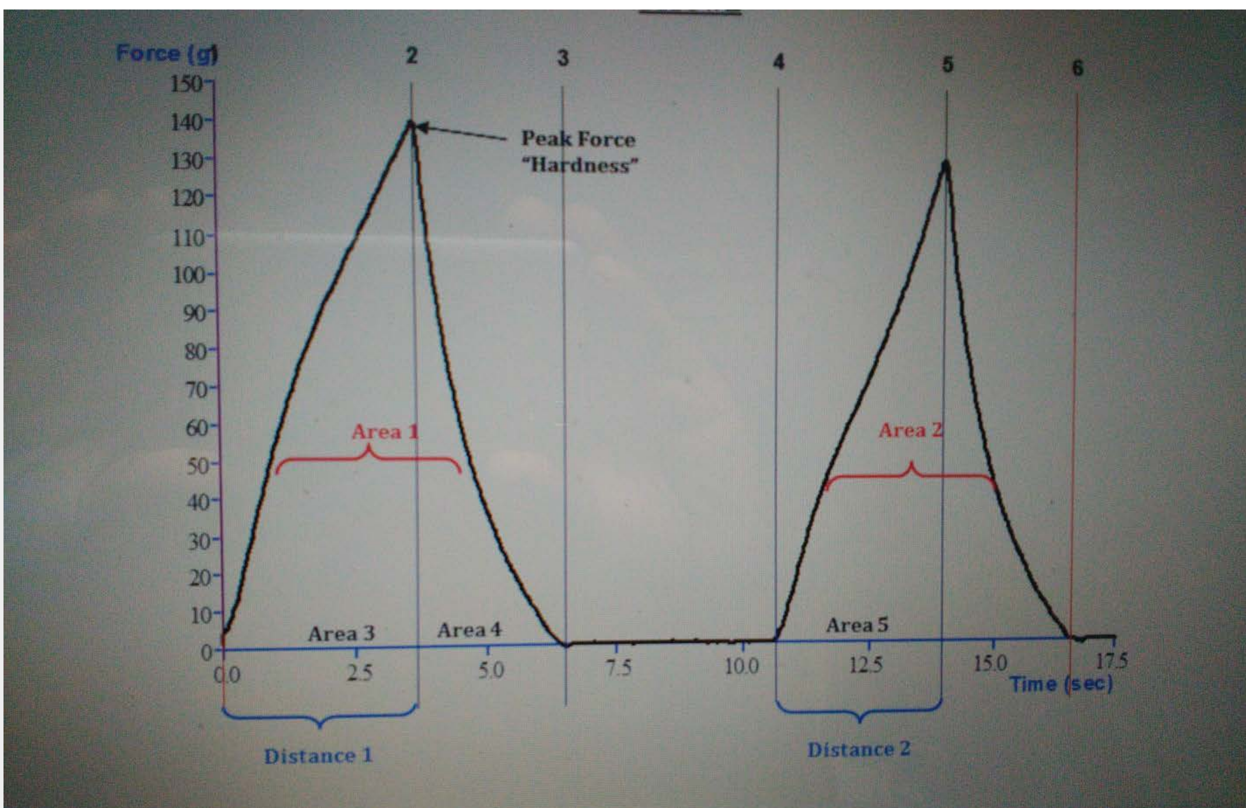

Figure 3.2: Sample graph adopted from Texture technologies.com

In texture profiling, hardness refers to the force required to compress the material by a given amount and it can be defined as the peak force during the first compression cycle i.e. first bite. That is the force required to attain a certain deformation. It was calculated as maximum force of the 1st compression (figure 3.2). Springiness is the elastic recovery that occurs when the compressive force is removed and is defined as the height that food recovers during the time that elapses between the end of the first bite and the start of the second bite; it is the rate at which a deformed material returns to un deformed condition after deforming force is removed. It was calculated as; Distance 2/ Distance 1(figure 3.2). Cohesiveness is the strength of internal bonds in the sample and is defined as the ratio of the positive area during the second compression to that during the first compression while resilience is how well a product fights to regain its original position. It was calculated as; Area 2/ Area 1 (figure 3.2). Gumminess is the energy required to chew/ masticate a semi solid food ready for swallowing and is defined as the product of cohesiveness and hardness , it was calculated as a product of hardness and cohesiveness (Abdelghafor *et al*, 2011; Scheuer *et al*, 2016).

3.5 Research design

The research used was factorial design since it involved two factors; plantain (which was incorporated in varying proportions) and gum Arabic (whose level of incorporation also varied from 1 - 3%).

3.6 Statistical analysis

All the analysis was done in triplicates. The data was subjected to analysis of variance for the single factor analysis. The difference between the means was obtained by Tukey pairwise comparison. Minitab 17 statistical package was used.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Physichochemical properties

4.1.1 Nutrient content

Wheat Flour was milled from Njoro BW II variety sourced from KARI in Njoro –Kenya. The flour obtained had 13.12% moisture content, 16.04% crude protein content, 1.63 % crude fat, 0.96% crude fiber content, 0.42% ash content and 71.17 % carbohydrate content on average (table 4.1). Plantain flour on the other hand was obtained from Ng'ombe variety. It contained 6.53% moisture content and 5.84% crude protein content, 0.31% crude fat content, 2.50% crude fiber content, 3.80 Ash content, 84.18% carbohydrate content on dry basis (table 4.1).

Table 4.1: Proximate composition of wheat and plantain flour (Tukey pairwise comparison)

FLOUR	Moisture	Crude protein	Crude fat	Crude fibre	Ash	Carbohydrate
Wheat	13.12±1.09^{a}	16.04±0.85^{a}	1.63±0.17^{a}	0.96±0.12^{b}	0.42±0.29^{b}	71.17±0.00^{b}
Plantain	6.53±0.11^{b}	5.84±0.22^{b}	0.31±0.01^{b}	2.50±0.24^{a}	3.80±1.42^{a}	84.18±0.00^{a}

C: control. Values followed by the same superscript letter in the same column are not significantly different at P> 0.05

Similar results were reported by Zakpaa *et al* (2010) i.e. 3.14%, 2.68%, 2.682%, 0.336%, 0.979%, 91.162 % for moisture, ash, protein, crude fat, fiber and carbohydrate respectively. Similarly, Oluwalana and Oluwamukomi (2011) reported 8.63%, 5.59%, 2.93%, 2.63%, 4.27% and 84.51% for moisture, protein, Ash, Fat, Total crude fibre and carbohydrate respectively. Although the two studies had a similar trend with this study, the Kenyan plantain under study (Ng'ombe cultivar) had noticeably higher protein and ash content and a lower crude fat content than the values reported by the two studies. Similarly, Shittu *et al* (2013) reported higher protein content in plantain at 9th and 10th week of maturity (i.e. 7.12 and 6.81 respectively) and unlike this study a lower protein content on the 7th week and 8th week of plantain maturity. High ash content has also been reported on other flours other than plantain for example Fenn *et al* (2010) while working with legume flours reported higher ash content than the control (wheat flour); Tharise *et al* (2010) reported Rice, cassava and soybean ash to be higher than that of the control (wheat flour).

Moisture content, crude protein (CP) and crude fat (CF) decreased as the level of plantain substitution increased (from 0 to 40%) i.e. from 13.12% to 6.53%, 16.04% to 5.84% and 1.63% to 0.31% respectively (table 4.2). 100% plantain flour recorded the lowest amount of moisture, crude protein and crude fat. A similar trend was recorded by Mepba *et al* (2007). Ovando-Martinez *et al* (2009) in their study reported a significant decrease in moisture content and protein content in raw spaghetti as the level of banana flour substitution increased. Contrary to this study other studies on different composites especially those from legumes reported an increase in protein content and fat content (Ogunsina *et al*, 2012). Low protein levels (i.e. 7- 9%) in flours is desirable attribute in making soft cakes, since high amounts of gluten makes the dough stronger and elastic therefore it tends to recoil after sheet formation (Al- Dmoor, 2013).

The carbohydrate content, crude fiber content increased as the level of plantain substitution increased from 10 to 40%. Moisture content for the 90:10 and 80:20 composites were not significantly different from the control ($P > 0.05$) while the moisture content of the 70:30, 60:40 and 100% plantain differed significantly ($P \leq 0.05$) from the control (table 4.2). In general, the moisture content of all the composites was below the recommended 14% moisture level thus the flours were not highly susceptible to microbial growth and chemical changes during storage (Tharise *et al*, 2010). The reduction in fat content and increase in fiber content is a desirable attribute because epidemiological studies have shown that low fat and high dietary fibre consuming populations, suffer less gastrointestinal disease especially colon cancers (Brouns *et al*, 2002).

Table 4.2: Effect of the level of plantain flour substitution (in wheat) on proximate composition (Tukey pairwise comparison)

Composite (W: P)	Moisture	Crude protein	Crude fat	Crude fibre	Ash	Carbohydrate
100:0 C	**13.12±1.09[a]**	**16.04±0.85[a]**	**1.63±0.17[a]**	**0.96±0.12[d]**	**0.42±0.29[b]**	**71.17±0.00[f]**
90: 10	12.39±1.64[ab]	13.11±0.81[b]	1.22±0.13[b]	1.49±0.23[cd]	1.06±0.12[b]	74.12±0.00[e]
80: 20	11.98 ±0.19[ab]	12.31±0.10[bc]	0.96±0.06[b]	1.55±0.17[c]	1.21±0.14[b]	75.27±0.00[d]
70:30	10.87±0.13[b]	11.27±0.29[cd]	0.69±0.03[c]	1.80±0.31[bc]	1.68±0.50[b]	76.98±0.00[c]
60:40	10.59±0.01[b]	10.14±0.20[d]	0.52±0.05[cd]	2.20±0.16[ab]	1.77±0.35[b]	77.85±0.00[b]
0: 100	**6.53±0.11[c]**	**5.84±0.22[e]**	**0.31±0.01[d]**	**2.50±0.24[a]**	**3.80±1.42[a]**	**84.18±0.00[a]**

C- control, W- wheat and P- plantain. Values followed by the same superscript letter in the same column are not significantly different at P> 0.05

Crude protein (CP) content of all the four composites differed significantly ($P \leq 0.05$) from the control (table 4.2). However, there was no significant difference ($P > 0.05$) with respect to crude protein between groups i.e. 90:10 vs. 80:20, 80:20 vs. 70:30 and 70:30 vs. 60:40. 100% plantain flour's crude protein differed significantly from the control and all the four composites ($P \leq 0.05$).

Crude fat content (table 4.2) of all the four composites plus the 100% plantain was significantly lower than that of the control ($P \leq 0.05$). The differences between, the following categories 90:10 vs. 80:20, 70:30 vs. 60:40 and 60:40 vs. 100% plantain were not statistically significant ($P > 0.05$) (table 4.2). Crude fiber of 100% plantain and all the composites except 90:10 differed significantly form the control ($P \leq 0.05$).There was no significant difference in fiber content among 90:10, 80:20 and 70:30 ($P > 0.05$). 60:40 composite flour did not differ significantly in fiber content with 70:30 composite flour ($P > 0.05$) but it differed significantly in fiber content from the control, 90:10 and 80:20 ($P \leq 0.05$) , (table 4.2).

Carbohydrate content of all the four composites and 100% plantain were significantly higher than those of the control ($P \leq 0.05$), (figure 4.1).The difference or increment as one moved from one level of plantain substitution to the next was also statistically significant ($P \leq 0.05$). Notably, the increase in plantain content had no significant effect on ash content ($P > 0.05$). Ash content for all the four composites i.e. 90:10, 80:20, 70:30 and 60:40 did not differ significantly from the control ($P > 0.05$) except for 100% plantain which differed significantly from all the four composites and the control ($P \leq 0.05$), (table 4.2).

4.1.2 Mineral profile

Phosphorous, cupper, calcium, zinc, magnesium, manganese and sodium in all the four wheat; plantain composites did not differ significantly ($P>0.05$) from the control (table 4.3).

The phosphorous values for 100% plantain were 0.025 ± 0.003 which confirmed the findings by Eggleston *et al* (1992) who recorded plantain phosphorous content in four cultivars under study as 0.020- 0.022. Potassium levels increased significantly with the increase in plantain substitution from 0 to 10% ($P \leq 0.05$) after which the increase was not statistically significant. The potassium levels for 100% plantain were significantly higher than that of the control ($P \leq 0.05$). Iron levels ranged from 8.77 in the control (100:0) to 26.05, with 70:30 recording the highest levels. 70:30 was the only group that differed significantly ($P \leq 0.05$) from the control with regard to iron content (table 4.3). This finding is similar to that reported by Ogunsina *et al* (2012) while working with wheat: debittered moringa composite to make bread and cookies, where only high levels of substitution produced a significant effect with regard to mineral composition as opposed to lower levels of substitution.

Table 4.3: Effect of the level of plantain flour substitution (in wheat) on mineral content in mg/100g (Tukey pairwise comparison)

Composite (W: P)	Phosp. (%)	Iron	Cu	Ca	K	Zn	Mg	Mn	Na
100:0 C	**0.007±0.003^{b}**	**8.77±1.28^{b}**	**0.64±0.05^{a}**	**94.0±25.9^{a}**	**17.17±0.39^{c}**	**1.55±0.10^{a}**	**12.22±0.09^{a}**	**4.10±0.54^{a}**	**4.16±0.46a**
0: 100	0.025±0.003^{a}	18.47±1.79^{ab}	0.58±0.08^{a}	96.54±8.51^{a}	62.59±6.69^{a}	0.96±0.10^{a}	12.36±0.14^{a}	3.52±0.17^{a}	4.58±0.10a
90: 10	0.011±0.003^{b}	9.15±1.42^{b}	0.57±0.02^{a}	98.22±8.59^{a}	30.14±5.38^{b}	1.76±0.39^{a}	12.29±0.18^{a}	4.27±0.47^{a}	4.78±0.62a
80: 20	0.012 ±0.003^{b}	10.72±1.21^{b}	0.56±0.06^{a}	106.82±8.06^{a}	29.74±3.53^{b}	1.41±0.10^{a}	12.30±0.23^{a}	4.07±0.77^{a}	4.52±0.34a
70:30	0.010±0.005^{b}	26.05±13.05^{a}	0.58±0.04^{a}	82.0±37.5^{a}	34.04±2.84^{b}	1.70±0.24^{a}	12.18±0.07^{a}	3.78±0.76^{a}	4.84±0.48a
60:40	0.008± 0.002^{b}	12.44±2.21^{ab}	0.68±0.09^{a}	64.50±29.1^{a}	35.61±0.83^{b}	1.73±0.56^{a}	12.41±0.09^{a}	4.20±0.93^{a}	4.51±0.83a

C: Control, Phosp; Phosporous, Cu: cupper,Ca: calcium, K: potassium, Zn: zinc, Mg: magnesium, Mn: manganese, Na: sodium, W:wheat, P: plantain. Values followed by the same superscript letter in the same column are not significantly different at P> 0.05

4.1.3 Other physical properties

The difference between the control and the composites was statistically significant ($P \leq 0.05$) at all levels of plantain incorporation (table 4.4) for water-holding capacity (WHC), foaming stability (FS), Emulsion capacity (EC), Emulsion stability (ES) and bulk density (BD). The same was true for oil absorption capacity (OAC) and foaming capacity (FC) except for 90: 10 and 70:30 (wheat: plantain) respectively which did not differ significantly from the control at ($P > 0.05$). The increase in water holding capacity as the level of plantain substitution increased is suggestive of the increase in the amount of hydrophilic carbohydrates (Idoko and Nwajiaku, 2013).

Water holding capacity (WHC) is otherwise referred to as water absorption capacity (Mepba *et al*, 2007) or water absorption index (Tharise *et al*, 2010). It refers to the ability of flour to absorb water and swell therefore improving food consistency (Offia- Olua *et al*, 2014). WHC increased significantly with the increase in plantain flour substitution from 0 - 40% (table 4.4). A similar trend was reported by Mepba *et al* (2007) and Kiin- Kabari *et al* (2015). Elsewhere, Offia- Olua *et al* (2014) reported that varying walnut flour seemed to have no significant effect on flour water absorption. In bread making, flours that can absorb a large amount of water are preferred since water absorption is regarded as an indicator of yield; it gives body to food (Al-Dmoor, 2013; Offia- Olua, 2014). The WHC in this study were reported as a percentage, similarly Mepba *et al,* (2007) and Kiin- Kabari (2015) reported it as a percentage, nonetheless other researchers reported it as ml water/ g sample (Ali *et al,* 2012). While others as g/g i.e. g water per g sample (Tharise *et al,* 2010; Ofia Olua, 2014).

Oil absorption capacity (OAC) is important in food systems for the reason that fats acts as flavor retainers and they increase the mouth feel of foods (Ali *et al,* 2012; Tharise *et al,* 2010). Oil absorption capacity initially increased as the level of plantain flour substitution increased from 0% to 20%, followed by a sharp decrease from 263.3% - 111.18% as the level of substitution increased from 30 % to 40% (table 4.4). Mebpa *et al* (2007) reported contrary results where the oil absorption capacity did not differ from the control ($P > 0.05$) at all levels (up to 50% plantain substituted in wheat) of plantain flour substitution except for 100% plantain that was statistically different from the control P≤ 0.05. In food systems where oil absorption is desired, low levels of plantain substitution will best suit the purpose.

There was a general increase in foaming capacity (FC), Foaming stability (FS) and Emulsion capacity (EC) as the level of plantain flour substitution increased from 0% to 20%, subsequent increase in plantain flour substitution caused a decrease in Foaming stability (FS), foaming capacity (FC), Emulsion capacity (EC) and Emulsion stability (ES) from 65.20 to 62.73% and 24.20 to 1.87% and 13.73% to 5.43% respectively (table 4.6). Emulsion stability reduced significantly as the level of plantain increased from 30- 40 % (P< 0.05). Kiin- Kabari *et al* (2015) reported an increase in emulsion stability in wheat- plantain composites which he attributed to the increase in protein from Bambara ground nut concentrate that was used as an improver in the study. Foams and emulsions are two phase systems in food whose development is significantly affected by protein surface activity (Ali *et al*, 2012; Kiin- Kabari *et al*, 2015; Mebpa *et al*, 2007). The reduction in foam and emulsion capacity and stability could be attributed to the reduction in the amount of protein in wheat flour (gluten) as a result of substituting wheat with plantain flour. Bulk density on the other hand, increased with increase in in plantain flour substitution from 0-40%.

With regard to bulk density, Mebpa *et al* (2007) reported contrary results where the bulk density, did not differ from the control (P> 0.05) at all levels of plantain flour substitution (i.e. 0-50% plantain substitution). The 0.34 g/ ml bulk density for 100% wheat control reported by Kiin- Kabari *et al* (2015) was much lower than the control wheat in this study which was 0.536g/ml (table 4.4). Bulk Density (BD) depends on intensity of attractive forces, particle size, number of particle contact points and the density of the flour among other factors (Ali *et al*, 2012; Offia- Olua, 2014). The difference in Bulk density among the control and the wheat-plantain composites could be due to the fact that wheat and plantain were from two different plant sources; they could have differed in a number of the above named factors. Information on bulk density is not only useful when determining packaging material for flours but also in material handling (Kiin- Kabari *et al*, 2015; Offia- Olua, 2014).

Table 4.4: Effect of the level of plantain flour incorporation on other physical properties (Tukey pairwise comparison)

Composite	OAC (%)	WHC (%)	FC %	FS %	EC %	ES %	BD (g/ml)
100:0 C	219.44 ± 8.78^b	57.55 ± 0.00^a	**16.27 ± 0.31^b**	**61.27 ± 0.31^c**	**12.13 ± 0.15^b**	**17.00 ± 0.27^a**	**0.536 ± 0.003^f**
90: 10	234.07 ± 5.07^b	83.70 ± 13.18^b	20.80 ± 0.20^a	65.53 ± 0.50^a	13.37 ± 0.15^a	14.27 ± 0.15^b	0.610 ± 0.000^e
80: 20	283.81 ± 13.41^a	98.46 ± 6.56^b	24.20 ± 0.20^a	65.53 ± 0.31^a	13.73 ± 0.15^a	10.47 ± 0.15^c	0.636 ± 0.009^d
70:30	263.3 ± 0.0^a	127.15 ± 6.48^c	16.60 ± 0.40^c	65.20 ± 0.40^a	7.33 ± 0.42^c	6.50 ± 0.10^d	0.676 ± 0.000^c
60:40	111.18 ± 13.41^c	130.49 ± 6.46^c	1.87 ± 0.92^d	62.73 ± 0.46^b	5.43 ± 0.15^d	4.13 ± 0.21^e	0.708 ± 0.011^b
0: 100	108.26 ± 5.07^c	324.52 ± 6.18^d	-0.07 ± 0.12^e	1.13 ± 0.81^d	1.90 ± 0.20^e	3.10 ± 0.20^f	0.798 ± 0.015^a

WHC: water holding capacity, OAC: oil absorption capacity, FC: Foaming capacity, FS: Foaming stability, EC: Emulsion capacity, ES: Emulsion stability, BD: Bulk density. Values followed by the same superscript letter in the same column are not significantly different at P> 0.05

4.2 Rheological properties of the dough

4.2.1 Farinograph

All the four composites (90:10, 80:20, 70: 30 and 60:40) differed significantly (table 4.5) from the control (P≤ 0.05) for water absorption (WA), dough stability (DS), departure time (DT) and peak time (PT).

As the level of plantain substitution increased from 0% (control) to 40%, water absorption (WA), Arrival Time (AT), Departure Time (DT) and Peak time (PT) increased steadily. A similar increase in water absorption was reported by Murang'a *et al* (2010) and Ribotta *et al* (2005) while working with banana (tooke) - wheat composite and soybean- wheat composite respectively. Yaseen *et al,* (2010) and Pečivová *et al,* (2010) reported different results i.e. a decrease in water absorption with the increase of the non-wheat factors while working with corn - wheat flour composite and L- glutamic acid incorporated in wheat flour respectively. Water absorption is the farinograph parameter with the greatest practical value (Hadnađev *et al,* 2011) since it offers the researcher a close approximation of optimal water for optimal dough preparation (Xu *et al*, 2014). It is directly related to the yield of finished bakery product and it is important parameter in product price calculation (Hadnađev *et al*, 2011; Xu *et al*, 2014). In the case of this research the increase in water absorption with the increase in the level of plantain substitution implied that the higher the level of plantain incorporation, the higher the amount of water required to optimally prepare the dough. The increase in water absorption could be attributed to increase in fiber as the level of plantain substitution increased (table 4.2). Fiber has higher hydroxyl groups in its structure which allows stronger interaction with water through hydrogen bonding (Nikolić *et al*, 2013).

Departure time (DT) gives an indication of the time when dough breakdown is beginning (Shittu *et al*, 2013). Wheat- plantain composites produced dough that took longer than the control to breakdown thus stronger dough (table 4.5); 60:40 (wheat: plantain) composite was the most resistant to dough breakdown i.e. it took the longest time to breakdown. Peak Time (PT) shows the dough development time, in this experiment the higher the level of plantain substitution the longer it took to mix the dough to achieve maximum consistency (table 4.5). The increase in peak time (PT) was statistically significant ($P \leq 0.05$) at all levels of plantain substitution. Xu *et al* (2014) reported a similar increase in Peak time (PT) with the increase in flaxseed flour substitution in wheat. Malomo *et al* (2011) reported different results where wheat-breadfruit and wheat- breadnut composite flours had a significantly lower peak time/ dough development time.

Dough stability increased as the level of plantain substitution increased from 0% (control) to 20%, after which there was a decrease in dough stability with further increase in plantain substitution (table 4.5). Stability time is a good indicator of dough strength and it is the time during which the dough maintains maximum consistency (Shittu *et al,* 2013; Xu *et al*, 2014). It defines the resistance of the dough to further mechanical or mechanical- chemical strain

(Pečivová *et al*, 2010). In this study, incorporation of low quantities of plantain i.e. upto 20% significantly increased dough strength with 20% producing the strongest dough 11.80 ± 0.20 compared to 9.00±0.10 control dough stability in minutes. Conversely higher levels of plantain incorporation (i.e. 30% and 40%) produced weaker dough; the doughs were weaker than the control. This reduction in dough strength was in agreement with findings made by Fenn *et al* (2010), Xu et al (2014). This sharp weakening of the dough could be due to the weakening or dilution of the gluten matrix (Xu *et al*, 2014).

The composites differed significantly (P≤ 0.05) from the control in respect with arrival time (AT) and mixing tolerance index (MTI) at all levels except for: 10% plantain incorporation (90:10 composite) and 40% plantain substitution (60:40 composite) respectively. Arrival time (AT) shows the rate of flour hydration or the rate at which the flour takes up water (Wheat Marketing Center, 2004). In this experiment, 10% plantain flour substituted in 90% wheat had the lowest hydration rate among the composites; infact, its hydration rate was not significantly different from the control. The hydration rate increased significantly with the increase in the level of plantain substitution. Mixing tolerance index (MTI) is an indicator of the degree of softening (Wheat Marketing Center, 2004). 90:10 composite had the lowest MTI while 80: 20 had the highest MTI (table 4.5). High MTI values are an indication of weak flours that form doughs that tend to break more rapidly during mixing (Xu *et al*, 2014). In this experiment low level of plantain substitution (10% plantain in wheat) produced the strongest dough that could withstand sustained mixing. Higher level of plantain substitution caused the dough to weaken/ increased dough softening. Xu *et al* (2014) reported a similar increase in MTI with the increase in flaxseed flour substitution in wheat although in this case the increase was at all levels of substitution.

Table 4.5: Effect of the level of plantain flour incorporation on farinograph reading (Tukey pairwise comparison)

Composites	WA (mL)	DS (min)	AT (min)	D T (min)	PT (min)	MTI (BU)
100:0 C	**34.90±0.08[a]**	**9.00±0.10[c]**	**1.50±0.30[d]**	**10.50±0.70[d]**	**2.07±0.12[a]**	**34.33±4.04[b]**
90: 10	39.90±0.16[d]	10.00±0.20[b]	2.00±0.20[c]	12.03±0.06[c]	2.97±0.06[b]	16.67±7.64[c]
80: 20	43.56±0.32[c]	11.80±0.20[a]	2.47±0.06[b]	14.27±0.15[b]	8.50±0.30[c]	70.00±5.00[a]
70:30	45.48±0.24[d]	8.00±0.25[d]	6.02±0.03[b]	14.00±0.20[b]	10.50±0.20[d]	60.00±5.00[a]
60:40	46.57±0.12[a]	7.68±0.16[d]	11.5±0.35[a]	19.25±0.25[a]	14.00±0.20[e]	30.00±5.00[bc]

WA: Water Absorption, AT: Arrival Time, DT: Departure Time, PT: Peak Time, MTI: Mechanical Tolerance Index. Values followed by the same superscript letter in the same column are not significantly different at P> 0.05

4.2.2 Pasting properties

The suitability of flour's starch in its application as functional ingredient in food and other industrial products is assessed by its pasting properties (Oluwalana e*t al*, 2011). There was a steady decrease in Breakdown Viscosity (BV) and final viscosity (FV): while peak viscosity (PV) increased steadily as the level of plantain flour substitution in wheat flour increased from 0% to 40% (table 4.6).

Peak Viscosity (PV) is the maximum viscosity developed in the course of or soon after heating the sample and is often correlated with product quality; it also gives an indication of the viscous load that is likely to be encountered during mixing (Kiin-Kabari *et al*, 2015; Offia- Olua 2014; Oluwalana and Oluwamukomi, 2011). In this experiment, peak viscosity increased with the increase in the level of plantain substitution. The control sample (100% wheat) had the lowest PV (table 4.6) while 60:40 (wheat- plantain) had the highest Peak Viscosity (PV). Murang'a *et al* (2010) reported a similar trend in peak viscosity where PV increased with the increase in the level of plantain substitution. Tharise *et al* (2010) too reported similar results where non- wheat composites had a higher Peak Viscosity than the control (100% wheat flour). These findings in PV differed from the findings by Kiin-Kabari *et al* (2015) who reported a decrease in peak viscosity with the increase in Bambara groundnut protein concentrates that were used to improve wheat- plantain flour and Offia- Olua (2014) where PV increased with the increase in walnut flour. The higher Peak Viscosity is indicative of a higher swelling index therefore 60:40 composite had the highest swelling index. On the other hand the lower peak viscosity is indicative of higher solubility which may be as a result of starch degradation or dextrinization (Oluwalana and Oluwamukomi, 2011).

Pasting temperature (PT) did not differ significantly from the control for 10% and 30% plantain flour substitution, while 20% and 40% plantain flour substitution were significantly higher than the control (table 4.6). Pasting temperature (PT) gives an indication of the minimum temperature required to gelatinize/ cook the flour (Tharise *et al*, 2010). The higher pasting temperature for 20% and 40% plantain flour substitution suggested a more ordered and very strongly bonded granule structure (Eggleston *et al*, 1992); therefore slightly higher temperature was required to gelatinize the flour. Murang'a *et al*, 2010 reported contrary results while working with green banana ('Tooke') flour where there was a decrease in pasting time (PT) with the increase in plantain flour substitution. Offia- Olua (2014) reported a similar increase in pasting temperature with the increase in walnut substitution but in their study the PT increased at all levels walnut flour of substitution (i.e. 10%, 20%, 30% and 50%) in wheat flour.

Time to peak viscosity (TPV) did not differ significantly from the control at all levels of plantain flour substitution in wheat (table 4.6). Murang'a *et al* (2010) reported similar results where time to peak viscocity (TPV) did not differ at all levels of substitution ($P>0.0001$). This implied that varying the amount of plantain flour substituted in wheat had no effect on the time the paste would take to achieve maximum viscosity.

Breakdown viscosity (BV), Setback viscosity (SV) and Final viscosity (FV) were significantly lower than the control ($P \leq 0.05$) at all levels of plantain substitution (table 4.6). Tharise *et al*, (2010) reported similar results where breakdown viscosity (BV) and final viscosity (FV) of the composites where lower than those of the control (wheat flour). Murang'a *et al*

(2010) reported a contrary trend where Breakdown viscosity (BV) and FV increased with the increase in plantain flour substitution. Breakdown viscosity (BV) is regarded as a measure of paste stability or the degree of paste disintegration (Kiin-Kabari *et al* 2015;Oluwalana and Oluwamukomi, 2011).The higher the breakdown viscosity (BV), the lower the ability in the flour samples to withstand heating and shear stress during processing (Offia- Olua 2014). Therefore, the lower Breakdown viscosity (BV) results in this study indicated that the ability of wheat-plantain composite flour samples to withstand heating and shear stress during processing increased with the increase in the level of plantain flour substitution.

Final Viscosity (FV) is an indicator of the ability of flour sample to form gel (Offia- Olua, 2014); it is an indication of the re- association of starch granules especially amylose during cooling to form a gel network (Tharise *et al*, 2010).

Setback viscosity (SV) indicates gel stability, therefore the tendency of the dough to undergo retrogradation (Oluwalana and Oluwamukomi, 2011). This is a phenomenon that causes the dough to become firmer and increasingly resistant to enzyme attack (Oluwalana and Oluwamukomi, 2011). Lower set back viscosity is indicative of higher potential of retrograding (Kiin-Kabari *et al* 2015); From the results, wheat –plantain composites had a significantly higher tendency to retrograde ($P \leq 0.05$) as compared to the control. Similarly, Offia- Olua (2014) reported a similar decrease in setback viscosity (SV) with the increase in the level of walnut flour. The 80:20 (wheat: plantain) composite recorded the highest tendency to retrograde. Starch with high tendency to retrograde have lower digestability or modulated digestibility therefore modulated glucose release (Oluwalana and Oluwamukomi, 2011; Zhou Lim, 2011; Haralampu, 2000). Low starch digestability has been attributed to a lower rate of colon cancer (Haralampu, 2000, Brouns *et al*, 2002). Time to peak viscosity (TPV) on the other hand was not significantly different from the control at all levels of plantain substitution ($P>0.05$). Murang'a *et al* (2010) reported similar results where time to peak viscosity (TPV) did not differ at all levels of substitution ($P>0.0001$).

Table 4.6: Effect of the level of plantain flour incorporation on pasting properties (Tukey pairwise comparison)

Composite	PT(^{O}C)	PV (BU)	TPV (min)	BV(BU)	FV (BU)	SV (BU)
100:0 C	**63.3±0.2^{c}**	**263.0±1.7^{c}**	**40.8±0.0^{a}**	**136.0±0.0^{a}**	**875.33±9.8^{a}**	**438.33±13.28^{a}**
90: 10	64.2±0.1^{abc}	263.3±9.2^{c}	40.7±0.2^{a}	114.0±0.0^{b}	782.00±29.4^{b}	391.67 ± 11.55^{b}
80: 20	65.4±0.9^{a}	267.0±1.7^{c}	40.6±0.0^{a}	84.0±5.2^{c}	716.00±26.0^{c}	357.0 ± 20.8^{b}
70:30	64.0±0.5^{bc}	296.7±2.1^{b}	40.4±0.1^{a}	75.0±2.0^{d}	741.33±12.9^{bc}	356.00 ± 7.00^{b}
60:40	65.2±0.5^{ab}	326.0±10.4^{a}	28.2±20.8^{a}	71.0±2.7^{d}	773.30±21.1^{b}	367.67 ± 13.58^{b}

PT(ºC):Pasting temperature, PV (BU): Peak viscosity, TPV (min):Time to peak viscosity, BV(BU): breakdown Viscosity, FV (BU): Final Viscosity, PT(˚C): time to peak viscosity, SV (BU): setback viscosity Values followed by the same superscript letter in the same column are not significantly different at P> 0.05

4.3 Bread characteristics

4.3.1 Texture Analysis

Texture analysis results indicated that on substituting wheat with plantain prior to the addition of gum arabic, 10% composite bread's hardness was significantly lower than that of the control. Thereafter, bread hardness increased as the level of plantain substitution increased from 10- 40% with 10% bread hardness being 4.32 (this was the lowest level of bread hardness) to 14.02 for 40% plantain substitution. This increase in bread hardness could be credited to the increase in fiber (Karuppasamy *et al*, 2013) as the level of plantain substitution increased (table 4.2). The increase in bread hardness was statistically significant with the exception of 20% and 30 % plantain substitution levels which did not differ significantly (P>0.05), (table 4.7).This agreed with the findings reported by Abdelghafor *et al,* 2011 who reported an increase in the bread hardness as the level of sorghum substitution increased from 0% (control) to 5, 10, 15 and finally 20%. Interestingly, on addition of gum Arabic, bread hardness reduced for 20, 30 and 40% plantain flour incorporation with the 3% gum Arabic incorporation being significantly lower than 0, 1 and 2 % (table 4.7). This indicated that at low levels of plantain incorporation i.e. 10% plantain substitution in wheat flour, gum Arabic addition 1% to 3% had no significant effect on bread hardness. At higher levels of plantain incorporation (40%, 30% and 20%) the 3% gum arabic addition produced significantly softer bread. This implied that the 3% plantain incorporation was the most appropriate to reduce the undesirable bread hardness for the three levels above.

Springiness was another parameter assessed as an indicator of bread quality. Prior to gum Arabic addition, all the four composites did not differ significantly from the control ($P > 0.05$) with respect to springiness (table 4.7). This was in agreement the findings by Abdelghafor *et al*, 2011 who reported no significant difference in composite breads prepared from 5, 10, 15% sorghum and 100% wheat control .On addition of gum Arabic, composite bread containing higher levels of gum Arabic i.e. 2 and 3 % resulted in a significant reduction in springiness while those with lower levels of gum Arabic (1%) were not significantly different from the control ($P>0.05$) except for 60: 40 composite bread containing 1% gum Arabic (table 4.7). All 90:10, 80:20 and 70:30- composite breads containing 2% or 3% gum Arabic recorded a significantly lower springiness when compared with the control except 90:10 containing 2% gum Arabic.

There were no significant (P>0. 05) variability from the control for cohesiveness and resilience regardless of the level of plantain or gum Arabic; this differed from the findings reported by Abdelghafor *et al* (2011) who reported a significant reduction in the two parameters as the level of sorghum substitution in wheat increased. This implied that cohesiveness and resilience were neither affected by variability in the level of plantain substitution in wheat nor gum Arabic addition.

Gumminess was the fifth among the parameter that was used to infer the bread quality. Prior to gum Arabic addition, only 80:20 composite bread did not differ significantly ($P > 0.05$) from the control, on the other hand 90:10 was significantly ($P \leq 0.05$) low in gumminess compared to the control while 70:30 and 60:40 composite breads were significantly ($P \leq 0.05$) higher in gumminess (table 4.7); this was in agreement with the findings by Abdelghafor *et al*, 2011. When the composite breads with 0% gum arabic were treated as group control, there was a general reduction in gumminess at low levels of plantain incorporation (10% plantain substituted in wheat flour) and gum Arabic addition at varied levels (1- 3%).This decrease was however not significant ($P > 0.05$) when compared to the group control. Conversely at higher levels of plantain substitution (20- 40%) the resultant composite bread showed a significant ($P \leq 0.05$) decrease in gumminess with the increase in gum arabic, when compared to the group control (table 4.7).

N/ B: For analysis, there were two sets of controls. Bread with 100% wheat (100:0) and composite breads with 0% gum Arabic (90:10, 0% GA, 80:20, 0% GA, and 70:30, 0% GA and 60: 40, 0% GA).

Table 4.7: Effect of the level of plantain flour incorporation on Texture (Tukey pairwise comparison)

Composites	Hardness	Springiness	Cohesiveness	Gumminess	Resilience
100% 0	$8.46 \pm 0.37^{c\,d\,e\,f}$	$0.829 \pm 0.037^{a\,b}$	0.571 ± 0.073^{a}	4.822 ± 0.611^{c}	0.255 ± 0.003^{ab}
90% 0	$4.32 \pm 0.28^{i\,j}$	0.838 ± 0.017^{a}	0.641 ± 0.026^{a}	$2.7667 \pm 0.0818^{f\,g}$	0.287 ± 0.018^{ab}
90% 1	$5.36 \pm 0.23^{f\,g\,h\,i\,j}$	$0.804 \pm 0.013^{a\,b\,c}$	0.597 ± 0.012^{a}	$3.205 \pm 0.201^{d\,e\,f\,g}$	0.255 ± 0.007^{ab}
90% 2	$4.41 \pm 0.55^{h\,i\,j}$	$0.748 \pm 0.020^{a\,b\,c\,d}$	0.602 ± 0.007^{a}	2.655 ± 0.322^{g}	0.254 ± 0.007^{ab}
90% 3	3.13 ± 1.36^{j}	0.628 ± 0.146^{d}	0.615 ± 0.072^{a}	1.868 ± 0.706^{g}	0.264 ± 0.058^{ab}
80% 0	$7.62 \pm 1.83^{d\,e\,f\,g\,h}$	$0.818 \pm 0.014^{a\,b}$	0.622 ± 0.005^{a}	$4.732 \pm 1.121^{c\,d}$	0.295 ± 0.016^{ab}
80% 1	$4.87 \pm 0.87^{g\,h\,i\,j}$	$0.806 \pm 0.058^{a\,b\,c}$	0.614 ± 0.025^{a}	$2.978 \pm 0.425^{e\,f\,g}$	0.274 ± 0.016^{ab}
80% 2	$7.34 \pm 0.34^{e\,f\,g\,h\,i}$	$0.700 \pm 0.036^{a\,b\,c\,d}$	0.597 ± 0.025^{a}	$4.3749 \pm 0.028^{c\,d\,e\,f}$	0.254 ± 0.017^{ab}
80% 3	$4.31 \pm 0.75^{i\,j}$	$0.710 \pm 0.018^{a\,b\,c\,d}$	0.596 ± 0.013^{a}	2.562 ± 0.434^{g}	0.249 ± 0.013^{ab}
70% 0	$10.74 \pm 0.62^{b\,c\,d}$	$0.804 \pm 0.009^{a\,b\,c}$	0.628 ± 0.018^{a}	6.744 ± 0.563^{b}	0.300 ± 0.012^{ab}
70% 1	$8.30 \pm 0.51^{c\,d\,e\,f}$	$0.800 \pm 0.023^{a\,b\,c}$	0.598 ± 0.008^{a}	4.959 ± 0.355^{c}	0.270 ± 0.011^{ab}
70% 2	$8.00 \pm 0.81^{d\,e\,f\,g}$	$0.689 \pm 0.016^{b\,c\,d}$	0.561 ± 0.019^{a}	$4.491 \pm 0.546^{c\,d\,e}$	0.238 ± 0.012^{ab}
70% 3	$5.35 \pm 0.27^{f\,g\,h\,i\,j}$	0.649 ± 0.015^{d}	0.558 ± 0.011^{a}	$2.9793 \pm 0.1394^{e\,f\,g}$	0.232 ± 0.005^{b}
60% 0	14.02 ± 1.17^{a}	$0.811 \pm 0.010^{a\,b\,c}$	0.646 ± 0.010^{a}	9.061 ± 0.845^{a}	0.327 ± 0.008^{ab}
60% 1	$12.29 \pm 2.80^{a\,b}$	0.687 ± 0.090b $^{c\,d}$	0.650 ± 0.109^{a}	$7.790 \pm 0.650^{a\,b}$	0.328 ± 0.103^{b}
60% 2	$11.28 \pm 0.66^{a\,b\,c}$	$0.668 \pm 0.0108^{c\,d}$	0.595 ± 0.020^{a}	6.704 ± 0.350^{b}	0.272 ± 0.017^{ab}
60% 3	$8.95 \pm 0.93^{c\,d\,e}$	0.653 ± 0.0162^{d}	0.563 ± 0.037^{a}	5.022 ± 0.297^{c}	0.248 ± 0.027^{ab}

Values followed by the same superscript letter in the same column are not significantly different at P> 0.05.

4.3.2 Bread Specific volume

Prior to gum Arabic addition 90:10 and 80:20 did not differ significantly from the control (P> 0.05), (table 4.8). In fact 90: 10 bread volume had a slightly higher specific bread volume although the high specific volume was not statistically significant (P> 0.05). Bread specific volume is an indicator of bread quality (Mohamed *et al,* 2010). It should not be too large or too small because this has an implication of breads crumb grain. Very small loaf volume gives a very compact and closed grain structure whereas too large loaf volume gives a more open structure (Sharandant and Khan, 2003). Even on adding gum Arabic (1- 3%) to the composite breads with low plantain substitution levels (10 % and 20 % plantain substituted in 90% and 80% wheat respectively) were not significantly different from the control (100:0) except 80:20 containing 2% gum Arabic which had a significantly lower ($P \leq 0.05$) specific volume than the control (100:0). This gives the implication that low levels of plantain may have no adverse effect on gluten functionality. This confirmed the findings by Shittu *et al* (2013) that 10-20% plantain flour substitution in wheat had no significant effect on specific loaf volume but differed with the findings by Abdelghafor *et al* (2011) who reported a reduction in specific volume with the addition of low quantities of non-wheat flours. The difference could have been due to the use of wheat- sorghum composite as opposed to the wheat – plantain composite that was used in this experiment. On the other hand, 70:30 and 60:40 had a significantly lower bread specific volume and in agreement with the findings reported by Abdelghafor *et al* (2011) while studying sorghum composite bread. They observed composite bread's specific volume reduced significantly with the increase in sorghum substitution. The reduction in specific volume in the plantain- wheat composite breads at high levels of plantain substitution can be ascribed to the reduced gluten network and interference with the gluten network in the dough which in turn leads to reduced ability of the dough to rise (Nkhabutlane *et al,* 2014; Abdelghafor *et al*, 2011).Wheat breads have a higher volume due to gluten proteins which form a network responsible for wheat dough extensibility and elasticity, (Nkhabutlane *et al,* 2014).The network formed can retain air while the proteins of non-wheat flours (as in composite breads) being more hydrophobic and insoluble in nature are unable to form a framework that will hold air during dough development thus the characteristic low volume of non- wheat breads (Nkhabutlane *et al,* 2014). Composite breads containing 1- 3 % gum Arabic and in which higher levels of plantain i.e. 30 % and 40 % plantain substituted in wheat had a significantly lower ($P < 0.05$) specific volume. This was not in agreement with what was reported by Yaseen *et al* (2010) where composite bread containing 10% corn was improved by 1-3% gum Arabic with 2 and 3 % recording the highest specific volume. This could be because a different non-wheat substitute (corn) was used and there may be a difference on how corn affects the bread matrix during baking. The results also differed from Asghar *et al* (2005) findings; they reported an increase bread volume with the increase in the level of gum Arabic; the study however reported bread volume and not specific volume thus explaining the increase because bread weight was not factored. The results however confirmed the findings by Hemeda and Mohamed (2010) who reported wheat pan bread's specific volume reduced with the addition of gum Arabic. The failure of gum Arabic to improve bread volume could be due to the fact that gum arabic just like plantain contains fiber (Hemeda and Mohamed, 2010). Fiber reduces bread volume through a number of mechanisms; first, it interferes with the dough structure therefore reducing carbon dioxide retention, secondly it dilutes gluten and lastly it may reduce bread's specific volume through physical interaction among fiber components, water and gluten (Sivan *et al*, 2011).

Interestingly in this two categories there was an exception; 70:30 composite bread's specific volume was significantly improved by 3% gum Arabic to a level where it was not significantly ($P < 0.05$) different to the control unlike its other three category members (table 4.8). Similar improvement was observed in the 60: 40 categories when 2% gum Arabic was used. The 60: 40 (W: P) containing 2% gum Arabic was not significantly different from the control ($P > 0.05$). This was in line with what was reported by Yaseen *et al* (2010) (corn-wheat composite bread with gum Arabic as an additive) and Sharandanant and Khan (2003) while working with frozen dough and 1-3 % gum Arabic among other gums. 90:10 composite bread containing 1-3% gum Arabic was not statistically different from the group mean 90:10 with 0% gum Arabic; the same was true for 80:20, 70: 30 and 60: 40 on subjecting the data to tukey pairwise comparison.

Table 4.8: Effect of plantain flour incorporation on Bread volume (Tukey pairwise comparison)

Composites	Vol (cc)	Loaf weight (g)	Specific volume
100% 0	400.0 ± 0.0^{abc}	146.9 ±4.5^{e}	2.7252 ± 0.0825^{ab}
90% 0	441.7 ± 60.1^{a}	157.7 ±8.6^{cde}	2.795 ±0.259^{a}
90% 1	411.7 ±27.5^{abc}	165.0 ±3.4^{abcde}	2.497 ±0.211^{abc}
90% 2	413.3 ±43.7^{abc}	164.8 ±4.8^{abcde}	2.512 ±0.308^{abc}
90% 3	436.7 ±32.1^{a}	173.5 ±2.4^{abc}	2.517 ±0.185^{abc}
80% 0	346.7 ±35.1^{abc}	147.2 ±16.2^{de}	2.3561 ±0.0451^{abcd}
80% 1	390.0 ±62.6^{abc}	161.0 ±3.2^{bcde}	2.425 ±0.402^{abcd}
80% 2	350.0 ±40.0^{abc}	165.4 ±2.9^{abcde}	2.118 ±0.261^{bcd}
80% 3	421.7 ±53.5^{abc}	174.8 ±6.1^{abc}	2.417 ±0.347^{abcd}
70% 0	336. 67 ±11.5^{abc}	168.0 ±3.6^{abcd}	2.0036 ±0.0262^{cd}
70% 1	356.7 ±50.1^{abc}	167.2 ±13.9^{abcde}	2.1266 ±0.1304^{abcd}
70% 2	345.0 ±22.9^{abc}	173.9 ±6.1^{abc}	1.9822 ±0.0649^{cd}
70% 3	433.3 ±34.0^{ab}	180.7 ±4.1^{ab}	2.3963 ±0.1535^{abcd}
60% 0	314.00 ±16.4^{c}	174.5 ±4.9^{abc}	1.7990 ±0.0457^{d}
60% 1	316.67 ±7.6^{bc}	176.7 ±4.7^{abc}	1.7933 ±0.0646^{d}
60% 2	408.3 ±63.5^{abc}	174.1 ±5.8^{abc}	2.354 ±0.427^{abcd}
60% 3	335.00 ±13.2^{abc}	185.6 ±0.9^{a}	1.8048 ±0.0627^{d}

Values followed by the same superscript letter in the same column are not significantly different at P> 0.05

CHAPTER FIVE

5.1 Conclusion

Bread quality considerably depends on the nutrient, rheological and bread characteristics like textural properties and bread specific volume. The results from the current study indicated that;

1. The wheat- plantain composite flour had higher fiber, carbohydrate, Iron and potassium. Plantain and wheat- plantain composite flours also had characteristic low moisture and its flour formed thick paste.
2. Prior to gum Arabic addition, 20% plantain substituted in 80% wheat was the highest level of substitution from which acceptable bread could be produced.
3. The use of gum Arabic improved the wheat - plantain composites' bread baking potential, where a soft and easy to chew bread was produced with levels of substitution as high as 40% plantain substituted in 60% wheat.

5.2 Recommendation

1. Industrial use and processing of plantain flour should be encouraged; it has low moisture content and can be processed commercially and sold as flour or used in other applications in industries requiring pseudo-cereal. It can also be embraced and its potential fully tapped in the baking industry. It could also be used in the culinary industry as a thickener in soups and sauces since it produces strong paste.
2. The application and processing of gum Arabic in food industry should be encouraged since it has proven from this study to improve bread quality attributes.
3. The information gathered from this research could be utilized by dieticians and food technologists in advising and/or formulating wheat- plantain composite bread or snacks for individuals seeking to eat healthy.

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5.4 Appendix

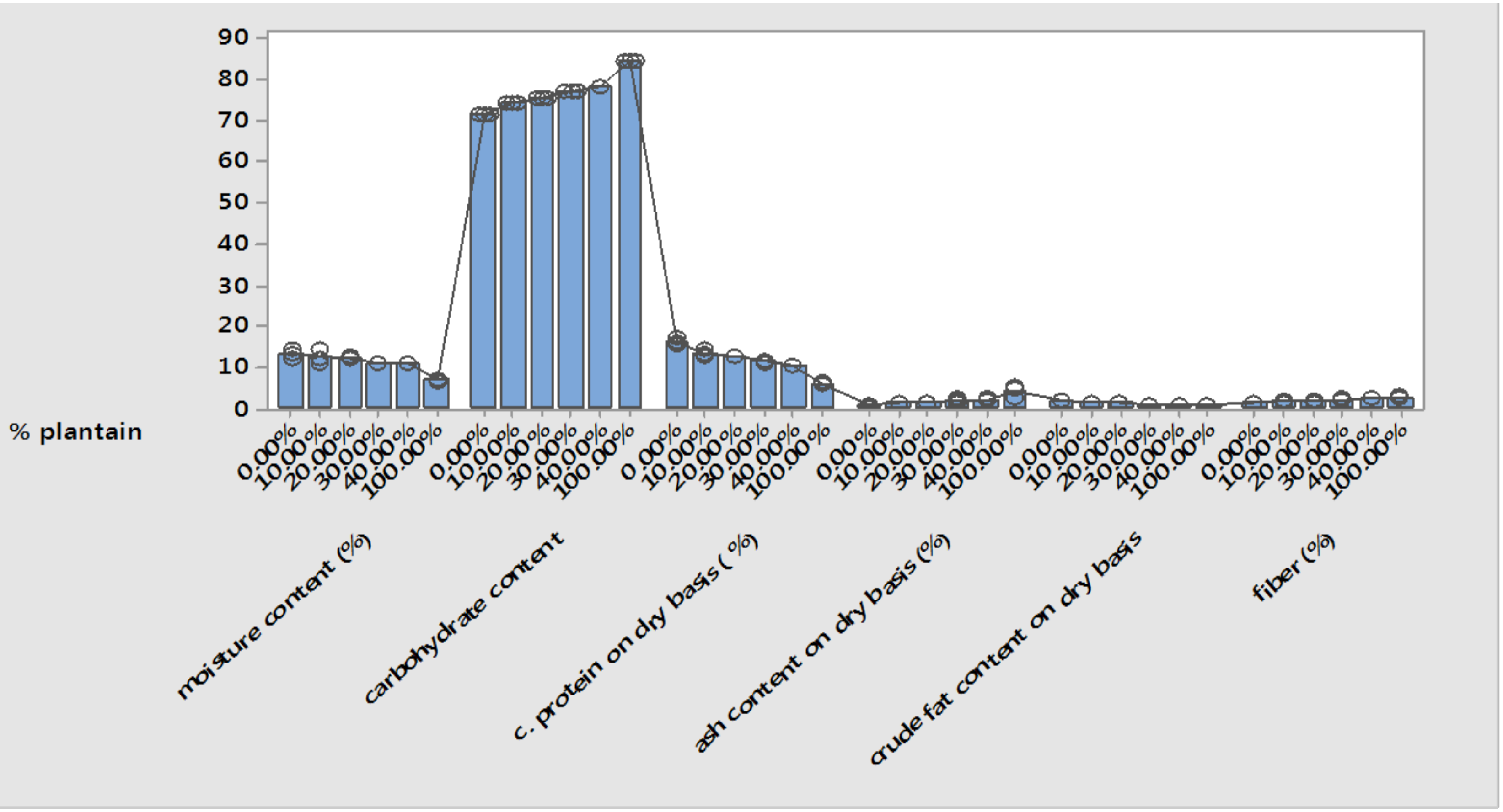

Figure 5.1: Effect of the level of plantain flour incorporation on proximate composition

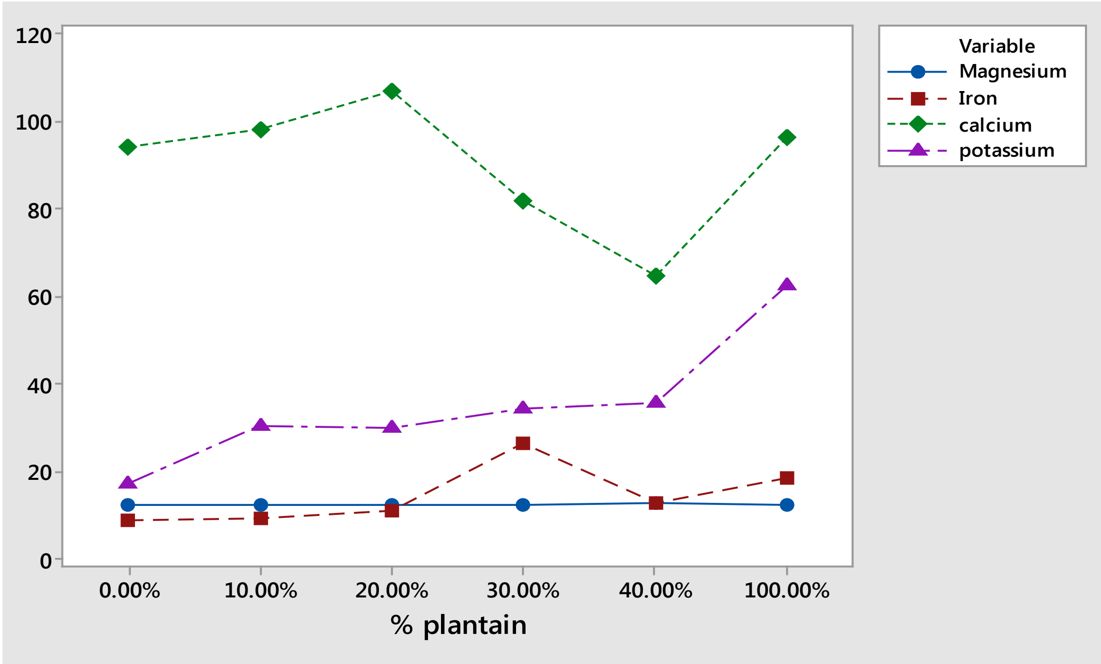

Figure 5.2: Line plots showing changes in magnesium, iron, calcium and potassium content with change in level plantain flour incorporation

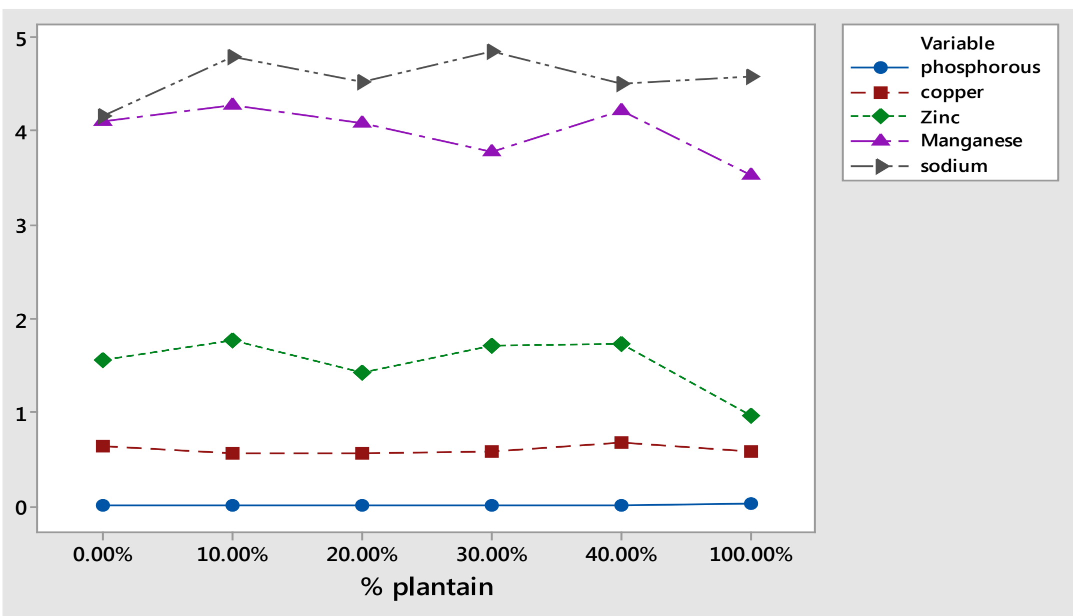

Fig 5.3: Line plots showing changes in phosphorous, copper, zinc, magnesium and sodium levels with change in plantain flour incorporation

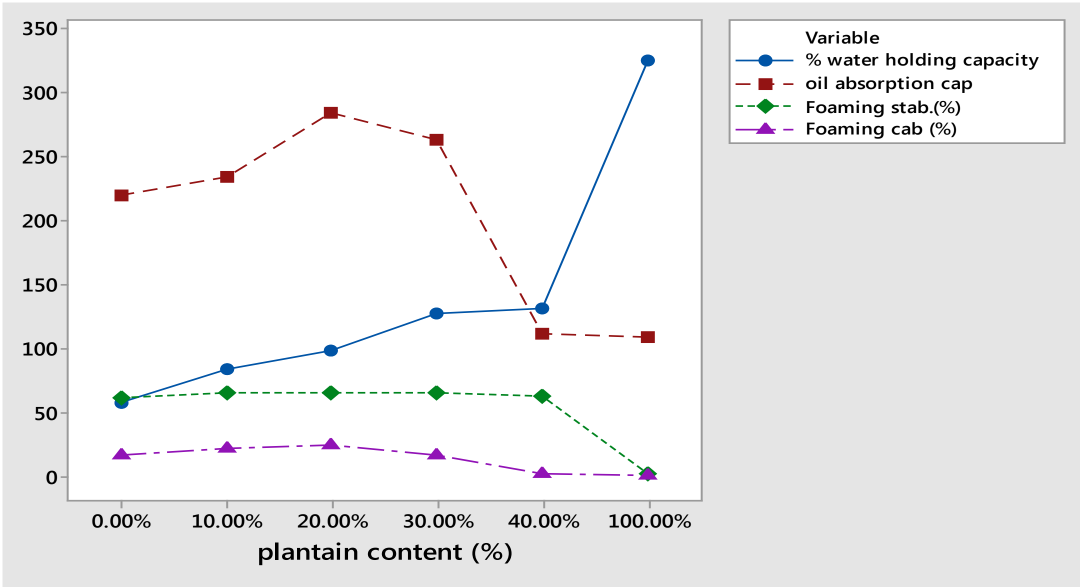

Figure 5.4: Line plot showing change in mean Water Holding Capacity, Oil Absorption Capacity Foaming stability and Foaming Capacity with change in the level of plantain incorporation

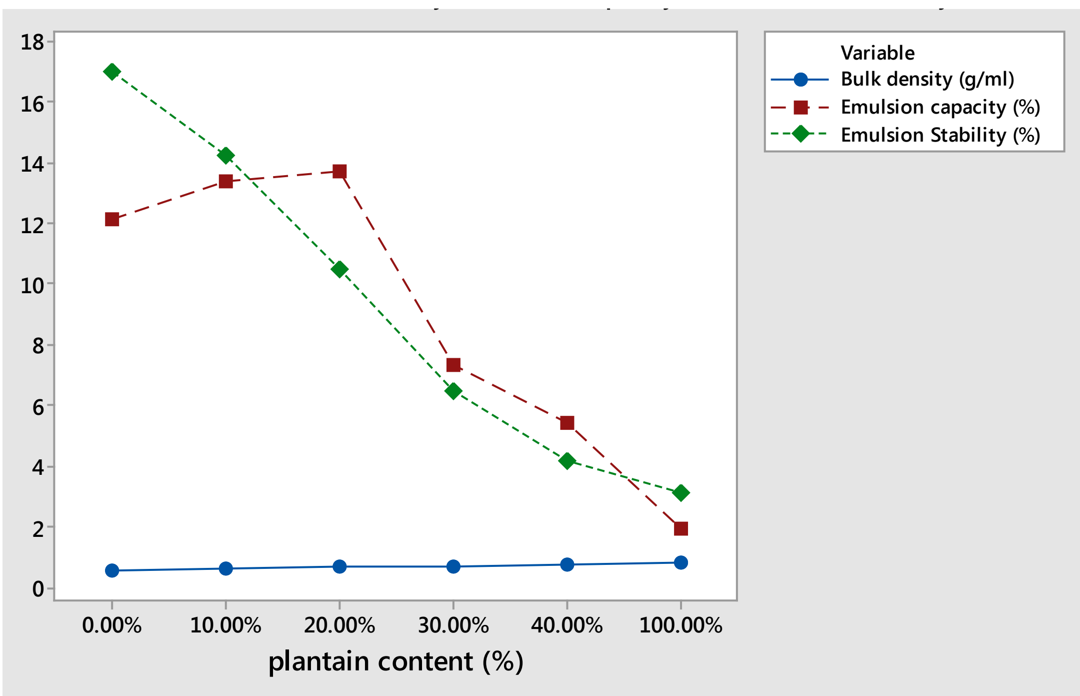

Fig 5.5: Line plot illustrating changes in bulk density, Emulsion capacity and Emulsion stability with *change in the level of plantain incorporation*

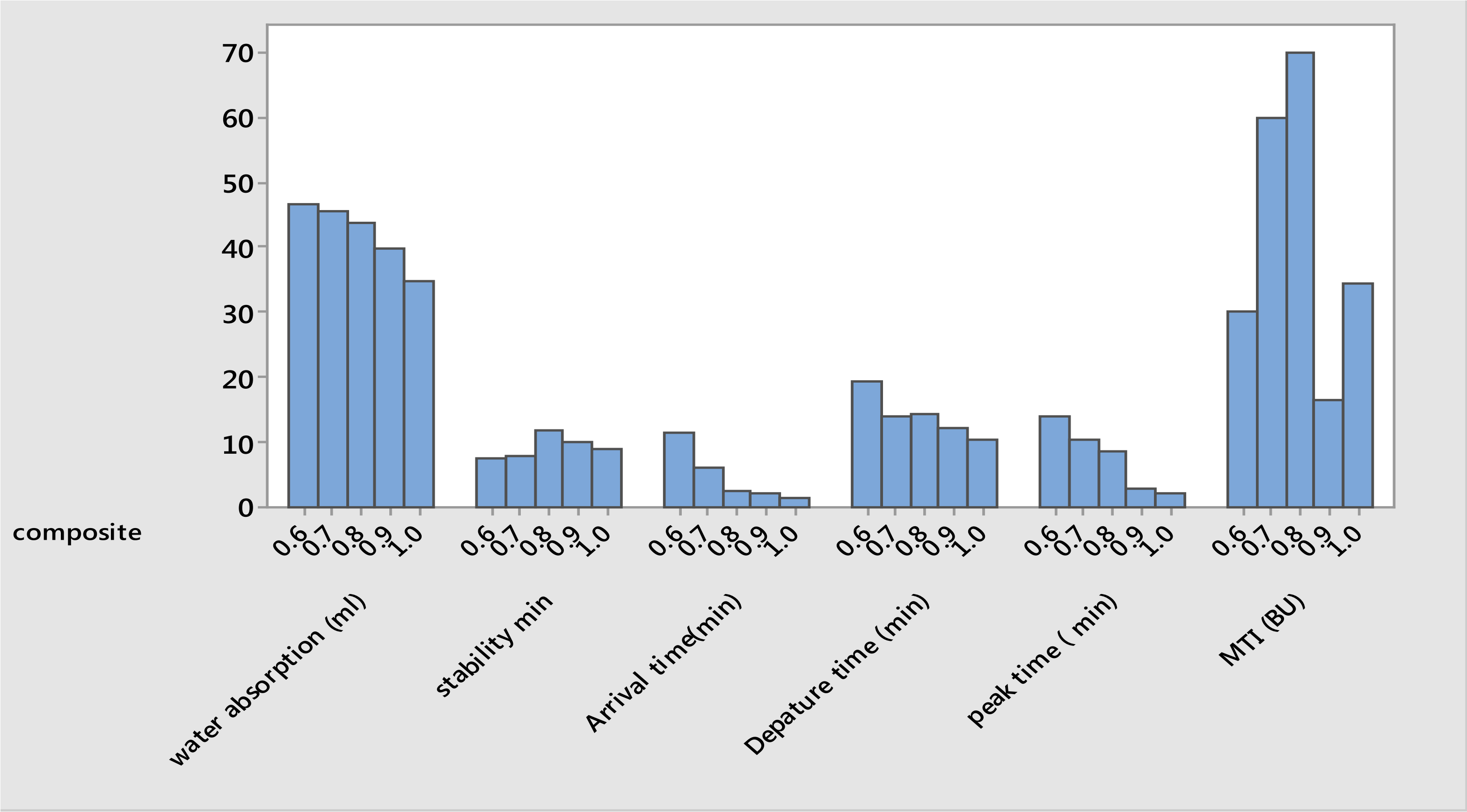

Figure 5.6: Bar chart of water absorption, stability, arrival time, departure time, peak time and Mechanical Tolerance Index vs % Plantain

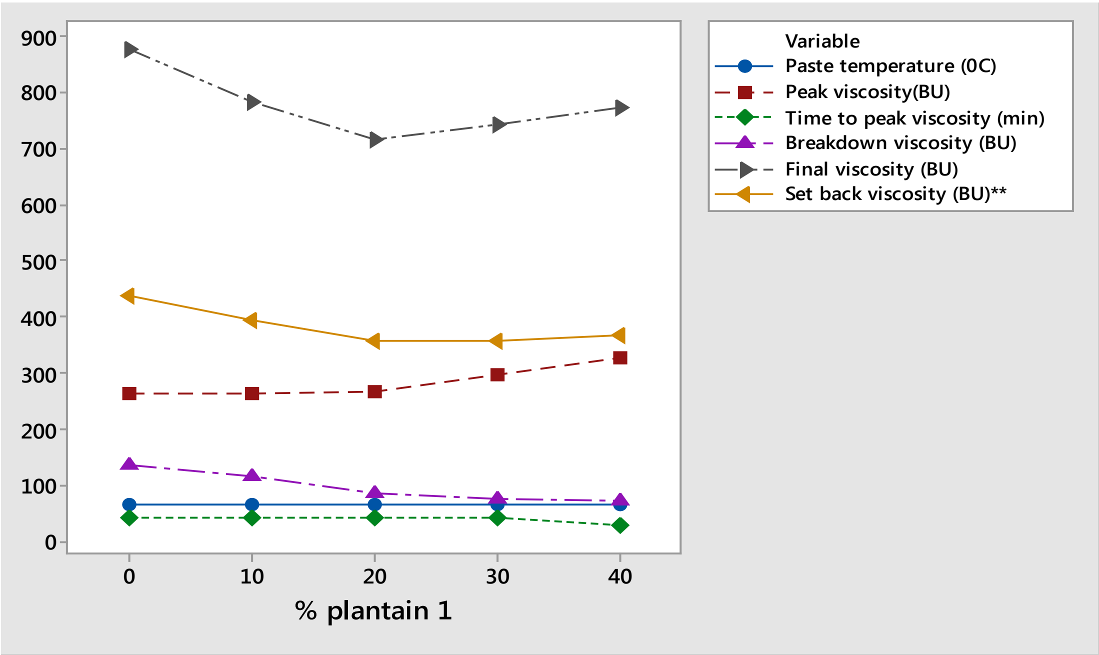

Figure 5.7: Line plot showing the effect of the level of plantain flour incorporation on pasting properties

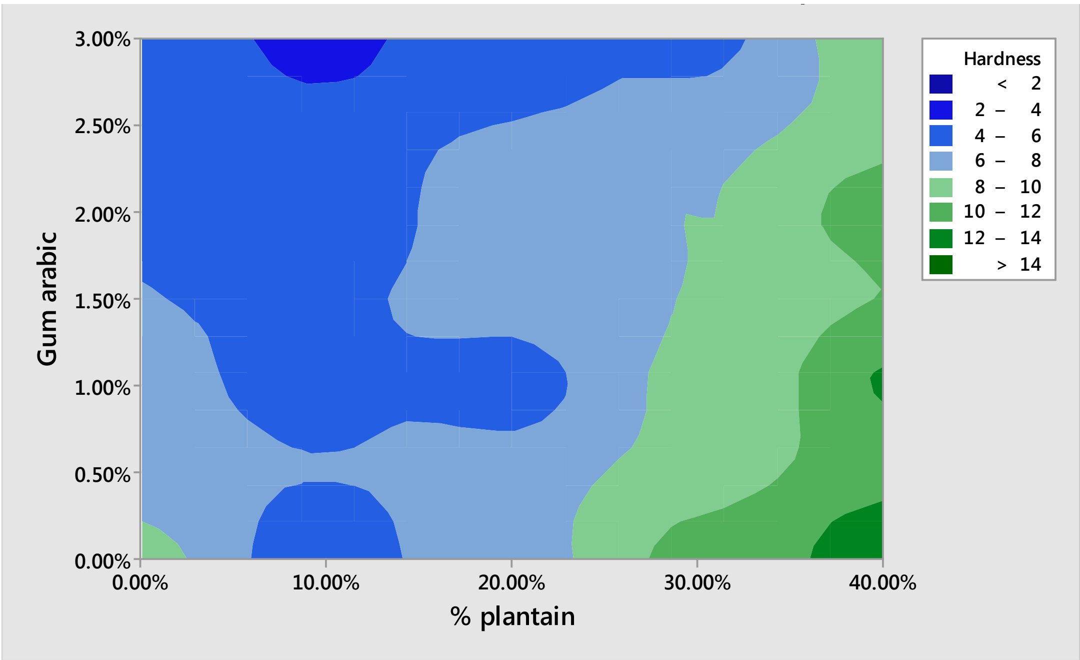

Figure 5.8: Contour plot illustrating the effect of the level of plantain flour incorporation on bread hardness

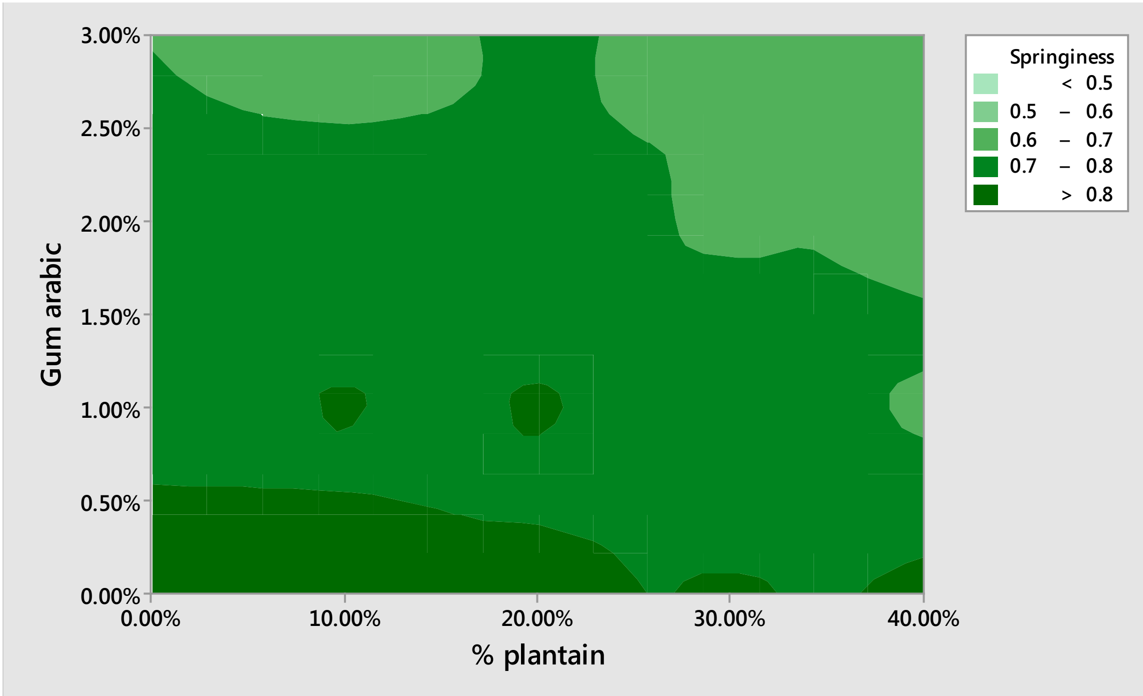

Figure 5.9: Contour plot illustrating the effect the level of plantain incorporation on bread springiness

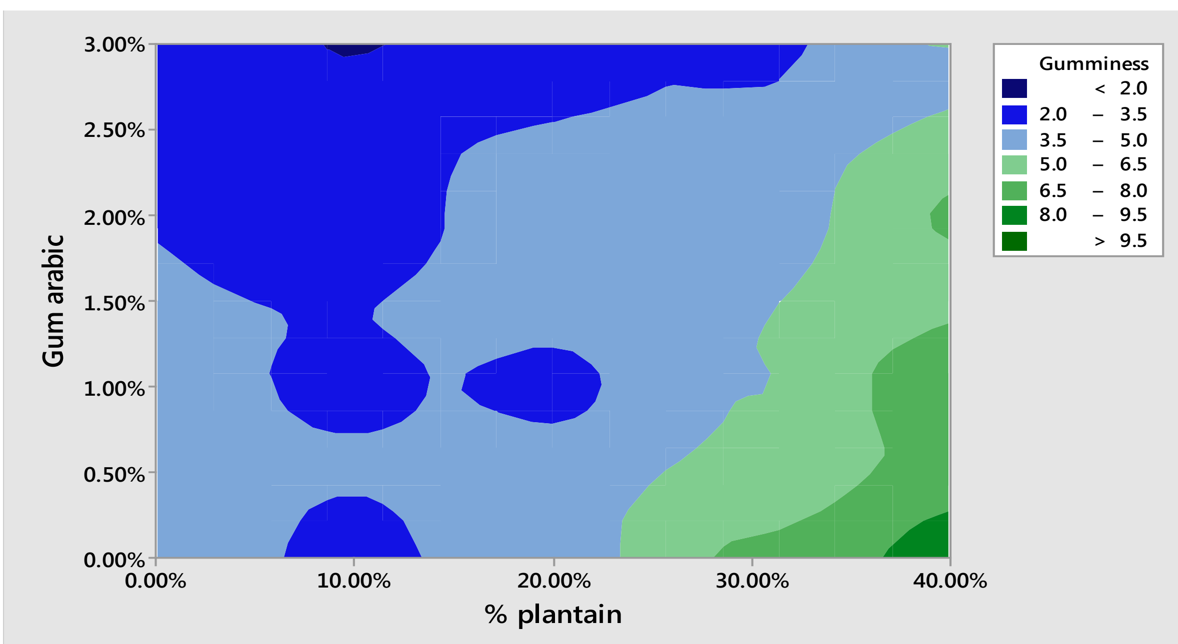

Figure 5.10: Contour plot illustrating the effect of the level of plantain incorporation on bread gumminess

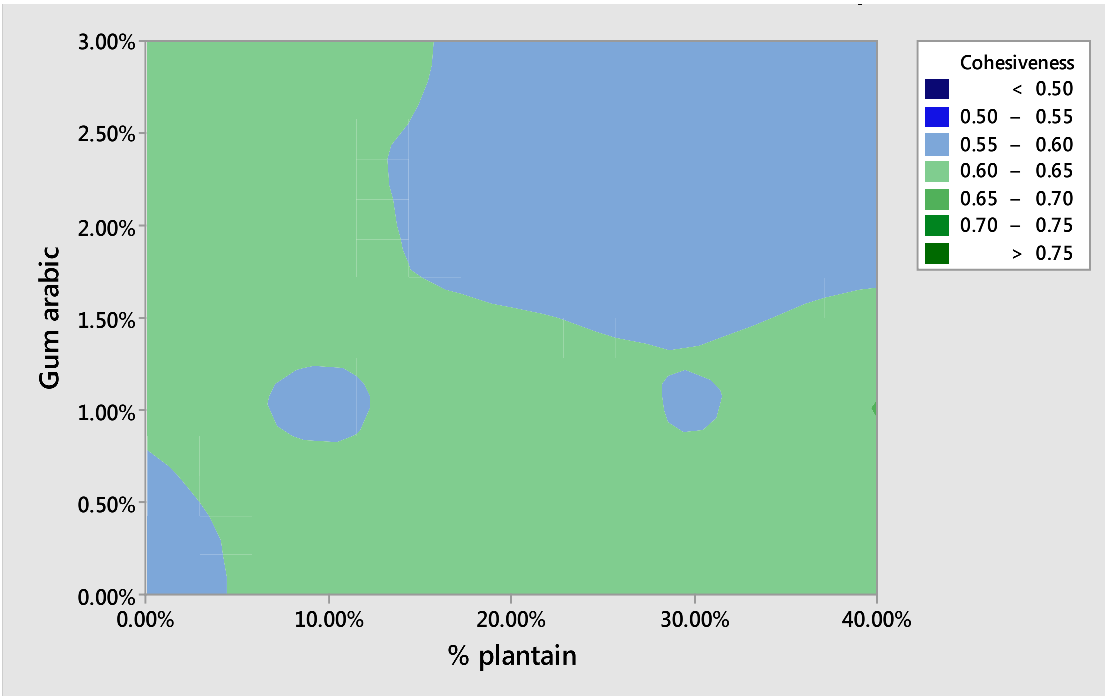

Fig 5.11: Contour plot illustrating the effect of the level of plantain incorporation on bread cohesiveness

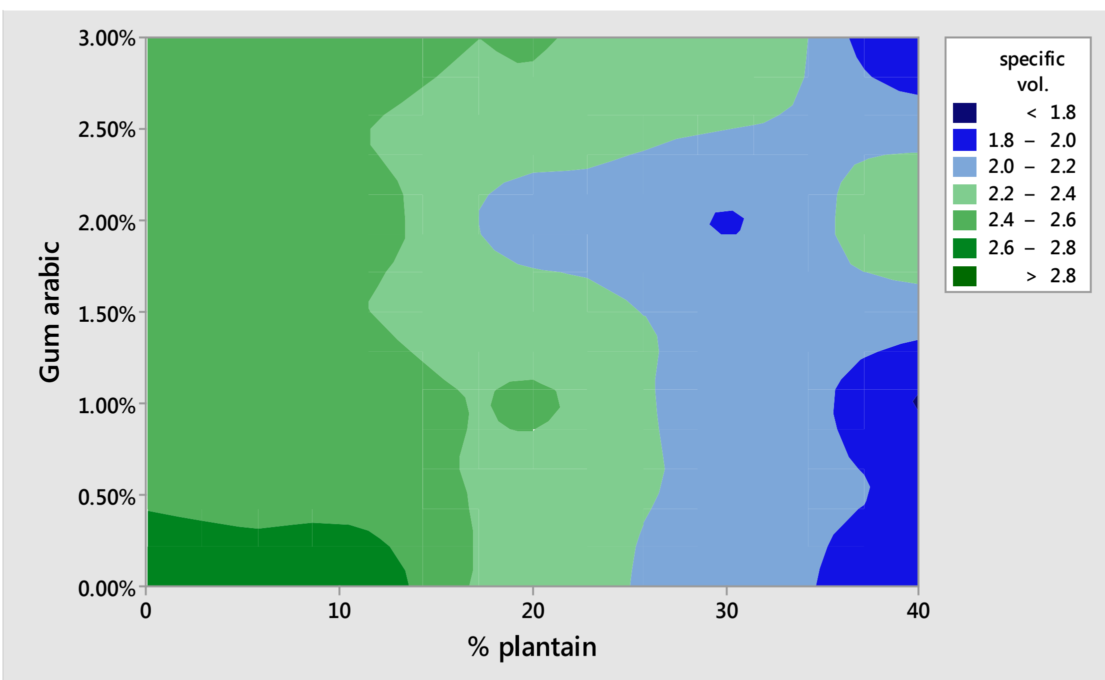

Fig 5.12: Contour plot illustrating the effect of the level of plantain incorporation on bread specific volume