

**EFFECT OF GUM ARABIC FROM *Acacia senegal* var. *kerensis* AS AN IMPROVER
ON QUALITY PROPERTIES OF WHEAT FLOUR DOUGH, BREAD and *CHAPATI***

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**A Thesis Submitted to the Graduate School in Partial Fulfilment of the Requirements
for the Master of Science Degree in Food Science of Egerton University**

EGERTON UNIVERSITY

OCTOBER, 2024

DECLARATION AND RECOMMENDATION

Declaration

This thesis is my original work and has not, wholly or in part, been presented for the award of a degree at Egerton University or any other institution.

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Recommendation

This thesis has been submitted with our approval as university supervisors.

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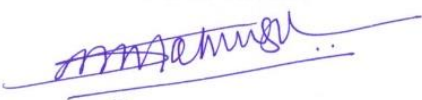
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DEDICATION

This work is wholeheartedly dedicated to God, my parents: Mr. Gidraph Kiama and Mrs. Gladys Wanjiku, my siblings: Nicholus, Danford and Maxwell; and Antony Nderitu for always being there for me. The support, prayers and words of encouragement have been very instrumental in the course of this academic journey.

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ABSTRACT

Synthetic improvers have been used in the baking industry to simplify production process and improve product quality. However, there is increasing demand for natural ingredients as consumers are demanding for healthier products. Gum Arabic from *Acacia senegal* var. *kerensis* is one of the promising alternatives as it exhibits excellent water binding capacity. However, very little is reported on how it affects dough rheological properties and baked products. Therefore, the aim of this study was to determine the effect of using gum Arabic as an improver on dough, bread and *Chapati*. Wheat flour samples containing gum Arabic at 1%, 2% and 3%, plain wheat flour (negative control), commercial bread flour and commercial *Chapati* flour were analyzed for physicochemical properties, dough rheological properties and consequently used to make bread and *Chapati*. The products were analyzed for: loaf volume, textural properties, microbial quality and sensory properties. It was noted that gum Arabic significantly increased moisture (12.74-12.93), fibre (1.30-1.62), ash (0.84-1.06) and carbohydrate (70.65-71.16) content of the wheat flour but decreased the protein (12.15-12.39) and fat (1.48-1.95) content. There was also a significant increase in water holding capacity (0.97-1.37), oil holding capacity (1.17-1.49), emulsion capacity (47.53-52.37) and emulsion stability (43.46-51.22) of wheat flour. Gum Arabic significantly increased all the Farinograph properties except dough consistency (490-505BU) and all extensograph properties but significantly decreased all the Viscograph parameters apart from the pasting temperature (69.50-71.68°C). Bread containing 2% gum Arabic recorded the highest specific volume (3.77). Addition of gum Arabic led to an increase in springiness (0.82-0.86), cohesiveness (0.51-0.59) and resilience (0.81-0.21) but a reduction in gumminess (438.66-1122.07) and chewiness (376.07-930.15). *Chapati* firmness (760.31-1081.33) significantly decreased with addition of gum Arabic. The microbial levels of total viable counts and yeasts and moulds in bread and *Chapati* samples were compliant with the Kenya Bureau of Standards guidelines on baked products. Principal component analysis indicated existence of 3 principal components in both bread and *Chapati* explaining 72.7% and 61.7% of the total variation respectively. Panelists preferred bread samples containing 2% gum Arabic and 3% in *Chapati*. Therefore, an optimal gum Arabic concentration of 2% in wheat flour dough is recommended in making of pan bread while that containing 3% recommended for making *Chapati*. These findings demonstrate the need to utilize gum arabic from *Acacia Senegal* var. *kerensis* in baking industries to aid in production of dough and high-quality baked products.

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LIST OF ABBREVIATIONS AND ACRONYMS

AACC	American Association of Cereal Chemists
AOAC	Association of Official Analytical Chemists
CRD	Completely Randomized Design
CSL	Calcium Stearoyl Lactylate
DATEM	Diacetyl Tartaric Esters of Mono and Diglycerides
FAO	Food and Agriculture Organization of the United Nations
JECFA	Joint Expert Committee for Food Additives
KSh	Kenya Shillings
KEFRI	Kenya Forestry Research Institute
KIRDI	Kenya Industrial Research and Development Institute
RUFORUM	Regional Universities Forum for Capacity Building in Agriculture
SDG	Sustainable Development Goals
TAGDEV	Transforming African Agricultural Universities to meaningfully contribute to Africa's growth and development
USA	United States of America
WHO	World Health organization

CHAPTER ONE

INTRODUCTION

1.1 Background Information

Wheat (*Triticum aestivum L.*) is one of the major staple food crops grown worldwide and the second most important cereal crop after maize (Tafese, 2020). The global production of wheat is about 653 million tonnes while in Kenya it is about 27,800 tonnes (Gitobu *et al.*, 2019). Wheat-based food products such as breads, cakes, pizza and breakfast cereals are widely consumed in the world (Omedi *et al.*, 2019). They are available in different forms depending on the composition, technology used and the quality of the product (Wang *et al.*, 2015). The basic steps in the production of baked products involves mixing of wheat flour and water followed by kneading to produce a dough (Li *et al.*, 2019). Gluten is a unique wheat protein due to its ability to form a three-dimensional network upon hydration which holds starch granules, fat, and other ingredients in place thus imparting the quality of the final product (Ferrero, 2017). Dough quality is affected by factors such as the type of wheat, choice of ingredients, their formulation and the changes that take place during processing (Omedi *et al.*, 2019). In order to standardize the final product, interventions such as the use of improvers have been advancing rapidly. The majority of improvers in use today are synthetic in nature (Yaxi & Catrin, 2021). Currently, consumers are demanding natural dough modifying additives since they are safe and healthier options (Koko *et al.*, 2021; Liang *et al.*, 2021). Thus, the need to identify natural ingredients with the capacity to enhance the rheology of dough.

Improvers are substances with specific functional characteristics used to modify doughs and compensate for changes in processing characteristics (Vargas & Simsek, 2021). They impact on dough properties such as water absorption, dough development, dough stability, strength, extensibility and viscosity (Ferrero, 2017). Thus, simplifying the production process and improving the quality of baked goods (Sciarini *et al.*, 2012). The most widely used improvers include chemicals such as calcium stearoyl lactylate (CSL), diacetyl tartaric esters of mono and diglycerides (DATEM) and ascorbic acid. They act by enhancing protein linking of the dough proteins through disulfide bonds, leading to improvement of the dough rheology (Liang *et al.*, 2021). Others include enzymes such as α -amylase, bacterial α -amylase and xylanase which hydrolyze starch thus reducing starch retrogradation (Yaxi & Catrin, 2021).

The current approach in flour improvers entails the use of hydrocolloids which are of natural origin such as xanthan and guar gum (Sciarini *et al.*, 2012). They have high molecular weight

with colloidal properties such that in water-based systems they produce gels (Li *et al.*, 2019). They are mostly from natural sources and their application in the baking industry is based on their rheological and physical properties (Koko *et al.*, 2021). Hydrocolloids form hydrophilic complexes with gluten proteins, that bind water and decrease moisture migration in the dough thereby modifying dough rheology (Omedi *et al.*, 2019). They have been used in the baking industry to slow staling rate, improve texture properties, enhance water holding capacity, prevent the loss of quality in frozen dough, and compensate for the diminished quality of gluten-free products (Ferrero, 2017). Studies have reported enhanced farinographic absorption of water upon addition of gums in wheat bread making (Correa & Ferrero, 2015; Reza *et al.*, 2017). Gum arabic from *Acacia senegal* var. *kerensis*, has superior properties compared to other gums such as high-water solubility which is desirable in the baking industry (Mugo *et al.*, 2020).

Gum arabic from *Acacia senegal* var. *kerensis*, is a dried exudate extracted from *Acacia senegal* stems and branches (Mugo, 2012; Mwove *et al.*, 2017). It consists of highly branched molecules comprising of hydrophilic sugar residues and hydrophobic amino acids in the Arabinogalactan protein (AGP). It has a high molecular weight of approximately 1.19×10^6 (Mugo *et al.*, 2020). The protein fraction constitutes about 3.5% of the total weight which contribute to the gum's amphiphilicity that favor its adsorption to air/water or oil/water interface (Prasad *et al.*, 2022). The viscosity of acacia gum solution is low compared to other polysaccharides of similar molecular mass and flow behavior is considered to be Newtonian up to 20-30% gum concentration or higher (Singh *et al.*, 2017). It's viscoelastic properties which mimic gluten are important in making non-wheat baked products (Soibe *et al.*, 2016). Gum Arabic from *Acacia senegal* var. *kerensis* is increasingly being used in the food industry on a global scale due to its desirable properties such as enhanced food texture, higher water absorption and improved shelf life (Mwove *et al.*, 2017).

Various studies have reported on the effect of gums on dough properties; xanthan gum increased water absorption and ability of the dough to retain the gas while guar gum increased mixing and moisture retention (Omedi *et al.*, 2019, Thombare *et al.*, 2016). Gum arabic from *Acacia senegal* var. *kerensis* has been reported to possess good water binding properties (Mugo *et al.*, 2020; Mwove *et al.*, 2017). However, there are no reports showing the impact of gum arabic from *Acacia senegal* var. *kerensis* on the quality properties of wheat flour-based dough, bread and *Chapati*. Thus, the objective of the current work was to

examine the effect of gum arabic from *Acacia senegal* var. *kerensis* on the rheological and quality characteristics of wheat flour dough, bread and *Chapati*.

1.2 Statement of the Problem

Wheat flour quality varies greatly within varieties whereby some types are characterized as of low protein content and quality. This affects dough rheology and consequently the quality of final baked products. In order to standardize wheat flour in terms of processing quality to improve dough handling properties and the quality of final product, different improvers have been used in the baking industry. Although most of the improvers used are synthetic, natural alternatives are gaining recognition and popularity since consumers are demanding healthier products. Therefore, the need to find additional natural alternatives with desirable functional characteristics. Gum Arabic from *Acacia senegal* var. *kerensis* is a natural gum with higher solubility than other gums and superior water holding properties. It has a high protein content and ability to increase the water holding capacity of the dough making it a viable option to be used as a dough improver. However, despite possessing these desirable properties and being produced in significant amounts in Kenya, it remains underutilized. Therefore, there is need to explore the use of Gum Arabic from *Acacia senegal* var. *kerensis* in wheat-based dough in order to expand its utilization in the baking industry.

1.3 Objectives

1.3.1 Broad Objective

To contribute to food and nutritional security through application of gum arabic from *Acacia senegal* var. *kerensis* as an improver on the quality properties of wheat flour dough, bread and *Chapati*.

1.3.2 Specific Objectives

- i. To determine the effect gum arabic from *Acacia senegal* var. *kerensis* on physicochemical properties of wheat flour.
- ii. To determine the effect of gum arabic from *Acacia senegal* var. *kerensis* on the rheological properties of dough.
- iii. To determine the effect of gum arabic from *Acacia senegal* var. *kerensis* on the baking quality attributes of bread and *Chapati*.
- iv. To determine the effect of gum arabic from *Acacia senegal* var. *kerensis* on the sensory properties of bread and *Chapati*.

1.4 Hypotheses

- i. Gum arabic from *Acacia senegal* var. *kerensis* has no significant effect on the physicochemical properties of composite wheat flour.
- ii. Gum arabic from *Acacia senegal* var. *kerensis* has no significant effect on the rheological properties of dough.
- iii. Gum arabic from *Acacia senegal* var. *kerensis* has no significant effect on the baking quality attributes of bread and *Chapati*.
- iv. Gum arabic from *Acacia senegal* var. *kerensis* has no significant effect on the sensory properties of bread and *Chapati*.

1.5 Justification

The increase in demand for healthy and natural ingredients by consumers provides a great opportunity in utilization of readily available raw materials such as gum Arabic in the baking industry. Gum Arabic is an accepted food additive exhibiting excellent functional properties such as high solubility, emulsification and stabilization. The production of gum Arabic is 400MT in Kenya with a potential of more production. Its utilization has a positive impact on the baking industry in Kenya and contributes to the socio-economic status of communities residing in the Kenyan drylands. This innovation contributes to achieving part of the social economic pillar of the Kenya's vision 2030 that recognizes the critical role played by value addition on the socio-economic advancement of the society. It also contributes to Sustainable Development Goals SDG: Goal 1-No poverty and Goal 2 – Zero hunger and Goal 12-Responsible consumption and production. This study generates useful information on the commercial utilization of gum Arabic in the baking industry in Kenya and other developing countries.

CHAPTER TWO

LITERATURE REVIEW

2.1 Wheat

Wheat (*Triticum spp.*) is a cereal grain that has origins from the Levant regions of the Near East and the Ethiopian Highlands, which is now grown globally (Tadesse *et al.*, 2018). It belongs to the grass family Gramineae which is the same for cereal grains like corn, rice, barley, oats, sorghum, and pearl millet (Tafese, 2020). The main commercial wheat cultivars include *Triticum aestivum*, *Triticum durum*, and *Triticum compactum*, which are largely grown in the USA for soft flour production (Gitobu *et al.*, 2019). Wheat is the most widely used cereal grain for baking purposes due to the gluten network that forms a dough and the mellow, nutty flavor of the baked products (Tafese, 2020). Given that it meets about 50% of dietary demands, this makes it a frequently consumed crop and essential for global food security (Omedi *et al.*, 2019). Nutritive composition differs significantly due to the diverse cultivating methods used and the varieties planted (Gitobu *et al.*, 2019). The kernels comprise of bran, germ and endosperm. The major components of the endosperm are starch, proteins, moisture, and lipids while the bran comprises of the pericarp, testa, nucellar layer, and aleurone layer (Koko *et al.*, 2021). The endosperm makes up the majority of the wheat seed, which contains the elements required for germination.

2.2 Wheat Production and Consumption

Wheat is regarded as the second-most significant crop in Kenya after maize (Tadesse *et al.*, 2018). The global production is about 734 million tonnes while in Kenya it is about 300 thousand tonnes (Gitobu *et al.*, 2019). The primary wheat-growing regions in Kenya are the highlands, specifically Timau, Meru, Uasin Gishu, Narok, and Nakuru (Tadesse *et al.*, 2018). In these regions, the lower temperatures enable longer periods of starch accumulation, which results in higher yields (Tafese, 2020). The key parameters impacting wheat farming are a gentle slope, altitude, moderate rainfall, mild temperatures, deep fertile volcanic soils and warm dry sunny spells (Gitobu *et al.*, 2019). Currently, per capita consumption of wheat in the country stands at 43 kilograms per person and is expected to grow at an average of 4% per year (Tadesse *et al.*, 2018). Convenience, rising incomes, population growth, urbanization, and women's participation in the labor force are some of the factors which have contributed to wheat consumption exceeding its supply. Due to this, Kenya has become a net importer of wheat, with consumption of 50.4% , which amounts to about 1018.81 metric tonnes of which 75% is utilized in urban areas (Gitobu *et al.*, 2019).

2.3 Types of Wheat

Different types of wheat are grown around the globe with majority of the cultivars growing in moderate conditions. Others thrive in the Arctic Circle and in the Andes Mountains near the equator (Tadesse *et al.*, 2018). Protein content, kernel colour, and harvest season are the three categories that millers and wheat farmers have developed to help them predict the likely performance qualities of wheat transported to market (Gitobu *et al.*, 2019). Wheat may be given a label such as "hard red winter," "soft white winter," or "hard red spring" before it is sold as shown in Table 1 below.

Table 1: Wheat classification

Variety	Protein Content	Kernel Color	Planting Season	Harvesting Season	Typical use
Soft red winter	8–11%	Red	Fall	Early summer	Cake, pastry flour
Soft white winter	8–11%	White	Fall	Early summer	Cake, pastry flour
Hard red winter	10-15%	Red	Fall	Early summer	Bread flour
Hard white winter	10-15%	White	Fall	Early summer	Bread flour
Hard red spring	12-18%	Red	Spring	Fall	Bread flour, high protein flour
Durum Spring	14-16%		Spring	Fall	Semolina, durum flour

Source: Khalid *et al.* (2023)

Hard winter wheat flour, which is produced in both red and white, has a protein content of 10–15%, thus it is most preferred by artisan bread bakers (Cao *et al.*, 2017). Bread wheat, *Triticum aestivum* (*T. vulgare*), and durum or macaroni wheat (*Triticum durum*) are the significant species (Tafese, 2020). Wheat can also be classified as hard wheat or soft wheat. Hard wheat is necessary for inclusion in bread manufacturing while a soft wheat is ideal for biscuit production. Soft wheats alone do not make decent breads, while hard wheats alone are unsuitable for biscuit and cake making (Cao *et al.*, 2017). Durum wheat must be used for high-quality pasta. On a worldwide basis, bread wheat *Triticum aestivum* (*T. vulgare*) contributes roughly 90 per cent of the wheat grown; the balance is devoted largely to durum wheat (Tadesse *et al.*, 2018).

2.4 Wheat Flour

Wheat flour is the primary product obtained from the milling of wheat by gradual reduction system which involves crushing, grinding and sieving to produce fine particles (Cappelli *et al.*, 2019). Flour performs a number of functions in baked goods: it provides structure, binds and absorbs, affects keeping qualities, affects flavor, and imparts nutritional value (Tafese, 2020). Wheat flour's ability to trap and retain gases from fermentation and thereby leaven bread is the reason it has become the preferred grain for bread making (Khalid *et al.*, 2023). Many bread labels include "wheat flour" as an ingredient. However, sifted wheat flour is not the same as whole wheat flour. Whole wheat flour is a whole grain, milled from the whole wheat kernel while wheat flour comprises of white flour, milled from the endosperm (Tebben *et al.*, 2018) .

2.5 Dough Rheology

Dough preparation is a critical process in the making of baked products which includes complex physical and biochemical modifications (Li *et al.*, 2019). Wheat flour and water are transformed to create a dough, a three-dimensional gluten network. This network creates a support structure involving hydrations, disulphide and ionic bonds, hydrogen bonds and hydrophobic connections (Ferrero, 2017). It embeds starch granules, fat and other dough components. Once the dough has been formed, the gluten structure holds the gases produced during the fermentation phase. As a result, the dough mass can expand and be baked into a variety of palatable products (Koksel & Scanlon, 2018). The performance of the dough plays a key role in defining the quality of the final product (Cappelli *et al.*, 2020).

Dough rheology is the flow and elastic behavior of the dough which entails factors such as water absorption, dough viscosity, elasticity, strength, cohesiveness, extensibility and gas retention capacity (Brandner *et al.*, 2019). These factors influence the mechanical qualities throughout processing such as mixing behavior, sheeting and baking performance and that of the product. Thus, helping in forecasting the quality of the finished product (Cappelli *et al.*, 2019). Gluten is a protein found in wheat that comprises of glutenin and gliadin. Gliadins determine the viscosity and extensibility, whereas toughness and elasticity are determined by glutenins which gives the dough its extensible and viscoelastic qualities (Wang *et al.*, 2020). The two components significantly affect the rheology of the dough and determines the quality of the finished product. In comparison to wheat dough, gluten-free doughs exhibit reduced elasticity and cohesion, poor gas retention capacity, weaker strength, inconsistent mixing, and poor texture (Tebben *et al.*, 2018). Dough also undergoes various changes during storage

that lead to the loss of its quality attributes resulting to inferior products compared to those produced from freshly prepared ones (Omedi *et al.*, 2019). Therefore, the baking industry is constantly seeking strategies and techniques that can improve the technological properties of dough and bread.

Rheological methods permit objective description of the effect of a particular addition on the behavior of bread during mixing, proving and baking. The main methods used include the Farinograph, extensograph and Viscograph methods (Miś *et al.*, 2012). The Farinograph studies the properties of dough at the development and mixing stage, whereby the response to mechanical mixing mimics shearing that takes place in bakeries is determined. The extensograph gives more information on dough viscoelastic property whereby it predicts the behavior during proofing as the structure formation is subjected to extensional deformations (Liang *et al.*, 2021). The Viscograph is used in measuring the pasting behavior of starch and usually predicts the behavior of the products after the baking process (Hussain *et al.*, 2022).

2.6 Pasting Properties

The presence of starch in wheat flour plays a crucial role in baking as they confer distinct functional characteristics in the product. Starch consists of amylose and amylopectin molecules whose ratio affects the functional, processing parameters and the edible quality of the end product (Mahmood *et al.*, 2017). During mixing and baking, starch undergoes gelatinization and gelation which plays a key role determining the quality of the final product. During cooling and long storage times, starch undergoes retrogradation and firming followed by staling (Mir *et al.*, 2016). Pasting properties show the level of molecular degradation, viscosity and paste stability. In order to improve the properties of flour and the quality of final products, it is important to study the pasting properties of flour (Li *et al.*, 2018).

Pasting properties refer to the changes that occur in the starch when subjected to heat in the presence of water. The starch granules undergo hydration, swelling, disintegration and deformation forming a paste (Mahmood *et al.*, 2017). Pasting behavior of any flour is important for the characterization of its starch. Its properties such as pasting, gelling and thickening are desirable in food processing due to the features they impart in different food products (Kiprop *et al.*, 2021).

Determination of pasting properties is important in food product development as it shows the modifications resulting from food interactions. Some of the modifications in pasting

properties influence the sensory and food stability during storage (Hussain *et al.*, 2022). Addition of hydrocolloids is one of the ways used in starch properties modification and helps in slowing down retrogradation, increasing moisture retention and extending the product quality during storage (Mir *et al.*, 2016).

2.7 Dough Improvers

The use of additives has become a common practice in the baking industry. Increased need for their use arises from the fact that numerous benefits are associated when they are incorporated in the dough (Yaxi & Catrin, 2021). Improvers are substances with specific functional characteristics used to modify dough and compensate for changes in processing characteristics. They simplify the production process and improve the quality of baked goods (Sciarini *et al.*, 2012). With this objective, a large number of these substances of various forms have been used. Some of the widely used improvers have been discussed below:

2.7.1 Emulsifiers

Emulsifiers are substances which contains both hydrophilic and lipophilic components. They are also referred to as surfactants or surface-active agents (Tebben *et al.*, 2018). Lecithin, diacetyl tartaric acid esters of mono- and diglycerides (DATEM), polysorbate, and sodium stearoyl lactylate are commonly used in the baking industry (Yaxi & Catrin, 2021). Emulsifiers constitute one of three sources of lipids used in the production of bread, along with the lipids found in the native flour and shortening/margarine. In the food industry, emulsifiers provide the needed functional roles to enable food processing (Cappelli *et al.*, 2020). They are often used in very small amounts but they have a significant impact on the finished products. Emulsifiers are frequently added to commercial bakery products to improve dough handling and enhance products' quality. They are used to aerate batters and foams, increase shelf life, promote fat aggregation, and enhance food texture (Yaxi & Catrin, 2021).

2.7.2 Oxidizing Agents

Oxidants increase dough strength mainly by oxidizing free sulfhydryl groups on the gluten proteins leading to formation of disulfide bonds (Tebben *et al.*, 2018). They also increase dough elasticity, handling tolerance, oven spring and final loaf volume. Examples of oxidants include ascorbic acid, potassium bromate, potassium iodate, calcium peroxide, and azodicarbonamide (ADA) (Liang *et al.*, 2021). Ascorbic acid is a reducing agent, however, in the presence of oxygen and the enzyme ascorbic acid oxidase it is transformed to the dehydro form. This form participates in oxidation reactions like the SH/SS interchange and contribute

to the stabilization of the gluten protein network (Tebben *et al.*, 2018). Certain synthetic oxidants, including potassium bromate and ADA have been banned in several nations outside the United States, including Australia, Singapore and in Europe, due to potential health effects (Shanmugavel *et al.*, 2019). In place of synthetic oxidants, oxidizing enzymes and ascorbic acid are increasingly used. However, oxidizing agents are less effective in wheat based products, thus they have to be used in large amounts (Tebben *et al.*, 2018).

2.7.3 Enzymes

The use of enzymes in commercial applications has increased in the recent years. Various types of enzymes such as phytase, amylases, and xylanase are utilized as improvers (Renzetti & Rosell, 2015). The most popular are the amylases, which facilitates the hydrolysis of 1,4-glycosidic linkages in starch polymers to produce low molecular weight polysaccharides and dextrans (Tebben *et al.*, 2018). Numerous industrially manufactured enzymes are added to flour because of their advantageous effects on the characteristics of dough and bread (Ooms & Delcour, 2019). Enzymes have been used to enhance volume and crumb texture, decrease rate of staling, improve dough handling and hydration, and improve nutritional characteristics (Renzetti & Rosell, 2015). However enzyme activity is affected by a number of parameters, such as temperature, pH, water activity, and enzyme concentration (Koksel & Scanlon, 2018).

2.7.4 Hydrocolloids

Food hydrocolloids are high molecular weight polysaccharides which are hydrophilic in nature and possess the ability to modify the rheology of aqueous systems which they are added (Tebben *et al.*, 2018). The most widely used in the food industry are gums, sodium alginate, carboxymethylcellulose (CMC) and hydroxypropyl methylcellulose (HPMC). Hydrocolloids are employed in foods to modify the texture and viscosity and are generally categorized as thickeners or gel formers (Ferrero, 2017). Due to their hydrophilic nature, the addition of hydrocolloids to wheat flour changes how much water is absorbed therefore increasing the water absorption capacity of the dough (Tebben *et al.*, 2018). The type of hydrocolloid added appears to be more important than its concentration (Li *et al.*, 2018). They are used in baked goods to delay staling and enhance the quality of the products.

a. Gums

Gums are high molecular weight polymers which are hydrophilic in nature. They create gels or extremely viscous suspensions in water based systems (Tebben *et al.*, 2018). They are mostly polysaccharides but also comprise of proteins such as gelatin. Hydroxyl groups allow

water binding and interactions in these substances (Sciarini *et al.*, 2012). Gums are obtained from different sources such as seeds, plant exudates or cell wall components, cellulose derivatives, microbial fermentation products, seaweed and modified starches (Ferrero, 2017). They are used as alternatives to chemical hydrocolloids. Gums have been widely utilized in gluten-free baked products to give some stability, strength and viscoelasticity in the absence of a gluten network (Li *et al.*, 2018). In bakery applications, hydrocolloids modify the characteristics of the dough, increase water absorption, stabilize frozen dough and par-baked bread. They also improve moisture retention, crumb texture and retard staling in the finished product (Ferrero, 2017; Li *et al.*, 2018; Reza *et al.*, 2017).

b. Gum Arabic

Gum arabic is an edible, dried, gummy exudate from the stems and branches of *Acacia senegal* and *A. seyal* that is rich in non-viscous soluble fiber (Mugo *et al.*, 2012; Mwove *et al.*, 2017). It is defined by the FAO/WHO Joint Expert Committee for Food Additives (JECFA) as ‘a dried exudation obtained from the stems of *A. senegal* (L.) Willdenow or closely related species of *Acacia* family Leguminosae (Mugo *et al.*, 2020). *Acacia Senegal* is a drought resistant tree found naturally in arid, subtropical and semi-arid climatic zones. It is a deciduous, small, spiny shrub and usually branched. Gum production comes from naturally growing trees and its formation is through natural exudation and/or injury (Prasad *et al.*, 2022) as shown in Figure 1.

Unlike other vegetable gums, gum Arabic has a high solubility in water of up to 50%, forming a colourless, tasteless solution. In addition, its interaction with other chemical compounds is minimal (Mwove *et al.*, 2016). Gum Arabic is a slightly acidic and is composed of glycoprotein and polysaccharides and their calcium, magnesium and potassium salts (Mugo *et al.*, 2020). It is mainly a galactane polymer with side chains of galactose and/or arabinose and ultimately ending in side chains of rhamnose or glucuronic acid (Mwove *et al.*, 2016). The structure of gum Arabic comprises of many arabinogalactan units attached to a protein chain. These units are classified as arabinogalactan, glycoprotein and arabinogalactan protein complex (Prasad *et al.*, 2022). The proteins present in gum Arabic are mainly hydroxyproline, aspartic acid, proline and serine (Prasad *et al.*, 2022).



Figure 1: Gum Arabic exudate from *Acacia senegal* tree (A), Exudate made into granules form (B) and(C)

Source: Patel and Goyal (2015)

Most of gum Arabic is produced from Africa with Kenya being among the top 17 producing countries (Mwove *et al.*, 2017). 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 (Mugo, 2012; Soibe *et al.*, 2016). 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 (Soibe *et al.*, 2016). 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 (Prasad *et al.*, 2022). The physicochemical properties of gum Arabic are as outlined in Table 2.

Table 2: Physicochemical and molecular characteristics of gum Arabic from *Acacia Senegal* var. *kerensis*

Physicochemical property	Amount
Moisture	14.5%
Ash	3.6%
Nitrogen	0.68
Protein (N×6.63)	3.42
Viscosity- Intrinsic viscosity	27 ml/g
pH-1%	4.54
Molecular weight	1.19×10^6

Source: Mugo *et al.* (2020)

2.8 Baked Products

The term "baked products" refers to food products produced through a process that mainly involves mixing of flour, water and additional ingredients to form a dough or batter which undergoes cooking using dry heat (Sciarini *et al.*, 2012). Dough is formed into

distinguishing shapes and undergoes a heat-processing step that involves the reduction in moisture using a dry heat source such as a bakery oven (Wang *et al.*, 2015). Most of the baked products are classified as breads, cakes, pastries, cookies and crackers. One of the earliest occupations performed by humans is making baked products, especially bread. Baked products are considered as essential to human nutrition since they are an important source of macronutrients, micronutrients, dietary fiber, vitamins, and antioxidants (Cappelli *et al.*, 2019).

2.8.1 Bread

Bread is an important staple food in most countries throughout the world (Cappelli *et al.*, 2020). It is generally made using wheat flour, water, yeast and salt through a procedure that involves mixing, kneading, proofing, shaping and baking. Breads have evolved to take numerous forms, each based on highly distinctive qualities differing in formulation, ingredients, and processing conditions (Li *et al.*, 2019). Bread may come in different forms such as regular yeast breads, flat breads and specialty breads (Cappelli *et al.*, 2020). Currently, bread production involves incorporation of several different compounds based on the type of bread and the functionality of the ingredient used. They include sugar, milk, eggs, shortening (fat), emulsifiers, anti-fungal agents, anti-oxidants, enzymes, flavoring, and bread enhancing additives (Yaxi & Catrin, 2021). Bread is characterized by a crust, a dry coating, that encloses a soft sponge-like cellular structure. The crust will normally have a light golden-brown color. In some bread products the color may be darker, like when whole meal (whole wheat), brown or non-wheat flours are used in its preparation (Sciarini *et al.*, 2012). Use of gums in bread has been extensively studied whereby effects such as crumb softening, increase in bread volume and anti-staling due to addition of gums such as xanthan gum, locust bean gum, and guar gum has been shown in bread (Correa & Ferrero, 2015; Reza *et al.*, 2017).

2.8.2 Flat Bread (*Chapati*)

Chapati is a staple food for many countries around the world. It is known as *roti* in India where it originated and is also widely consumed (Thombare *et al.*, 2016). It has gained popularity throughout the world accounting for nearly 80% of all flat breads consumed (Parimala & Sudha, 2015). It is an unleavened flatbread made from whole wheat flour baked on heated flat plates. In *Chapati* preparation, whole wheat flour is mixed with water to make a dough which is normally rested for 15-30 min, before rolled and flattened to a sheet of about 2 to 3 mm thick (Mir *et al.*, 2014). The flat dough to a diameter of 12 to 15cm is baked

or fried on a hotplate at 220°C on both sides for a few seconds. Some of the most desirable characteristics in *Chapati* are light creamish- brown colour, increased pliability, slight chewiness, complete and full puffing, soft texture and baked wheat aroma (Giri *et al.*, 2021). Use of gums in *Chapati* has been studied whereby it was observed that use of gums such as xanthan and guar gums in *Chapati* helped to retard staling, impart softness and decreased loss of extensibility in stored *Chapaties* (Ahmed *et al.*, 2013; Pahwa *et al.*, 2016; Thombare *et al.*, 2016).

2.9 Texture

Texture is defined as the combination of the mechanical, geometrical and surface attributes of a product which are perceived by the sense of touch, sight or hearing. It is usually as a result of the core structure of food (Monteiro *et al.*, 2021). Texture is usually determined using two methods which include objective instrument analysis and subjective sensory analysis. The instrumental analysis uses sophisticated equipment such as texture analyzers and texturometer which analyze a wide range of food characteristic while sensory analysis is carried out by trained or untrained panelists (Guiné, 2022).

Texture is an important attribute in baked products as they contribute to the quality, consumer acceptance and the shelf life of the product. It also serves as an essential tool for product development and modification. Some of the textural descriptors for bread include softness/firmness, hardness, cohesiveness, chewiness, gumminess and springiness (Hussain *et al.*, 2022). Hydrocolloids have been applied in gluten free or low gluten doughs due to their ability to mimic the viscoelastic properties of dough (Pahwa *et al.*, 2016). Addition of hydrocolloids such as Arabic gum, guar gum, xanthan gum and locust bean gum has shown improved textural properties such as improved softness, lower crumb firmness, higher springiness and cohesiveness in pan breads. In flatbreads, xanthan and guar gum have helped to lower firmness and retard staling (Ferrero, 2017; Pahwa *et al.*, 2016; Rathnayake *et al.*, 2018).

2.10 Quality Characteristics of Baked Products

Food quality is the collection of distinctive qualities and properties which determine the degree of consumer acceptance. It mostly encompasses different attributes such as texture, flavor, and appearance. Monitoring the quality attributes of a product is vital as it helps in taking the necessary steps in creating a product with the right quality characteristics and in detecting quality deviation (Culetu *et al.*, 2021). The quality of baked products is evaluated from both its interior and the exterior and is mostly influenced by the processing conditions,

the type of flour used and the ingredients or additives added (Teben *et al.*, 2018). Quality is mostly determined by physical, nutritional, microbiological and sensory attributes. Physical attributes include specific volume, weight, colour and texture. Nutritional properties entail the protein, fiber, minerals, vitamins and carbohydrate content while sensory properties entail the appearance, taste, flavor and texture attributes (Monteiro *et al.*, 2021).

Baked products quality can be objectively measured or determined using sensory analysis. Instrumental methods are used to measure and quantify attributes such as volume, specific weight, specific volume, crust and crumb colour and texture profile. Sensory analysis is mainly based on consumers' judgement and measures visual appearance, flavor, taste, odor and texture while nutrition or proximate composition is mainly determined using chemical methods (Cappelli *et al.*, 2020). The most common attributes of baked products which influence customers' decision to buy are an appealing colour, crispy crust, a soft texture, springiness, specific volume, appealing colour and an enticing flavor (Olahanmi *et al.*, 2023).

2.11 Sensory Evaluation

Sensory analysis is a scientific discipline that uses the five senses of sight, sound, smell, and taste and touch to examine the sensory qualities of food (Ruiz *et al.*, 2021). Sensory analysis has a number of advantages, including the ability to assess how a product is perceived by consumers and helps to understand ways of improving it (Civille & Oftedal, 2012). In contrast to descriptive tests, which require a trained panel, discrimination tests can be employed with participants who do not have a high level of expertise (Ruiz *et al.*, 2021). The most basic tests for sensory evaluation are discrimination analysis and they are frequently employed. In sensory evaluation, discrimination analysis can be divided into two types: overall difference tests and attribute difference tests (Liu *et al.*, 2023). Participants are asked if they can detect any differences between the samples in the overall difference. Attribute difference tests ask participants to concentrate on a single quality (Civille & Oftedal, 2012). Descriptive sensory analysis usually involves a combination of detection and describing the qualitative and quantitative sensory aspects of a product by trained panelists (Ruiz *et al.*, 2021). The qualitative attributes include appearance, aroma, texture, flavor and aftertaste properties which are quantified to facilitate description of these attributes. This helps in determining the effect of ingredients and processing attributes on the final quality attributes of a product (Liu *et al.*, 2023)

CHAPTER THREE

MATERIALS AND METHODS

3.1 Raw Materials and Study Site

Wheat flour (Russian type, not treated with any additive) was obtained from Unga Limited-Nairobi. Gum Arabic was obtained from Acacia EPZ Limited, Athi River, Off Nairobi-Namanga Highway. The gum Arabic was prepared by removal of foreign matter and milled into a fine powder using a roller mill (UTL USCH/UZ- Bauermeister GmbH, Hamburg, Germany) with a mesh size of 0.8mm at the Cereal Chemistry laboratory at the Kenya Industrial Research and Development Institute (KIRDI). The gum Arabic was stored in airtight containers. Other ingredients; such as sugar, cooking oil, active dry yeast, wheat flour, sodium chloride (food grade), reagents and apparatus were obtained from the local registered suppliers. The study was conducted at the Cereal Chemistry laboratory at the Kenya Industrial Research and Development Institute (KIRDI).

3.2 Experimental Design

The study employed a completely randomized design (CRD) where the treatment was addition of gum Arabic: The treatments included: plain wheat flour (negative control), gum Arabic substitution at varying levels (1%, 2%,3%) to wheat flour (Soibe *et al.*, 2016), commercial bread (pan bread) flour and commercial *Chapati* flour that were used as the positive control. The statistical model for the design was:

$$Y_{ij} = \mu + \alpha_i + \epsilon_{ij}$$

Where; Y_{ij} is the observation on the response variable; μ is the overall mean; α_i is the effect due to the i^{th} level of gum Arabic and ϵ_{ij} is the random experimental error. The response variables included; proximate composition, physicochemical properties, Farinograph properties, Viscograph properties, loaf volume, textural properties, microbial quality and sensory properties. The study was carried out in triplicates.

Completely randomized design in factorial arrangement was used in determination of extensograph properties. The factors were the different gum Arabic levels and the resting time. The statistical model for the design was:

$$Y_{ijk} = \mu + \alpha_i + \beta_j + \alpha\beta_{ij} + \epsilon_{ijk}$$

Where; Y_{ijk} is the observation on the response variable (extensograph properties); μ is the overall mean; α_i is the effect due to the i^{th} level of gum Arabic, β_j is the effect due to the j^{th}

level of resting time; $\alpha\beta_{ij}$ is the interaction effect between the i^{th} level of gum Arabic and the j^{th} level of resting time; and ϵ_{ijk} is the random error associated with Y_{ijk} .

3.3 Flour Formulation

Plain wheat flour was weighed into a clean container using a digital weighing scale separately. Followed by substituting gum arabic from *Acacia senegal* var. *kerensis* into plain wheat flour in the ratio (gum arabic: wheat flour) 0:100 (negative control), 1:99, 2:98, 3:97 and mixing thoroughly till it was homogenous. Commercial bread (pan bread) flour and commercial *Chapati* flour were used as the positive control. Commercial bread flour had an improver comprising of a mixture of alpha-amylase enzyme, emulsifiers, an oxidizing agent and a preservative while in commercial *Chapati* flour the improver present had enzymes and emulsifiers.

3.4 Determination of Physicochemical Characteristics

3.4.1 Proximate Composition Analysis

The flours were analysed for moisture, crude protein ($N \times 6.25$), total fat, dietary fibre and ash content using AOAC (2000) standard methods.

a. Moisture Content and Total Solids

The AOAC Method 950.46 (oven method) was used (AOAC, 2000). Flour samples of 2.0 g were accurately weighed and transferred into respective aluminium dishes. The samples were dried in a dry air oven at 105°C to constant weight and cooled in a desiccator for 10 minutes. The amount of moisture in percentage was calculated as follows:

$$\text{Moisture content \%} = \frac{\text{Initial weight before drying} - \text{Final weight after drying}}{\text{Initial weight before drying}} \times 100. \text{ Equation 1}$$

b. Crude Protein

Crude protein content was determined according to the improved Kjeldahl method (AOAC, 2000) Method 955.04. Sample (1g) of known dry matter content was accurately weighed in a nitrogen free-filter paper (Whatman no. 1), folded carefully and placed in a Kjeldhal flask. One tablet of Kjeldhal catalyst and 15 mL of concentrated sulphuric acid were added to the flask. The mixture was digested in a Gerhardt Kjeldahl therm digester (Model: KB40; Gerhardt GMBH and CO. Kg; Germany) for about 2 hours at 420°C until a clear solution was obtained. A blank sample was also digested. After cooling, the samples were transferred to distillation unit whereby the Kjeldahl flask was connected to a source of 40% sodium hydroxide solution to alkalize the solution and liberate ammonia. The liberated ammonia was harnessed by 4% boric acid premixed with methyl orange indicators to yield ammonium

borate. Ammonium borate distillate was then titrated against 0.2 mol/L hydrochloric acid solution until a pink colour was detected. The excess hydrochloric acid solution in the distillate was back titrated with 0.1 mol/L sodium hydroxide. The percent nitrogen obtained was multiplied by 6.25 to convert to percent protein.

$$\text{Nitrogen (\%)} = N \text{ HCl} \times \frac{\text{Corrected acid volume}}{\text{Weight of sample}} \times \frac{14}{\text{Mol}} \times 100 \dots\dots\dots \text{Equation 2}$$

$$\text{Protein (\%)} = \text{Nitrogen (\%)} \times 6.25 \dots\dots\dots \text{Equation 3}$$

where: Corrected acid volume= (mL acid used in sample titration – mL acid used for blank), N HCl is Normality of HCl, 14 is the atomic weight of nitrogen, mol=molarity and 6.25 is the conversion factor on assumption that the sample will contain 16% nitrogen.

c. Crude Fat

Crude fat was determined by the Soxhlet method (AOAC, 2000) method 934.01 with slight modifications. Approximately 5 g of the sample was weighed accurately into an extraction thimble and covered with cotton wool. The thimble was placed into the soxhlet extractor (Model: EME 6250/CF; Cole Parmer; England) and the fat extracted into a tared flask for 8 h using petroleum ether (B.P. 40-60 °C). The solvent was then evaporated in a rotary evaporator and the residue dried in an air oven at 105 °C for 1 h before weighing. The crude fat content was calculated and expressed as percentage of the sample dry matter content.

$$\text{Crude fat (\%)} = \frac{\text{Weight of fat in the sample}}{\text{Weight of the dry sample}} \times 100 \dots\dots\dots \text{Equation 4}$$

d. Ash Content

Ash content was determined using (AOAC, 2000) method 920.39 where 5.0 g of sample was accurately weighed and placed into silica crucibles. The samples were ashed in a muffle furnace (Model: MR170; S/N: 6800616; Heraeus GMBH, Hanau, Germany) at 550⁰C for 6 hours. The ash was cooled in a desiccator to room temperature and weighed. Ash content was calculated as a percentage of the dry sample.

$$\text{Ash (\%)} = \frac{\text{Weight after ashing} - \text{Tare weight of the crucible}}{\text{Original sample weight}} \times 100 \dots\dots\dots \text{Equation 5}$$

e. Crude Fibre

Crude fibre was determined according to AOAC (2000) method 985.29. Approximately 2 g sample of known dry matter content was accurately weighed into a graduated 500 ml beaker and about 200ml of 1.25% sulphuric acid solution added. The mixture was allowed to boil for 30 minutes on a hot plate after which it was filtered using a funnel lightly packed with glass

wool. The residue was washed three times with boiled distilled water. The residue was transferred into a beaker and boiled in 200 ml of 1.25% potassium hydroxide solution on a hot plate for 30 minutes. The mixture was filtered again using glass wool and washed three times with boiled 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 °C for 2 hours to a constant weight. The sample was cooled in the dish and weighed. The crude fibre content was calculated and expressed as a percentage of the sample dry matter content.

$$\text{Fibre \%} = \frac{\text{Weight of residue before drying} - \text{weight of residue after drying}}{\text{Original sample weight}} \times 100 \dots \dots \dots \text{Equation 6}$$

f. Total Carbohydrates

Total carbohydrate content was estimated by the difference between 100% and the sum of values for moisture, crude fat, crude protein, crude fibre and ash content. Carbohydrate content was determined by difference as shown:

$$\text{Carbohydrate \%} = 100\% - (\% \text{ moisture} + \% \text{protein} + \% \text{fat} + \% \text{fibre} + \% \text{ash}) \dots \text{Equation 7}$$

3.4.2 Water Holding Capacity

The water holding capacity (WHC) was determined according to the method described by Sarfaraz *et al.* (2017) with slight modifications. Distilled water (25ml) was mixed with 1 g of sample at room temperature for 24 h and stirred for 30 minutes. After which, centrifugation using Beckman CS-6 centrifuge at 4000g for 15 min was done and the residue was collected and weighed. The WHC was expressed as grams of water per gram of dry sample as given in equation below:

$$\text{WHC (g/g)} = \frac{\text{Weight of wet residue} - \text{Weight of dry residue}}{\text{Weight of dry residue}} \dots \dots \dots \text{Equation 8}$$

3.4.3 Oil Holding Capacity

The oil holding capacity (OHC) was determined using the method described by Sarfaraz *et al.* (2017) with slight modifications. Corn oil (25ml) was mixed with 1.0 gram of sample at room temperature for 20 minutes. After which, centrifugation at 4000g for 15 min was done and the supernatant was decanted from the centrifuge tube and weighed.

The OHC was expressed as g of oil per mg of dry sample as given in the equation below:

$$\text{OHC (g/g)} = \frac{\text{Weight of sample with oil} - \text{Weight of dry sample}}{\text{Weight of dry sample}} \dots \dots \dots \text{Equation 9}$$

3.4.4 Emulsion Capacity

Emulsion capacity and stability was determined using the method described by Mebpa *et al.* (2007) with slight modifications. Flour sample (2g) was weighed and homogenized with 25ml of distilled water for 10 minutes. After complete dispersion, about 25ml of sunflower oil was added from a burette and the mixture was centrifuged at 4000g for 15 min until phase separation occurred and the volume of oil used (volume of oil emulsified) determined. The oil emulsified by 2g flour was expressed as the emulsion capacity.

$$\text{Emulsion capacity} = \frac{\text{Volume of emulsified layer}}{\text{Volume of the suspension}} \times 100 \dots \dots \dots \text{Equation 10}$$

3.4.5 Emulsion stability

About 2 g flour sample was mixed with 25 mL distilled water followed by addition of 25 ml of sunflower oil and centrifugation of the sample at 4000g for 10 minutes. The mixed sample was then transferred into a 250ml cylinder. The volumetric changes in foam, oil and aqueous layers were recorded after 3 hours. The emulsion stability was expressed as percentage and calculated as the ratio of the height of emulsified layer to the total height of the mixture.

3.5 Analysis of Dough Rheological Properties

3.5.1 Farinograph Test

A Brabender Farinograph-AT (Brabender GmbH & Co. KG, Duisburg, Germany) was used to determine parameters such as water absorption capacity (WAC), dough development time (DDT), stability (S), mixing tolerance index (MTI) and Farinograph quality number (FQN) according to AACC 2000 method 54-21.02. A flour sample weighing 300 g on a 14% moisture basis was placed in a farinograph mixing bowl and water (estimated from the farinograph at 500BU) added to form a dough. As the dough was being mixed, a curve was recorded by the farinograph. The curve was centered on the 500 Brabender Unit (BU) line \pm 20 BU by adding the appropriate amount of water and run until the curve left the 500-BU line. The farinograph data was recorded at the end of the test

3.5.2 Uniaxial Extension Test

The uniaxial extension test of the dough was carried out using a Brabender extensograph-E (Brabender GmbH & Co. KG, Duisburg, Germany) according to AACC 2000 method 54-10. Dough was made in the Farinograph-AT using 300g of flour sample, water (estimated from the Farinograph at 500BU) and 6 g of salt. Dough was shaped into a standard cylindrical shape using the extensograph molder. The test piece of dough was allowed to rest in the extensograph rest cabinet for 45 min at 30°C. After this period, the dough was stretched after

45, 90 and 135 minutes by the extensograph hook until it ruptured. The stretching force was recorded as a function of time. Measurements of maximum resistance, the extensibility, the energy and the maximum resistance to extensibility ratio (R/E) were recorded.

3.5.3 Pasting Properties

Pasting properties were determined using a Brabender Viscograph-E (Brabender GmbH & Co. KG, Duisburg, Germany) using AACC 2000 method 22-12 at 85 rpm and 700 cmg torque. A flour sample of 40g adjusted to 14% moisture content was completely dispersed in 420 ml distilled water and added into a Viscograph-E canister. This was followed by heating the slurry from 30°C to 93°C at a rate of 1.5°C/ min, held at 93°C for 15 min followed by cooling to 30°C at a rate of 1.5°C/ min and finally held at 30°C for 15 min. Curves of torque (Brabender Units [BU] versus time [min]) were generated for each sample. The curves were used to generate pasting temperature (°C), peak viscosity (BU), minimum viscosity (BU), breakdown viscosity (BU), setback viscosity and final viscosity.

3.6 Bread Making Procedure

Bread samples were baked according to AACC 2000 approved method 10-09 (AACC, 2000). They were made using the straight dough method. The ingredients: flour containing gum arabic/ commercial bread flour, 1% active dry yeast, 1% salt, 4% of shortening, 5% of sugar and percentage of water added as per the Farinograph findings. The components were then mixed in a kitchen mixer at low speed for 6 minutes and medium speed for 3 minutes. The dough was then put in a bowl, covered and left to rest for thirty minutes. Dough for each treatment, was portioned into 400g pieces, molded and then put into pre-greased baking pans and allowed to proof for one hour at 30-40°C in a proofing cabinet. Once the dough rose to the rim of the pan, the dough pans were placed in pre-heated oven maintained at 220 °C for about 30-40 minutes or until the crust turned golden brown. The baked loaves of bread were then cooled at room temperature (approximately 22 °C for 1 hour) before being sliced and packed into packaging bags. This process was carried out for all formulations.

3.7 Chapati Making Procedure

Chapati samples were made according to the method of Mwangome (2004) with slight modifications. The ingredients were: flour containing gum Arabic/commercial *Chapati* flour, percentage of water determined by Farinograph, 10% of oil, and 2% of salt, 3% sugar. The ingredients were mixed in kitchen mixer for 3 minutes forming a dough which was kneaded and allowed to rest for half an hour. The dough was then divided into portions of 100g which were placed on a rolling board and sheeted to a diameter of 155 mm and thickness of 2mm

using a rolling pin. The raw *Chapati* was immediately placed on a hot pan at about 125°C and was baked for one and a half minutes on both sides. The *Chapatis* were allowed to cool for 10 minutes and then packed in polythene pouches where they were stored in a cool and dry place. The process was carried out for all formulations.

3.8 Analysis of Bread/*Chapati* Quality Properties

3.8.1 Loaf Specific Volume

The average bread volume was measured using rapeseed displacement method according to the AACC 2000 approved method 10.05 (AACC, 2000). The cooled loaf of bread was placed inside the container with higher and greater perimeter than the bread. The void space was then filled to the top with rape seeds and the amount of rape seeds used measured in a graduated cylinder and recorded as V2. The product was also weighed and the weight (W) recorded in grams. The empty container was filled again with rapeseed until it was level with the top edge of the container and recorded as V1. The specific volume of the loaf was calculated using the following equation;

$$\text{Specific volume} = \left(\frac{V1-V2}{W} \right) \dots\dots\dots \text{Equation 11}$$

3.8.2 Texture profile analysis of bread

Crumb texture was evaluated by a Texture Analyzer equipped with a 50N load cell according to AACC 2000 approved method 61-01 (AACC, 2000). A compression test was carried out using a flat compression probe 75mm in diameter(P/75). Two slices were taken from the center of each bread after cooling and a 55 mm diameter ring punched out from the slices after which it was compressed twice at 1.00 mm/s to 40% strain with a 5g trigger force and 3 s pause between compressions.

3.8.3 *Chapati* texture analysis

The texture analysis of *Chapati* was evaluated using a Texture Analyzer equipped with a 50N load cell according to AACC 2000 approved method 61.04 (AACC, 2000). A 1.5 cm by 5cm piece was cut from the center of the *Chapati* and analyzed using Volodkevich Bite Jaws probe which simulate biting with front teeth connected to the load cell. The sample was compressed up to 40% height at test speed of 2.00 mm/s with a 5g trigger force. The firmness (N, peak force) under the force deformation curve was obtained.

3.8.4 Microbial Quality of bread and *Chapati*

The microbiological analyses on total viable counts and yeast and moulds were conducted by the aerobic spread plate count method based on the standard AACC 2000, Method 42-11 and

Method 42-50, respectively (AACC, 2000). A bread sample of 10g and *Chapati* of 10g were weighed separately and mixed with 90 mL of a sterile peptone–water solution. A serial of homogenized sample dilution from 1 to 1×10^{-4} was prepared through transferring 1ml of sample into 9ml diluent to produce 10^{-2} , 10^{-3} , and 10^{-4} . To determine the yeasts and moulds present, 1ml of each sample dilution was pipetted into a labelled petri dish containing 15 mL of Potato Dextrose Agar (PDA) and spread gently with a sterile glass rod. The plates were incubated at 25°C for 7 days after which colonies were examined and counted.

To determine the total viable count (TVC), 1ml of each sample dilution was pipetted into a labelled petri dish of containing 15 mL of Plate Count Agar and spread evenly using a sterile glass rod. The plates were incubated at 37°C for 48 hours. The colonies were counted and the average value taken after a duplicate count. To determine the colony forming units (CFUs) per gram of bread/ *Chapati*, the number of CFUs was multiplied by the dilution factor and divided by the inoculation amount.

Most Probable number was used in the detection of *E. coli* whereby 10g of each sample was serially diluted in sterile peptone water. A total of 10^{-4} dilutions were made for each sample followed by inoculation of 1 ml into tubes containing 9 ml of the lauryl sulphate tryptose agar. The tubes were then incubated at 37 °C for 48 hours. The most probable number was estimated based on the gas production in the tubes.

3.9 Sensory Analysis of Bread and *Chapati*

3.9.1 Descriptive analysis of bread/*Chapati* samples containing gum Arabic

A total of twenty members comprising of students and staff at KIRDI who are regular consumers of bread/ *Chapati* were initially recruited to be part of the sensory panel for quantitative descriptive analysis of the bread and *Chapati*. They underwent an introductory training to familiarize with the sensory attributes of bread and *Chapati*. They were then screened based on their sensory acuity which led to a total of twelve panelists. The recruited panelists comprising of males and females between 22-35 years were asked to consent to the test and underwent training according to procedures of Meilgaard *et al.* (2006). The training was conducted for 5 days in a two-hour session whereby the panelists came up with respective scale anchors and lexicons for the descriptors of the bread and *Chapati* together with their respective references. Descriptive sensory analysis was carried out in individual testing booths under white lighting in the sensory analysis room at KIRDI. For bread sensory analysis, each panelist was presented with the 5 different samples of each which had 4-digit codes which were randomly assigned. The samples were presented in sequential monadic

way and were evaluated using a 10-point line scale. Half slices were provided in order to ensure proper evaluation of all the attributes. Water was provided in between the samples evaluation to clear the judges' palates. The descriptive profiling yielded fourteen descriptors as represented in Table 13 and 14. Each panelist entered their sensory information in the respective score sheet (Appendix I). The responses were analysed using SAS JMP software version 16.1 (SAS Institute, Inc.).

In a different session, panelists analysed the sensory properties of *Chapati*. Each panelist was presented with the 5 different samples of 6*6 cm pieces of *Chapati* from the different formulations which had 4-digit codes. The samples were presented in sequential monadic way and were evaluated using a 10-point line scale. Water was provided in between the samples evaluation to clear the judges' palates. The descriptive profiling yielded fifteen descriptors as represented in Table 18 and 19. Each panelist entered their sensory information in the respective score sheet (Appendix II). The responses were analysed using SAS JMP software version 16.1 for analysis (SAS Institute, Inc.).

3.9.2 Consumer acceptability of bread/ *Chapati* samples containing gum Arabic

The consumer acceptability test of bread and *Chapati* was carried out with thirty semi-trained panelists comprising of both males and females between 22 and 45 years. The panelists were first asked to consent to the test. An affective sensory test with a 7-point hedonic scale with 1 representing the least score (dislike extremely) and 7 the highest score (like extremely) was performed to know the acceptability of the control and gum Arabic/wheat flour breads/*Chapati*. Each panelist was presented with the different samples which had 4-digit codes which were randomly assigned. Half slices were provided for bread samples and 6*6 cm pieces of *Chapati* for proper evaluation of all the attributes whereby they were presented in a sequential monadic way. Water was provided in between the samples evaluation to clear the judges' palates. The sensory attributes including appearance, colour, aroma, taste, texture, and overall acceptability were evaluated in bread (Appendix III) and *Chapaties* (Appendix IV). The samples were presented to the panelists in testing booths under white light.

3.10 Data Analysis

Data was analyzed using the PROC GLM procedure of the Statistical Analysis System (SAS Institute Inc., 2006) software Version 9.4. Before analysis, data was subjected to normality and homogeneity test. Study hypotheses was tested by performing analysis of variance (ANOVA) and the level of significance established at $p < 0.05$ confidence level (Appendix VI). The difference between the means was obtained by Tukey Honest significant difference.

The samples were analysed in triplicates. Principal Component Analysis was analyzed using PROC Factor of SAS JMP software version 16.1 for analysis (SAS Institute, Inc.) to establish relationships in bread and *Chapati* sensory attributes scored by sensory panelists (Appendix VII).

CHAPTER FOUR
RESULTS AND DISCUSSION

4.1 Effect of gum Arabic on physicochemical properties of wheat flour

4.1.1 Effect of gum Arabic on proximate composition of wheat flour

The effect of gum Arabic on the proximate composition of wheat flour are shown in Table 3. Gum Arabic addition significantly ($p<0.05$) increased moisture, fibre and ash but decreased fat and protein content.

Table 3: Effect of gum Arabic substitution level on proximate composition of wheat flour

Sample	Moisture	Fat	Protein	Fibre	Ash	Carbohydrates
WFCF	12.82±0.01 ^c	1.59±0.01 ^c	12.24±0.02 ^b	1.30±0.01 ^e	0.89±0.02 ^{cd}	71.16±0.02 ^a
WFGA0	12.74±0.02 ^d	1.95±0.03 ^a	12.39±0.01 ^a	1.43±0.01 ^c	0.84±0.01 ^d	70.65±0.01 ^c
WFGA1	12.83±0.01 ^c	1.72±0.02 ^b	12.36±0.02 ^a	1.52±0.01 ^b	0.90±0.01 ^c	70.67±0.02 ^{bc}
WFGA2	12.90±0.01 ^{ab}	1.55±0.02 ^c	12.25±0.02 ^b	1.60±0.01 ^a	0.97±0.01 ^b	70.73±0.01 ^{bc}
WFGA3	12.93±0.02 ^a	1.48±0.01 ^d	12.16±0.02 ^c	1.62±0.01 ^a	1.06±0.01 ^a	70.75±0.02 ^b
WFVB	12.87±0.01 ^{bc}	1.61±0.01 ^c	12.15±0.01 ^c	1.35±0.01 ^d	0.90±0.02 ^c	71.12±0.03 ^a

WFCF- commercial *Chapati* flour, WFGA0- plain wheat flour, WFGA1- wheat flour with 1% gum Arabic, WFGA2- wheat flour with 2% gum Arabic, WFGA3- wheat flour with 3% gum Arabic, WFVB- commercial bread flour. Means sharing the same letters within a column are not significantly different (Tukey Honest significant difference at $p<0.05$)

Moisture content ranged between 12.74 and 12.93 and was significantly ($p<0.05$) influenced by the addition of gum Arabic. Moisture content was significantly higher ($p<0.05$) in wheat flour containing 3% gum Arabic (12.93) but significantly lower in plain wheat flour (12.74). There was a significant ($p<0.05$) increase in moisture content as the level of gum Arabic increased. The increase in moisture content is mainly influenced by the abundant hydrophilic sugar residues of gum Arabic (Mwove *et al.*, 2016). This enables water molecules to bind to the hydrophilic sites which leads to an increase in water holding and retention thereby increasing the moisture content of the flour (Hamdani *et al.*, 2019). Similar observations were reported by Nyaguthii *et al.* (2023) where an increase in moisture content in mushroom-based sausage analogues containing gum Arabic.

Fat content of the flours ranged from 1.48 to 1.95 and it was observed to decrease as the level of gum Arabic was increased. Among the treatments, plain wheat flour (1.95) recorded a significantly higher ($p<0.05$) fat content with constant decrease as the level of gum Arabic increased. Wheat flour containing 3% gum Arabic (1.48) recorded the lowest fat content.

This is due to the low-fat content in gum Arabic which is a polysaccharide and the overall observation is due to the dilution effect of the gum. These results are in line with China *et al.* (2020) who reported a decrease in fat content in biscuits containing wheat and water yam after incorporation of gum Arabic.

Protein content significantly ($p < 0.05$) decreased with increase in gum Arabic. It ranged from 12.15 in commercial bread flour to 12.39 in plain wheat flour. There was no significant ($p < 0.05$) difference between commercial bread flour which recorded the lowest protein content with wheat flour containing 3% gum Arabic (12.16). This is because gum Arabic contains a small fraction of protein comprising of arabinogalactan protein complex in its structure which is also the hydrophobic residue in the gum (Prasad *et al.*, 2022). These results align with Mwove *et al.* (2016) who reported a decrease in protein content of beef rounds injected with gum Arabic from *Acacia Senegal* var. *kerensis* in comparison to the control.

Addition of gum Arabic significantly ($p < 0.05$) increased the fiber content of the wheat flour. Fiber content increased proportionally to the amount of gum Arabic added and it ranged from 1.30 in plain wheat flour to 1.62 in wheat flour containing 3% gum Arabic. This is attributed to the high fiber content of gum Arabic which is also recognized as soluble dietary fiber. It has been accepted as a low-calorie value food and as an ingredient in functional foods (Hamdani *et al.*, 2019). These results align with Gakuru (2020) who reported an increase in the fiber content of plums and pineapple jams containing gum Arabic from *Acacia Senegal* var. *kerensis*.

The ash content increased with increase in the level of gum Arabic. Among the treatments, ash content was significantly ($p < 0.05$) higher in wheat flour containing 3% gum Arabic (1.06) but lowest in plain wheat flour (0.84). Ash content is an indication of minerals present in a sample. The increase in ash content with gum Arabic increase is attributed to the presence of minerals such as magnesium, calcium and potassium salts (Prasad *et al.*, 2022). These results align with Kurniadi *et al.* (2022) who reported an increase in the ash content of guava and banana leathers containing gum Arabic.

Carbohydrate content ranged between 70.65 and 71.16. It was recorded highest in commercial *Chapati* flour with no significant ($p < 0.05$) difference in commercial bread flour. In comparison of the plain wheat flour to flours containing different levels of gum Arabic, it was observed that carbohydrate levels increased as the level of gum Arabic increased. This could be attributed to the polysaccharide nature of the gum which has a high portion of

carbohydrates which comprise of D-galactose, L-arabinose, L-rhamnose and D-glucuronic acid (Prasad *et al.*, 2022). These results are in line with China *et al.* (2020) who reported an increase in carbohydrate content in biscuits containing wheat and water yam with incorporation of gum Arabic

4.1.2 Effect of gum Arabic on physicochemical properties of wheat flour

The effect of gum Arabic on physicochemical properties of wheat flour containing gum Arabic are shown in Table 4. Increase in gum Arabic led to an increase in all the properties with WFGA3 recording significantly ($p < 0.05$) highest values.

Table 4: Effect of gum Arabic substitution level on physicochemical properties of wheat flour

SAMPLE	WHC	OHC	EC	ES
WFCE	0.97 ± 0.01^f	1.17 ± 0.00^e	48.61 ± 0.11^e	43.46 ± 0.17^f
WFGA0	1.02 ± 0.00^e	1.23 ± 0.00^d	47.03 ± 0.22^f	45.67 ± 0.22^e
WFGA1	1.13 ± 0.01^c	1.28 ± 0.00^c	50.50 ± 0.11^c	47.40 ± 0.14^d
WFGA2	1.23 ± 0.01^b	1.33 ± 0.01^b	51.39 ± 0.08^b	49.68 ± 0.28^b
WFGA3	1.37 ± 0.01^a	1.49 ± 0.00^a	52.37 ± 0.20^a	51.22 ± 0.10^a
WFVB	1.07 ± 0.01^d	1.24 ± 0.01^d	49.57 ± 0.27^d	48.58 ± 0.22^c

WHC- water holding capacity, OHC – oil holding capacity, EC- emulsion capacity, ES- emulsion stability, WFCE- commercial *Chapati* flour, WFGA0- plain wheat flour, WFGA1- wheat flour with 1% gum Arabic, WFGA2- wheat flour with 2% gum Arabic, WFGA3- wheat flour with 3% gum Arabic, WFVB- commercial bread flour. Means sharing the same letters within a column are not significantly different (Tukey Honest significant difference at $p < 0.05$).

Water absorption capacity was significantly ($p < 0.05$) influenced by the addition of gum Arabic whereby there was an increase in water absorption capacity with increase in gum Arabic. It varied between 0.97 and 1.37%. Commercial *Chapati* flour (0.97%) recorded a significantly lower ($p < 0.05$) water absorption followed by plain wheat flour (1.02%) while wheat flour containing 3% gum Arabic (1.37) was significantly higher. Commercial bread flour (1.07%) recorded a significantly lower ($p < 0.05$) water absorption capacity compared to the flours containing gum Arabic. These results are in line with Nyaguthii *et al.* (2023) who reported an increase in water absorption capacity in mushroom sausages upon addition of gum Arabic. Water absorption capacity is the ability of flour to absorb and entrap water

which is a measure of the interaction between water and food (Godswill, 2019). Gum Arabic imparted a high-water holding capacity due to its polysaccharide nature and the presence of abundant hydrophilic groups in the polymer chains. This is a desirable attribute since it leads to increased plasticizing effect of water thus increasing springiness and softness of the baked product (Yamul & Navaro, 2020).

Oil absorption capacity increased as the level of gum Arabic was increased in the flour samples. It ranged between 1.17 and 1.49%. Oil absorption capacity was significantly lower ($p < 0.05$) in commercial *Chapati* flour (1.17) but significantly higher ($p < 0.05$) in wheat flour containing 3% gum Arabic (1.49). There was no significant ($p < 0.05$) difference between commercial bread flour (1.24) and plain wheat flour (1.23). These results are in line with Nyaguthii *et al.* (2023) who reported an increase in oil absorption capacity in mushroom-soy sausages upon addition of gum Arabic. Oil absorption capacity is the ability of flour to absorb and retain oil (Godswill, 2019). This indicates that gum Arabic increased the amount of oil that was absorbed and retained by the flour due to the ability of the non-polar side chains binding with the hydrocarbon side chain of the oil. Oils help in increasing the mouthfeel and in retention of flavours which is desirable in baked products and thus flour containing gum Arabic could result into products with superior flavor qualities.

Emulsification capacity ranged between 47.03 and 52.37% with significant ($p < 0.05$) differences recorded across all the treatments. Flours containing gum Arabic recorded increased emulsification capacity with increase in the level of gum Arabic. Plain wheat flour (47.03) recorded the lowest emulsification capacity but it was highest in wheat flour containing 3% gum Arabic (52.37). Emulsion capacity is the volume of oil that can be absorbed by a gram of protein before phase inversion occurs. The increase in emulsification capacity upon addition of gum Arabic resulted from increased adsorption capacity at the oil-water interface resulting from the hydrophobic activity of the protein fraction of the gum (Hamdani *et al.*, 2019).

Emulsification stability ranged between 43.46% and 51.22% whereby there was an incremental increase upon increase in the level of gum Arabic. Emulsification stability was significantly lower ($p < 0.05$) in plain wheat flour but highest in wheat flour containing 3% gum arabic. The protein fraction in gum Arabic constitutes about 3.5% of the total weight which contributes to the gum amphiphilicity that favor its adsorption to air/water or oil/water interface thus enhancing the emulsification stability (Prasad *et al.*, 2022).

4.2 Effect of gum Arabic on dough rheology

4.2.1 Dough Development Properties (Farinograph properties)

Farinograph analysis is carried out to determine the flour attributes during the mixing phase and development of the dough (Miś *et al.*, 2012). The effect of gum Arabic addition level to wheat flour dough on Farinograph properties is shown in Table 5. The results indicate that the addition of gum Arabic in wheat dough had a significant ($p < 0.05$) positive influence on all Farinograph properties except for dough consistency that remained largely unchanged. Wheat dough with 3% gum Arabic showed a significantly ($p < 0.05$) higher dough development time, water absorption capacity, dough stability, mixing tolerance index, Farinograph quality number and time to breakdown. Plain wheat flour recorded the lowest values (Table 5). The commercial *Chapati* flour recorded a significantly ($p < 0.05$) lower dough development time, water absorption capacity, stability, farinograph quality number and time to breakdown except minimum tolerance index. There was no significant ($p < 0.05$) difference between commercial bread flour and wheat flour containing 1% gum Arabic in all Farinograph properties apart from time to breakdown.

The water absorption capacity (WAC), varied between 59.34% and 59.96% (Table 5). The results indicate that an increase in quantity of gum Arabic added to the wheat flour resulted in an increase in the WAC. The results obtained are consistent with previous studies reported by Raya *et al.* (2021) whereby increasing Arabic gum level recorded an increase in water absorption capacity in pan bread flour. Commercial *Chapati* flour which contained enzymes and emulsifiers as improvers recorded the lowest water absorption capacity while commercial bread flour comprising of a mixture of alpha-amylase enzyme, emulsifiers, an oxidizing agent was comparable to wheat flour containing 1% gum Arabic. Wheat flour with 3% gum Arabic had the highest water absorption capacity with a notable increase observed with the increase in gum addition. This shows that there was more uptake of water with increase in gum Arabic which can be attributed to the high number of hydroxyl groups in gum Arabic which increased the interactions with water molecules (Mir *et al.*, 2016).

Table 5: Effect of gum Arabic substitution level in wheat dough on Farinograph properties

Treatment	Dough Development Time (DDT) (min)	Consistency (BU)	Water Absorption Capacity (WAC) (%)	Stability (S) (min)	Mixing Tolerance Index (M.T.I)	Farinograph Quality Number (F.Q.N)	Time to Breakdown (TBD) (min)
WFCF	4.22± 0.05 ^c	498.20±1.50 ^a	59.34±0.07 ^c	8.25±0.08 ^c	24.80±1.83 ^b	89.60±1.86 ^c	8.78±0.17 ^c
WFGA0	1.44± 0.01 ^d	496.00±5.77 ^a	59.44±0.04 ^{bc}	6.34±0.10 ^d	12.00±0.32 ^c	48.60±2.71 ^d	4.33±0.05 ^d
WFGA1	1.34± 0.01 ^d	505.80±4.50 ^a	59.50±0.10 ^{abc}	8.17±0.06 ^c	35.80±1.28 ^a	89.40±1.12 ^c	8.81±0.16 ^c
WFGA2	5.84± 0.14 ^b	490.00±1.90 ^a	59.90±0.10 ^{ab}	9.62±0.10 ^b	34.00±0.55 ^a	108.00±1.87 ^b	10.36±0.04 ^b
WFGA3	6.45± 0.03 ^a	495.00±4.18 ^a	59.96±0.04 ^a	10.75±0.14 ^a	34.20±0.86 ^a	122.20±1.20 ^a	12.05±0.13 ^a
WFVB	1.46± 0.03 ^d	499.00±2.85 ^a	59.58±0.20 ^{abc}	8.16±0.06 ^c	32.20±1.46 ^a	86.40±2.40 ^c	9.94±0.13 ^b

Key: DDT- dough development time, WAC- water absorption capacity, S-stability, M.T.I- minimum tolerance index, F.Q.N- farinograph quality number, TBD- Time to breakdown, min-minutes, BU- Brabender Units. WFCF- commercial *Chapati* flour, WFGA0- plain wheat flour, WFGA1- wheat flour with 1% gum Arabic, WFGA2- wheat flour with 2% gum Arabic, WFGA3- wheat flour with 3% gum Arabic, WFVB- commercial bread flour. Means sharing the same letters within a column are not significantly different (Tukey Honest significant difference at $p < 0.05$)

Dough development time (DDT) varied between 1.44 and 6.45 minutes and was significantly ($p < 0.05$) influenced by the percentage of gum Arabic added to wheat flour (Table 5). The results show an increasing trend with corresponding increase in gum Arabic additions. Compared to commercial bread flour containing a mixture of alpha-amylase enzyme, emulsifiers, an oxidizing agent as improvers and *Chapati* flour containing enzymes and emulsifiers as improvers, the DDT increased approximately 1.5-4.5 times to wheat flour with 3% gum Arabic. The DDT are within the acceptable times, very low times may also indicate lower quality protein flours and a weaker gluten network (Jarvan *et al.*, 2017). The increase in dough development time shows that gum Arabic addition to the wheat flour increased the optimum mixing time for the dough. This is attributed to flours with higher protein content since it takes more time for hydration to achieve the desired gluten network (Hussain *et al.*, 2022; Jarvan *et al.*, 2017).

Dough stability (S) was significantly ($p < 0.05$) influenced by the percentage of gum Arabic added to wheat flour (Table 5). The dough stability varied between 6.34 and 10.75 minutes indicating an increase in stability upon the incremental addition of gum Arabic to wheat flour. The flour with 1% gum Arabic had a similar stability with the commercial bread and *Chapati* flours. The results are in line with Hussain *et al.* (2022), who reported an increase in dough stability upon addition of Acacia gum to wheat flour. Dough stability time indicates tolerance to under-mixing or overmixing and is related to the overall quality of protein (Dowell *et al.*, 2008). Increase in stability upon addition of gum Arabic indicated that there was an increase in the flour strength. Therefore, the increased time the dough maintained the maximum consistency showed that gum Arabic strengthened the gluten network. Flours with longer stability times are generally suited for bread production and often require longer mixing times.

The mixing tolerance index (MTI) in Brabender units was not significantly ($p < 0.05$) influenced by the addition of gum Arabic to the wheat flour (Table 5). The MTI values after addition of gum Arabic were above 30BU but below 50BU. Commercial bread flour did not differ significantly ($p < 0.05$) with the samples containing gum Arabic but commercial *Chapati* flour recorded significantly lower ($p < 0.05$) MTIs. The MTI for the flours after addition of gum Arabic were slightly above 30BU which indicated an acceptable tolerance to mixing. Generally, acceptable MTI values below 50BU indicates better mechanical properties in dough development (Hussain *et al.*, 2022). Above 50BU, there will be less tolerance often indicating difficulties in mechanically handling of the dough. Higher MTI values in wheat

flour containing gum Arabic indicated that there was a higher degree of softening and the dough formed were less stiff compared to the control (Jarvan *et al.*, 2017).

The Farinograph quality number (FQN) varied between 48.60 and 122.20 (Table 5). The results indicated that the FQN increased with an increase in the percentage of gum Arabic in wheat flour. The increase in gum Arabic resulted in an increase in the FQN. The results obtained are consistent with previous studies reported by Ferrero (2016). There was no significant ($p<0.05$) difference in FQN between commercial *Chapati* flour, wheat flour containing 1% gum Arabic and commercial bread flour. FQN value is an indication of flour strength with higher values showing higher strength (Ferrero, 2016). Dough with added gum Arabic exhibited significantly ($p<0.05$) higher FQN values which indicates an increase in the strength of the flour.

The time to breakdown varied between 4.33 and 12.05 minutes (Table 5). The results indicate that an increase in gum Arabic resulted in an increase in the TBD. The results obtained are consistent with previous studies reported by Hussain *et al.* (2022). Time to break down in commercial *Chapati* flour was similar to wheat flour containing 1% gum Arabic while in commercial bread flour it was similar to wheat flour containing 2% gum Arabic. Time to breakdown increased with addition of gum Arabic and upon the use of commercial *Chapati* and bread flour. This shows that there was an increase in the time the gluten structure broke down after reaching its full development.

The addition of gum Arabic exhibited qualities associated with high quality protein flour such as higher dough development time, dough stability and Farinograph quality number. It enhanced the Farinograph properties through enhancement and reinforcement of a strong gluten network (Hussain *et al.*, 2022).

4.2.2 Extensograph properties

An extensograph is used to measure dough resistance to stretching and the distance the dough stretches before it ruptures. It examines the behaviour of dough at further stages of proofing and baking (Mir *et al.*, 2016). The effect of gum Arabic addition level in wheat dough on extensograph properties are shown in Table 6. The commercial bread flour recorded a significantly ($p<0.05$) higher energy, resistance to extension, ratio number but the lowest extensibility. There was no significant ($p<0.05$) difference in energy between the commercial bread flour and wheat flour with 2% gum Arabic.

Table 6: Effect of gum Arabic substitution level in wheat dough on extensograph properties

Treatment	Energy (cm²)	Resistance to Extension (BU)	Extensibility (mm)	Ratio Number (Ratio No)
WFCF	100.22 ± 2.45 ^b	364.89 ± 10.86 ^c	152.67 ± 0.53 ^b	2.37 ± 0.08 ^c
WFGA0	94.22 ± 1.34 ^d	362.89 ± 7.52 ^c	146.00 ± 1.91 ^c	2.43 ± 0.09 ^{bc}
WFGA1	96.11 ± 1.48 ^{cd}	383.56 ± 7.27 ^c	145.11 ± 1.82 ^c	2.62 ± 0.08 ^b
WFGA2	108.44 ± 2.64 ^a	405.33 ± 9.34 ^b	146.67 ± 1.39 ^c	2.64 ± 0.05 ^b
WFGA3	99.00 ± 1.03 ^{bc}	380.11 ± 6.94 ^c	153.11 ± 1.39 ^a	2.66 ± 0.09 ^b
WFVB	105.33 ± 2.62 ^a	596.56 ± 33.24 ^a	123.11 ± 3.60 ^d	4.98 ± 0.42 ^a

WFCF- commercial *Chapati* flour, WFGA0-plain wheat flour, WFGA1- wheat flour with 1% gum Arabic, WFGA2- wheat flour with 2% gum Arabic, WFGA3-wheat flour with 3% gum Arabic, WFVB- commercial bread flour, Ratio No- ratio number, BU- Brabender Units, mm-millimetres. Means sharing the same letters within a column are not significantly different (Tukey Honest significant difference at p<0.05).

Wheat flour with 2% gum Arabic recorded the second highest resistance to extension while there was no significant ($p < 0.05$) difference in wheat flour with 1%, 3% gum Arabic and commercial *Chapati* flour. Wheat flour with 3% gum Arabic recorded a significantly higher ($p < 0.05$) extensibility with wheat flour with 0%, 1%, 2% of gum Arabic having no significant ($p < 0.05$) difference. Energy was significantly ($p < 0.05$) influenced by the percentage of gum Arabic added to the wheat flour (Table 6). Energy varied between 94.22 and 108.44 cm² indicating an increase in energy upon incremental addition of gum Arabic to 2% with a decrease at 3% gum Arabic addition. Wheat flour with 2% gum Arabic had the highest energy. The results are consistent with Raya *et al.* (2021) whereby addition of Arabic gum to wheat flour resulted in increase in energy in lower levels of Arabic gum but a reduction in energy at higher levels.

The resistance to extension varied between 362.89 and 596.56 Brabender Units (Table 6). The results indicate that there was a significant ($p < 0.05$) increase in resistance to extension up to 2% gum Arabic addition with a decrease at 3% gum Arabic addition. Commercial bread flour which contained a mixture of alpha-amylase enzyme, emulsifiers, an oxidizing agent and a preservative as improvers recorded the highest resistance to extension. In previous reports, Hussain *et al.* (2022) reported impaired resistance to extension of the dough upon addition of 3% and 6% Acacia gum to wheat flour. There was no significant ($p < 0.05$) difference between commercial *Chapati* flour, wheat flour containing 1% and 3% gum Arabic in resistance to extension.

Dough exhibiting stronger resistance to extension and energy at the moment of sample rupture has better bread making quality (Raya *et al.*, 2021). The commercial bread flour recorded significantly ($p < 0.05$) higher resistance to extension due to the presence of different types of improvers such as alpha-amylase enzyme, emulsifiers and an oxidizing agent which could positively work on the dough synergistically. The energy and resistance to extension recorded an increase upon addition of 2% gum Arabic, which indicates maximum strength and dough's ability to hold gas (Table 6). Wheat flour with 2% gum Arabic is most preferred in pan bread making as it had significantly higher ($p < 0.05$) energy and resistance to extension and was most comparable with the commercial bread flour. Addition of gum Arabic in higher levels of 3% to wheat flour resulted in lower energy and resistance to extension. This shows that there was presence of high levels of hydrogen bonds and increased moisture content in flours that had higher levels of gum Arabic. These attributes led to a softer texture that is

attributed to the loosening of dough structure leading to weaker strain resistance (Miš *et al.*, 2012).

The extensibility varied between 123.11 and 153.11 mm (Table 6). Wheat flour with 3% gum Arabic had a significantly ($p < 0.05$) higher extensibility with levels 0%, 1%, 2% showing no significant ($p < 0.05$) difference among the levels. These results are consistent with Hussain *et al.* (2022), who recorded an increase in dough extensibility upon addition of Acacia gum to wheat flour. Wheat flour with gum Arabic at 3% yielded the best extensibility which shows that gum Arabic was favourable for formation of more extensible dough. A dough with high extensibility is more preferred for making of flat breads such as *Chapati*. This therefore indicates that, since wheat flour with 3% gum Arabic was almost comparable to the commercial *Chapati* flour, it is ideal for flat bread production.

The ratio number varied between 2.37 and 4.98 (Table 6). Commercial bread flour had significantly ($p < 0.05$) higher ratio number while commercial *Chapati* flour had significantly ($p < 0.05$) lower ratio number. Wheat flour with 1%, 2%, and 3% gum Arabic had similar ratio number. A good flour for pan bread making should have a favourable ratio of resistance to extension to extensibility and should fall between 2 to 3 (Raya *et al.*, 2021). The results show that the ratio number of all the flours with gum Arabic fell in this category with a notable increase upon addition of gum Arabic. This shows that the flours had good bread making properties due a favourable ratio of high mechanical strength and high extensibility.

The effect of resting time in wheat dough containing gum Arabic on extensograph properties is shown in Figure 2. Significant ($p < 0.05$) difference in the measuring times was recorded in all extensograph properties apart from resistance to extension which did not show any significant ($p < 0.05$) difference between the 90th and 135th minute resting time. The extensograph analysis after the 90th minute recorded significantly ($p < 0.05$) higher energy, ratio number and resistance to extension (Figure 2). Extensibility was significantly ($p < 0.05$) higher after the 45th minute followed by the 90th minute. It shows that the gluten network was already formed by the 90th minute and there was minimal resistance to the formation of the gluten network. Extension of proofing time to 135th minutes caused a significant ($p < 0.05$) decrease in the resistance to extension, energy and extensibility which could have been attributed to disintegrating of the gluten network with over proofing. This indicates that 90 minutes would be sufficient proofing time in bread production.

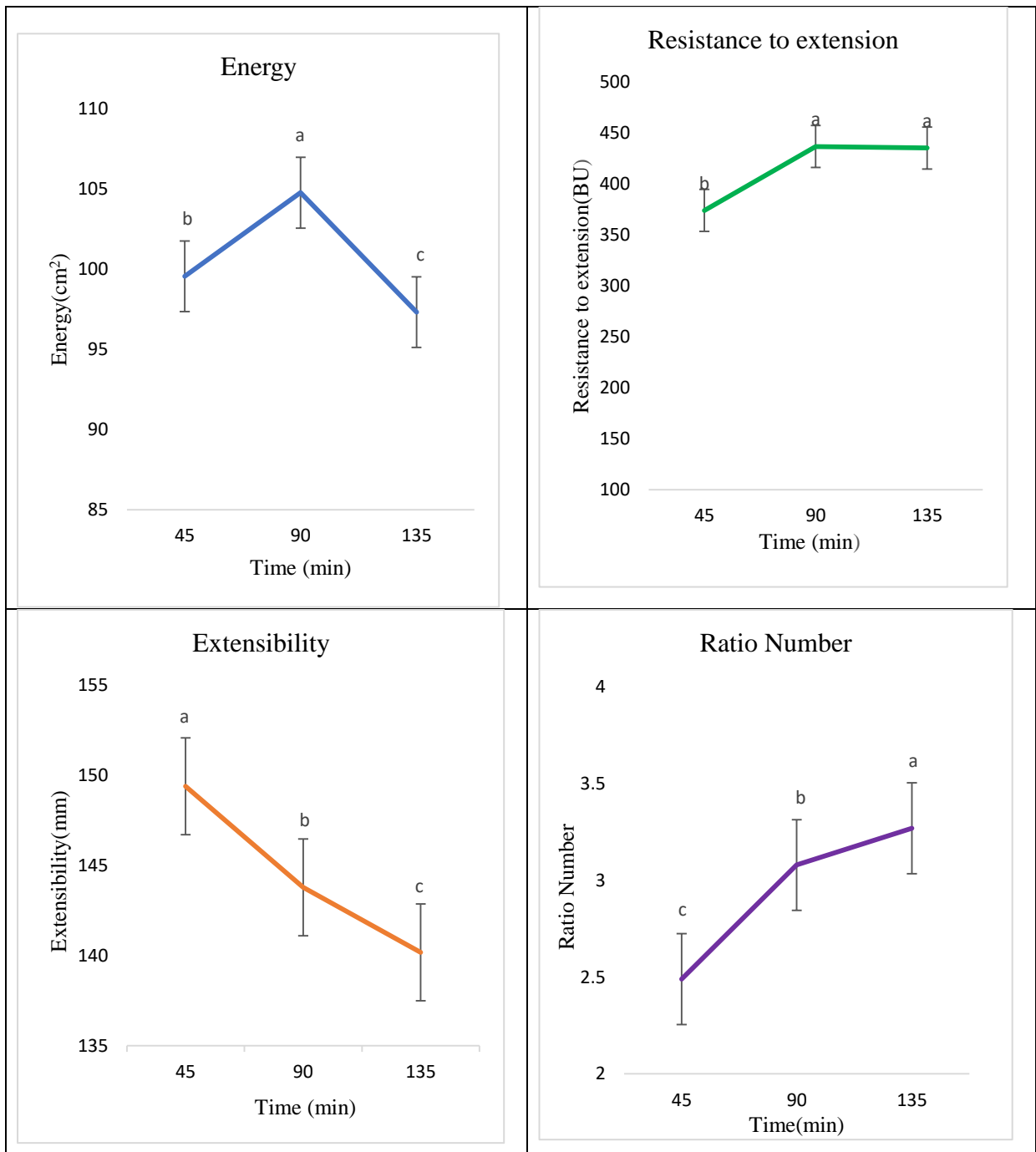


Figure 2: *Effect of resting time in wheat dough containing gum Arabic on extensograph properties*

Effect of gum Arabic addition and resting time on extensograph properties of wheat dough are shown in Table 7. The energy varied between 89.00 and 117.67cm² (Table 7). Wheat flour with 2% gum Arabic at the 90th minute recorded the significantly ($p<0.05$) higher energy while plain wheat flour at 135th minute was significantly lower. The resistance to extension varied between 321.67 and 671.33 Brabender Units. The commercial bread flour at 135th minute recorded a significantly higher ($p<0.05$) resistance to extension, while wheat flour with 2% gum Arabic at 135th minute recorded a significantly ($p<0.05$) higher resistance to extension in the different levels of gum Arabic addition. The ratio number varied between 2.07 and 6.07. It was significantly higher ($p<0.05$) in the commercial bread flour at 135th minute but lowest in commercial *Chapati* flour at 45th minute. Extensibility was significantly ($p<0.05$) higher in wheat flour with gum Arabic at 3% at 90th minute but lowest in commercial bread flour at 135th minute. It varied between 112.00 and 155.67 mm.

Good baking properties are exhibited in flours with greater resistance to extension and extensibility which also results to greater energy (Miś *et al.*,2012). Effect of wheat flour with 2% gum Arabic and 90th minute resting time resulted to significantly ($p<0.05$) higher energy. Commercial bread flour recorded a significantly($p<0.05$) higher resistance to extension across the three different measuring times due to synergistic effect of alpha-amylase enzyme, emulsifiers and an oxidizing agent on the dough followed by wheat flour with 2% gum Arabic at the 90th minute. Wheat flour with 3% gum Arabic at 90th minute recorded significantly ($p<0.05$) higher extensibility which indicates enhanced viscous flow of dough. Most of the parameters were significantly ($p<0.05$) higher at the 90th minute which shows that the maximum changes in the biochemical activity of the dough influenced by either the inherent flour properties or presence of improver had already occurred.

Table 7: Effect of gum Arabic substitution level and resting time on extensograph properties of wheat dough

Treatment	Time (min)	Energy (cm²)	Resistance to Extension (BU)	Extensibility (mm)	Ratio No
WFCF	45	90.67 ± 0.33 ^{ij}	321.67 ± 1.45 ^g	153.67 ± 0.33 ^{ab}	2.07 ± 0.03 ^g
	90	104.67 ± 1.33 ^{bcde}	385.33 ± 1.33 ^{def}	152.33 ± 1.20 ^{ab}	2.50 ± 0.00 ^{defg}
	135	105.33 ± 1.20 ^{bcd}	387.67 ± 2.85 ^{cdef}	152.00 ± 1.00 ^{abc}	2.53 ± 0.03 ^{defg}
WFGA0	45	96.67 ± 0.33 ^{efghij}	357.33 ± 5.21 ^{efg}	152.00 ± 1.53 ^{abc}	2.33 ± 0.07 ^{defg}
	90	97.00 ± 0.00 ^{efghij}	343.33 ± 6.77 ^{efg}	146.33 ± 1.33 ^{bcde}	2.20 ± 0.10 ^{fg}
	135	89.00 ± 1.00 ^j	388.00 ± 9.17 ^{cdef}	139.67 ± 1.20 ^{ef}	2.77 ± 0.03 ^{dc}
WFGA1	45	99.67 ± 0.88 ^{degh}	362.00 ± 1.15 ^{efg}	152.00 ± 1.00 ^{abc}	2.30 ± 0.00 ^{efg}
	90	96.00 ± 2.52 ^{efghij}	408.67 ± 8.67 ^{cd}	143.00 ± 1.00 ^{ef}	2.80 ± 0.00 ^{de}
	135	92.67 ± 2.60 ^{hij}	380.00 ± 2.08 ^{def}	140.33 ± 0.67 ^{ef}	2.77 ± 0.03 ^{de}
WFGA2	45	103.33 ± 1.33 ^{bcdef}	375.00 ± 4.04 ^{def}	151.00 ± 1.00 ^{abcd}	2.53 ± 0.07 ^{defg}
	90	117.67 ± 3.84 ^a	432.33 ± 13.17 ^{bc}	144.33 ± 1.20 ^{de}	2.73 ± 0.12 ^{de}
	135	104.33 ± 1.76 ^{bcde}	408.67 ± 5.17 ^{cd}	144.67 ± 2.60 ^{cde}	2.67 ± 0.03 ^{def}
WFGA3	45	97.33 ± 1.20 ^{defgh}	361.33 ± 3.71 ^{efg}	151.33 ± 1.33 ^{abcd}	2.37 ± 0.03 ^{defg}
	90	102.00 ± 1.53 ^{cdef}	402.00 ± 1.53 ^{cde}	155.67 ± 2.73 ^a	2.77 ± 0.09 ^{de}
	135	97.67 ± 1.45 ^{defghi}	377.00 ± 11.85 ^{def}	152.33 ± 2.96 ^{ab}	2.83 ± 0.18 ^d
WFVB	45	109.67 ± 0.88 ^{abc}	468.00 ± 12.06 ^b	136.33 ± 1.86 ^f	3.37 ± 0.12 ^c
	90	111.33 ± 0.88 ^{ab}	650.33 ± 13.69 ^a	121.00 ± 1.00 ^g	5.50 ± 0.21 ^b
	135	95.00 ± 0.00 ^{ghij}	671.33 ± 20.54 ^a	112.00 ± 0.00 ^h	6.07 ± 0.20 ^a

WFCF- commercial *Chapati* flour, WFGA0-plain wheat flour, WFGA1- wheat flour with 1% gum Arabic, WFGA2- wheat flour with 2% gum Arabic, wheat flour with 3% gum Arabic, WFVB- commercial bread flour, Ratio No- ratio number, BU- Brabender Units, mm-millimetres, min-minutes. Means sharing the same letters within a column are not significantly different (Tukey Honest significant difference at $p < 0.05$)

4.2.3 Pasting properties

Effect of gum Arabic addition level in wheat dough on Viscograph properties are shown in Table 8. Plain wheat flour recorded significantly higher ($p < 0.05$) Viscograph properties while wheat flour containing 3% gum Arabic recorded significantly lower ($p < 0.05$) Viscograph properties apart from the pasting temperature. Compared to plain wheat flour, all the properties apart from pasting temperature decreased approximately 2 times to wheat flour with 3% gum Arabic. Pasting temperature was significantly ($p < 0.05$) lower in commercial bread flour. A general decrease was recorded in peak viscosity, minimum viscosity, final viscosity, breakdown and setback as the level of gum Arabic increased. The results are in line with Kiprof *et al.* (2021) who reported a significant ($p < 0.05$) decrease in all Viscograph properties apart from the pasting temperature with increasing substitution levels of gum Arabic in corn and cassava starches.

The pasting temperature varied between 69.50 and 71.68°C (Table 8). It was significantly higher ($p < 0.05$) in plain wheat flour but significantly lower ($p < 0.05$) in commercial bread flour. There was no significant ($p < 0.05$) difference between commercial *Chapati* flour and wheat flour containing 1% gum Arabic. Pasting occurs when starch granules are continually heated in sufficient amount of water leading to granule swelling and leaching of the starch molecules (Mahmood *et al.*, 2017). The leaching of amylose as a result of granule swelling leads to an increase in viscosity while the rupture of the granules upon further heating leads to a decrease of the same. Pasting temperature is the temperature at the onset of gelatinization (Hussain *et al.*, 2022). The results show that plain wheat flour did not differ significantly ($p < 0.05$) from wheat flour with 3% gum Arabic. This is an indication that addition of gum Arabic did not affect the onset of gelatinization showing that minimum energy would be required for cooking the flours (Table 8). Commercial wheat flour had a significant ($p < 0.05$) decrease in the pasting temperature. This suggests that the alpha-amylase present in the commercial flour broke down the starch into its different saccharides and monosaccharides which sped up the gelatinization process, consequently lowering the gelatinization temperature.

Table 8 : Effect of gum Arabic substitution level in wheat flour on Viscograph properties

Treatment	Pasting Temperature(°C)	Peak Viscosity (BU)	Minimum Viscosity (BU)	Final Viscosity (BU)	Breakdown Viscosity (BU)	Setback Viscosity (BU)
WFCF	69.74 ± 0.58 ^{bc}	84.00 ± 1.26 ^c	48.80 ± 0.58 ^c	175.00 ± 3.07 ^c	35.20 ± 0.92 ^b	126.20 ± 2.50 ^b
WFGA0	71.68 ± 0.23 ^a	103.00 ± 2.28 ^a	60.40 ± 1.50 ^a	215.20 ± 6.34 ^a	42.60 ± 1.03 ^a	154.80 ± 4.85 ^a
WFGA1	69.82 ± 0.16 ^{bc}	94.40 ± 1.47 ^b	54.60 ± 0.68 ^b	192.80 ± 1.93 ^b	39.80 ± 1.24 ^a	138.20 ± 1.36 ^b
WFGA2	70.58 ± 0.45 ^{abc}	67.80 ± 0.86 ^d	38.00 ± 1.05 ^d	138.40 ± 2.54 ^d	29.80 ± 0.49 ^c	100.40 ± 1.69 ^c
WFGA3	71.46 ± 0.56 ^{ab}	45.20 ± 1.83 ^e	25.80 ± 1.07 ^e	99.00 ± 2.72 ^e	19.40 ± 0.87 ^d	73.20 ± 1.91 ^d
WFVB	69.50 ± 0.49 ^c	74.20 ± 1.71 ^d	40.20 ± 1.11 ^d	149.80 ± 3.48 ^d	34.00 ± 1.30 ^{bc}	109.60 ± 2.42 ^c

WFCF- commercial *Chapati* flour, WFGA0-Plain wheat flour, WFGA1- wheat flour with 1% gum Arabic, WFGA2- wheat flour with 2% gum Arabic, WFGA3-wheat flour with 3% gum Arabic, WFVB- commercial bread flour, BU- Brabender Units. Means sharing the same letters within a column are not significantly different (Tukey Honest significant difference at p<0.05)

Peak viscosity was significantly ($p < 0.05$) influenced by the percentage of gum Arabic added to wheat flour (Table 8). It varied from 45.20 and 103.00 BU indicating a decrease in peak viscosity upon the addition of gum Arabic to wheat flour and usage of commercial bread and *Chapati* flour. Peak viscosity is the maximum viscosity developed immediately after heating the sample which is indicative of the swelling index or starch solubility (Soibe *et al.*, 2016). Significant ($p < 0.05$) decrease in the peak viscosity upon addition of gum Arabic suggests that gum Arabic promoted granule association thus, restricted maximum swelling of the starch granules. This affected the leaching out of amylose and starch-gel formation leading to a significant ($p < 0.05$) reduction in peak viscosity (Kiprop *et al.*, 2021). Hydrocolloids are able to form stable polymeric network which entraps starch molecules thus delaying the release of amylose molecules which are attributed to the thickening and increase in viscosity (Mahmood *et al.*, 2017).

Minimum viscosity was significantly ($p < 0.05$) influenced by gum Arabic addition to wheat flour. It varied between 25.80 and 60.40BU (Table 8) indicating a decrease in minimum viscosity upon addition of gum Arabic and using commercial bread and *Chapati* flour. Final viscosity varied between 99.00 and 215.20 BU (Table 8) and was significantly ($p < 0.05$) influenced by the addition of gum Arabic which shows a constant decreasing trend upon incremental addition of gum Arabic. Final viscosity measures the ability of gelatinized starch to form a paste after cooling. The significant ($p < 0.05$) decrease in final viscosity on addition of gum Arabic shows that it retarded the reaggregation of the leached fractions of starch thus inhibiting an increase in viscosity during cooling (Singh *et al.*, 2017).

Breakdown viscosity was significantly ($p < 0.05$) influenced by gum Arabic and varied between 19.40 and 42.60BU (Table 8). There was a significant ($p < 0.05$) decrease with incremental addition of gum Arabic. Breakdown viscosity did not differ significantly ($p < 0.05$) in commercial *Chapati* flour and commercial bread flour. Breakdown viscosity is an indicator of granules stability to shear and heat during continuous cooking. In comparison with plain wheat flour, breakdown viscosity was significantly ($p < 0.05$) lower in wheat flour with gum Arabic at 2 and 3%, commercial *Chapati* flour and commercial bread flour. This shows that addition of gum Arabic and the presence of commercial improvers contributed to increased starch stability during cooking and the flours were able to withstand the heating and shearing stress during cooking compared to the plain wheat flour (Hussain *et al.*, 2022).

Setback viscosity varied between 73.20 and 154.80 BU (Table 8) and was significantly ($p < 0.05$) influenced by addition of gum Arabic. The results show a decreasing trend with

increasing addition of gum Arabic. Commercial bread and *Chapati* flour also recorded

Treatment	Loaf Weight	Loaf Volume	Specific Volume
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significantly lower ($p < 0.05$) setback viscosity compared to plain wheat flour. Setback Viscosity indicates the tendency of the dough to undergo retrogradation causing an increase in viscosity (Singh *et al.*, 2017). There was a significant ($p < 0.05$) reduction in setback viscosity upon addition of gum Arabic to wheat flour implying a reduction in retrogradation of starch (Li *et al.*, 2018) which enhances the storage abilities of the end products (Ashraf *et al.*, 2020).

4.3 Effect of gum Arabic on bread and *Chapati* quality properties

4.3.1 Loaf specific Volume

The effects of gum Arabic level on the volume, weight and specific volume of bread are shown in Table 9. Volume is one of the features that are appealing to the customers and attract attention of the product. Volume mainly results from the entrapment of carbon dioxide gases which are held in the dough matrix during fermentation process (Rathnayake *et al.*, 2018). Results show that loaf volume was significantly higher ($p < 0.05$) in bread containing 2% gum Arabic (1448.50), while it was significantly lower ($p < 0.05$) in bread made from plain wheat flour (1226.08). The volume of bread from commercial flour (1320.12) did not have any significant ($p < 0.05$) difference with bread containing 1% gum Arabic (1301.94).

Addition of gum Arabic led to incremental rise of the bread volume up to 2% (1448.50) with a significant ($p < 0.05$) decrease upon addition of gum Arabic to 3% (1378.71). This indicates that gum Arabic increased the ability of the dough matrix to hold and retain more gases. The reduction in the volume at 3% level of gum Arabic indicates that it increased dough viscosity and lowered the elasticity of the dough matrix and its ability to hold gases. This regulated the diffusion of gases leading to a lower rise of the bread (Culetu *et al.*, 2021). The weight of the bread was significantly higher ($p < 0.05$) in the bread containing 3% gum Arabic (420.90) while it was significantly lower ($p < 0.05$) in the bread from commercial bread flour (349.90). Gum Arabic is a hydrocolloid thereby it was able to bind more water in dough matrix leading to more weight in the samples.

Table 9 : Effect of gum Arabic substitution level on loaf specific volume

WFGA0	400.11 ± 1.61 ^c	1226.08 ± 0.62 ^d	3.06 ± 0.01 ^d
WFGA1	413.10 ± 1.21 ^b	1301.94 ± 0.63 ^c	3.15 ± 0.01 ^d
WFGA2	412.62 ± 0.97 ^b	1448.50 ± 15.85 ^a	3.51 ± 0.04 ^b
WFGA3	420.90 ± 0.9 ^a	1378.71 ± 4.57 ^b	3.28 ± 0.02 ^c
WFVB	349.90 ± 1.54 ^d	1320.12 ± 5.14 ^c	3.77 ± 0.01 ^a

WFGA0- plain wheat flour, WFGA1- wheat flour with 1% gum Arabic, WFGA2- wheat flour with 2% gum Arabic, WFGA3- wheat flour with 3% gum Arabic, WFVB- commercial bread flour. Means sharing the same letters within a column are not significantly different (Tukey Honest significant difference at $p < 0.05$).

Specific volume is an important quality in bread as it is an indicator of the amount of gas that gluten is able to retain during proofing and the crumb structure (Monteiro *et al.*, 2021). It is the ratio of loaf volume to the weight. Specific volume was significantly higher ($p < 0.05$) in bread made from commercial bread flour (3.77) and was significantly lower ($p < 0.05$) in bread made from plain wheat flour (3.06). When comparing breads with gum Arabic to the bread made from plain wheat flour, it was noted that breads containing gum Arabic had higher specific volumes. Bread containing 2% gum Arabic had the highest specific volume (3.51) among the different levels which was attributed to its high loaf volume. Bread containing 3% gum Arabic recorded lower specific volume (3.28) compared to the bread containing 2% due to its lower loaf volume. These results are in line with Peressini *et al.* (2011) who reported that 0.5% xanthan gum gave maximum specific volume of bread with a notable decrease upon further addition of the gum. Specific volume increased due to the ability of gum Arabic to enhance the viscosity of the dough by increasing the stability of the gluten-starch matrix. However, at higher gum levels, there was reduction in dough elasticity and its ability to retain gases leading to lower specific volume in the bread (Culetu *et al.*, 2021).

4.3.2 Bread Texture Profile Analysis

Texture profile analysis is an imitative test based on developed set of measures which resembles the chewing and mastication of food by human. It entails attributes such as springiness, cohesiveness, gumminess, chewiness, resilience and hardness (Rathnayake *et al.*, 2018). The effect of gum Arabic in the texture profile analysis of bread is shown in Table 10. Texture profile analysis was greatly influenced by addition of gum Arabic.

Springiness varied between 0.82 to 0.88. There was a significant ($p < 0.05$) increase in springiness upon addition of gum Arabic to wheat flour. Bread made from plain wheat flour

recorded the lowest springiness (0.82) while bread containing 2% gum Arabic (0.88) recording the highest springiness. However, there was a decrease in springiness from 0.88 in bread containing 2% gum Arabic to 0.83 upon further increase of gum Arabic to 3%. Bread from commercial bread flour (0.86) recorded the second-best springiness with bread containing 1% gum Arabic (0.83) and 3% gum Arabic (0.83) being similar. Mwove *et al.* (2016) also reported increased springiness in beef rounds upon addition of gum Arabic. Springiness measures the recovery of food shape upon its compression (Hussain *et al.*, 2022). Gum Arabic led to an increase in springiness indicating an increase in crumb elasticity and the ability to easily regain shape after compression. The decrease in springiness observed in 3% gum Arabic addition, shows that there was formation of a more viscous dough.

SAMPLE	Springiness	Cohesiveness	Gumminess	Chewiness	Resilience
WFGA0	0.82 ± 0.00 ^c	0.51 ± 0.00 ^c	1122.07 ± 26.62 ^a	930.15 ± 25.35 ^a	0.18 ± 0.00 ^c
WFGA1	0.83 ± 0.01 ^{bc}	0.51 ± 0.01 ^c	817.22 ± 53.97 ^b	716.22 ± 41.92 ^b	0.19 ± 0.00 ^{bc}
WFGA2	0.88 ± 0.01 ^a	0.57 ± 0.01 ^{ab}	634.56 ± 13.08 ^c	625.7 ± 18.45 ^{bc}	0.21 ± 0.01 ^a
WFGA3	0.83 ± 0.01 ^{bc}	0.54 ± 0.02 ^{bc}	764.46 ± 20.72 ^{bc}	528.87 ± 13.37 ^c	0.19 ± 0.01 ^{ab}
WFVB	0.86 ± 0.01 ^{ab}	0.59 ± 0.01 ^a	438.66 ± 35.66 ^d	376.07 ± 31.31 ^d	0.19 ± 0.00 ^{bc}

Table 10: Effect of gum Arabic substitution level on texture profile of bread

WFGA0- plain wheat flour, WFGA1- wheat flour with 1% gum Arabic, WFGA2- wheat flour with 2% gum Arabic, WFGA3- wheat flour with 3% gum Arabic, WFVB- commercial bread flour. Means sharing the same letters within a column are not significantly different (Tukey Honest significant difference at $p < 0.05$)

Cohesiveness varied between 0.51 and 0.59. Cohesiveness was lowest in bread made from plain wheat flour (0.51) and bread containing 1% gum Arabic (0.51). Hussain *et al.* (2022) also reported increased cohesiveness in wheat gels upon addition of Arabic gum. Cohesiveness measures internal cohesion of food material and is the ability of food to remain together in a matrix (Monteiro *et al.*, 2021). The increase in cohesiveness upon addition of gum Arabic shows that bread containing gum Arabic had better structural integrity. A more cohesive structure is desirable in breads as it reduces the susceptibility to breakage and crumbling.

Gumminess was significantly ($p < 0.05$) reduced by addition of gum Arabic. It varied between 438.66 and 1122.07. Bread made from plain wheat flour (1122.07) recorded a significantly higher ($p < 0.05$) gumminess with a decrease noted upon addition of gum Arabic. Bread from commercial flour (438.66) recorded the lowest gumminess followed by bread containing 2% gum Arabic (634.56). These results are in line with Soibe *et al.* (2016) who reported reduction in gumminess with addition of gum Arabic to breads made from wheat-plantain composite flour. Gumminess is a product of cohesiveness and hardness and is the amount of energy required in reduction of disintegrating food before swallowing (Hussain *et al.*, 2022). Breads containing gum Arabic had lower gumminess which indicates that less product density remained in the mouth during the process of chewing.

Chewiness was significantly ($p < 0.05$) reduced by addition of gum Arabic. It varied between 930.15 and 376.07. There was a constant decrease in chewiness with increase in the level of gum Arabic addition. Bread made from plain wheat flour (930.15) recorded the highest chewiness while bread made from commercial flour (376.07) had the lowest. Chewiness is the effort required to masticate food before swallowing (Monteiro *et al.*, 2021). There was a constant reduction in chewiness upon addition of gum Arabic which reduced the retrogradation of the bread thus less force was required in chewing the bread.

Resilience was significantly ($p < 0.05$) increased by addition of gum Arabic. It varied between 0.18 and 0.21 and was significantly lower ($p < 0.05$) in bread made from plain wheat flour (0.18) and significantly higher ($p < 0.05$) in bread containing 2% gum Arabic (0.21). There was no significant ($p < 0.05$) difference in resilience in bread containing 1%, 3% gum Arabic and bread made from commercial bread flour (0.19). Resilience is the speed and force in which a food product regains its original height or form after deforming force is removed which shows the elasticity of the crumb (Yamur & Navarro, 2020). Increase in resilience indicates that gum Arabic increased dough's elasticity which also acts in reducing bread's susceptibility to crumbling. Similar observations were made by Yamur and Navarro (2020) who reported an increase in resilience in wheat-potato flour products upon addition of hydroxypropyl methylcellulose.

4.3.3 Chapati Texture

Results for texture properties of *Chapati* are shown in Table 11. Gum Arabic addition significantly ($p < 0.05$) influenced *Chapati* texture. The results show a decrease in firmness from 1081.33 to 760.31 with the addition of gum Arabic after 24 hours storage. *Chapati* samples containing gum Arabic had significantly lower ($p < 0.05$) firmness compared to the

negative and positive control. Firmness was significantly higher ($p < 0.05$) in *Chapati* made from plain wheat flour (1081.33) while it was significantly lower ($p < 0.05$) in *Chapati* made from samples containing 3% gum Arabic (760.31). Gum Arabic being a hydrocolloid led to increased water absorption and retention through hydrogen bonding (Mohammadi *et al.*, 2014). It also possesses the ability of associating with starch molecules thus reducing starch swelling and reducing the amylose leaching (Kiprop *et al.*, 2021). This retarded retrogradation of starch helped to reduce firming in *Chapati*. Thus, *Chapati* containing gum Arabic had decreased firmness, remained softer and were more pliable during storage. The results are in line with Pahwa *et al.* (2016) who reported that addition of guar gum at 0.75% to *Chapati* resulted to a softer and pliable *Chapati* with higher extensibility.

Table 11: Effect of gum Arabic substitution level on *Chapati* texture

Sample	Firmness
WFCF	918.50 ± 3.67^c
WFGA0	1081.33 ± 16.47^a
WFGA1	980.20 ± 6.91^b
WFGA2	870.94 ± 8.91^d
WFGA3	760.31 ± 11.85^e

WFCF- commercial *Chapati* flour, WFGA0- plain wheat flour, WFGA1- wheat flour with 1% gum Arabic, WFGA2- wheat flour with 2% gum Arabic, WFGA3- wheat flour with 3% gum Arabic. Means sharing the same letters within a column are not significantly different (Tukey Honest significant difference at $p < 0.05$)

4.3.4 Microbial quality of bread and *Chapati* containing gum Arabic.

Microbial analysis is important in determining the microbial load of a product which indicates the quality and safety of the product. It also gives an indication of the handling procedures which could be a source of contamination (Giri *et al.*, 2021). The results of microbial load of bread and *Chapati* samples containing gum Arabic are shown in Table 12. There was no growth observed for all the samples for yeast and moulds, and *Escherichia coli*. Total viable count varied from 1.00 to 2.54 CFU/g with no significant ($p < 0.05$) difference being observed in the samples. The absence of yeast and moulds in all the samples indicate that the spores were destroyed during the baking process and there was no recontamination during the subsequent processing steps. The absence of *Escherichia coli* also indicates that there was no likelihood of faecal contamination which points out that sanitary procedures were practiced during the baking process. The microbial counts for the yeast and moulds,

total viable counts and *Escherichia coli* are within the standard permissible units by Kenya Bureau of Standards which states that the microbial counts must not exceed 10^3 for yeasts and moulds, 10^4 for total viable count and *E. coli* should be absent (KEBS, 2012). These results indicate that the baking process was adequate and that the products were microbiologically safe for consumption.

Table 12: Microbiological analysis of bread/ *Chapati* samples containing gum Arabic

Product	Sample	Yeast and moulds (Log ₁₀ CFU/g)	Total Viable Count (Log ₁₀ CFU/g)	E. coli (Log ₁₀ CFU/g)
Bread	WFGA0	NG	2.15 ±0.15 ^a	NG
	WFGA1	NG	2.15± 0.15 ^a	NG
	WFGA2	NG	2.15± 0.15 ^a	NG
	WFGA3	NG	1.15± 1.15 ^a	NG
	WFVB	NG	1.00 ±1.00 ^a	NG
Chapati	WFGA0	NG	2.39± 0.09 ^a	NG
	WFGA1	NG	2.54± 0.06 ^a	NG
	WFGA2	NG	2.39 ±0.09 ^a	NG
	WFGA3	NG	2.54 ± 0.06 ^a	NG
	WFCF	NG	2.54 ±0.06 ^a	NG

WFCF- commercial *Chapati* flour, WFGA0- plain wheat flour, WFGA1- wheat flour with 1% gum Arabic, WFGA2- wheat flour with 2% gum Arabic, WFGA3- wheat flour with 3% gum Arabic, WFVB- commercial bread flour, NG- no growth. Means sharing the same letters within a column are not significantly different (Tukey Honest significant difference at $p < 0.05$)

4.4 Effect of gum Arabic on bread and *Chapati* sensory properties

4.4.1 Effect of Gum Arabic on bread sensory properties

The descriptive profiling of the 5 types of bread (Appendix V) yielded fourteen descriptors and references which were grouped into appearance, aroma, taste and texture to describe the bread as represented in Table 13 and 14.

Table 13: Lexicon for descriptive sensory analysis of bread appearance and aroma properties

Attribute	Description	Reference/ Rating scale
Appearance		
Crust colour description	Intensity of crust colour in the presence of light	Pale brown (1) Dark brown (10)
Crumb colour description	Intensity of crumb colour in the presence of light	Dark brown (1) Cream (10)
Crust thickness	Crust thickness as viewed in presence of light	Very Thin (1) Very thick (10)
Crumb cell distribution	Uniformity on distribution of crumb cells	Not uniform (1) Very uniform (10)
Size of crumb cells	Area occupied by crumb cells	High percentage of cells larger than a lentil (1) High percentage of cells smaller than a lentil (10)
Aroma		
Baked aroma intensity	Aroma sensation associated with baked wheat	Weak aroma after 5 minutes bake (1) Strong aroma after 5 minutes bake (10)
Additional aroma	Aroma sensation associated with barks of trees	Strong woody aroma (1) No woody aroma (10)

Table 14:Lexicon for descriptive sensory analysis of bread texture and taste properties

Attribute	Description	Reference/ Rating scale
Texture		
Crust hardness	Force required to bite through the crust	Hard force– biting a cookie (1) Soft force – biting a sponge cake (10)
Crumb hardness	Force required to bite through the crumb	Hard force– biting a cookie (1) Soft force – biting a sponge cake (10)
Chewiness	Number of chews required for mastication	Greater than 20 chews (1) Less than 10 chews (10)
Cohesiveness	Degree in which the sample holds together	Compact - Biscuit type (1) Crumble -Sponge cake (10)
Taste		
Salty	Degree of taste associated with iodized salt	Weak salty solution (1) Concentrated salty solution (10)
Sweet	Degree of taste associated with sugars	Weak sugary solution (1) Concentrated sugary solution (10)
Sour	Degree of taste associated with fermented products	Strong taste of fermented dough (1) Weak taste of fermented dough (10)

a. Quantitative Descriptive Analysis of Bread containing gum Arabic

Means scores for sensory properties of wheat bread with different levels of gum Arabic (Appendix V) are shown in Table 15 and 16. Addition of gum Arabic significantly ($p < 0.05$) influenced the scores of the crumb cells distribution, the size of crumb cells, additional aroma, crumb hardness, crust hardness, chewiness, cohesiveness and sourness. However, there was no significant ($p < 0.05$) influence of gum Arabic on crust colour, crumb colour, crust thickness, saltiness and sourness. Crumb cell distribution was influenced by the addition of gum Arabic whereby uniformity was significantly higher ($p < 0.05$) in bread containing 3% gum Arabic (9.08). The size of crumb cells was also significantly ($p < 0.05$) influenced by addition of gum Arabic whereby bread containing 2% gum Arabic (8.67) had significantly higher ($p < 0.05$) percentage of small cells. Gum Arabic stimulated the porosity of the final bread product thereby creating a uniform starch-gluten matrix which results to uniformly distributed crumb cells. It also prevented the coalescing of small cells which inhibited formation of large crumb cells (Rathnayake *et al.*, 2018).

Across the different samples, additional aroma significantly ($p < 0.05$) increased with the addition of gum Arabic. Bread containing 3% gum Arabic (8.17) exhibited significantly higher ($p < 0.05$) additional aroma while in bread made from plain wheat flour had the lowest additional aroma. This resulted from the entrapment of aromatic compounds associated with the gum Arabic. The sample made from plain wheat flour (WFGA0) had significantly lower ($p < 0.05$) score of crust hardness (6.92) and crumb hardness (7.67) exhibiting a lower preference of these attributes. However, there was no significant ($p < 0.05$) difference on the crumb hardness and crust hardness for the other samples. Bread samples with gum Arabic exhibited higher preference owing to the ability of gum Arabic to entrap more moisture in the matrix which has a plasticizing effect leading to reduced force required for the deformation of the product (Torbica *et al.*, 2019).

Chewiness was affected by gum arabic addition with samples from plain wheat flour (WFGA0) exhibiting significantly lower ($p < 0.05$) score at 6.08 indicating a higher degree of chewiness. Reduced chewiness in samples containing gum Arabic indicates reduced resistance during chewing thus reduced effort required for mastication of food (Guiné, 2022). Cohesiveness was significantly higher ($p < 0.05$) in samples with gum Arabic, whereby the samples containing 2% gum Arabic (WFGA2) at 8.83 had the highest cohesiveness while the samples from plain wheat flour (WFGA0) at 6.00 had the lowest. Increase in cohesiveness of bread containing gum Arabic shows that there was increased internal cohesion thus reducing

the susceptibility of crumbling during mastication (Torbica *et al.*, 2019). Sourness was significantly higher ($p < 0.05$) in the samples prepared from commercial bread flour (WFVB) at 7.42, which exhibited the strongest aroma of fermented dough while the lowest was in samples prepared using plain wheat flour (WFGA0) at 4.17.

Table 15: Means scores \pm standard deviation of appearance and aroma properties of wheat bread samples containing gum Arabic

Sample	Crust colour	Crumb Colour	Crust thickness	Crumb cell distribution	Size of crumb cells	Baked aroma	Additional aroma
WFGA0	3.33 \pm 0.14 ^a	9.33 \pm 0.26 ^a	4.58 \pm 0.15 ^a	7.08 \pm 0.26 ^c	6.75 \pm 0.25 ^c	8.92 \pm 0.23 ^a	7.25 \pm 0.23 ^b
WFGA1	3.58 \pm 0.15 ^a	9.08 \pm 0.29 ^a	4.58 \pm 0.15 ^a	7.50 \pm 0.19 ^{bc}	8.00 \pm 0.25 ^{ab}	9.17 \pm 0.24 ^a	8.00 \pm 0.25 ^{ab}
WFGA2	3.58 \pm 0.15 ^a	9.00 \pm 0.28 ^a	4.42 \pm 0.15 ^a	7.33 \pm 0.19 ^c	8.67 \pm 0.28 ^a	9.17 \pm 0.21 ^a	8.00 \pm 0.25 ^{ab}
WFGA3	3.58 \pm 0.15 ^a	9.17 \pm 0.27 ^a	4.33 \pm 0.22 ^a	9.08 \pm 0.23 ^a	7.17 \pm 0.24 ^{bc}	9.17 \pm 0.21 ^a	8.17 \pm 0.24 ^a
WFVB	3.50 \pm 0.15 ^a	9.08 \pm 0.29 ^a	4.42 \pm 0.15 ^a	8.33 \pm 0.22 ^{ab}	7.08 \pm 0.23 ^{bc}	8.83 \pm 0.27 ^a	7.92 \pm 0.19 ^{ab}

Key: WFGA0- bread made from plain wheat flour, WFGA1- bread made from wheat flour with 1% gum Arabic, WFGA2- bread made from wheat flour with 2% gum Arabic, WFGA3- bread made from wheat flour with 3% gum Arabic, WFVB- bread made from commercial bread flour. Means followed by different superscript letters in the same column are significantly different ($p < 0.05$).

Table 16: Means scores \pm standard deviation of texture and taste properties of wheat bread samples containing gum Arabic

Sample	Crust hardness	Crumb hardness	Chewiness	Cohesiveness	Saltiness	Sweetness	Sourness
WFGA0	6.92 \pm 0.31 ^b	7.67 \pm 0.14 ^b	6.08 \pm 0.26 ^d	6.00 \pm 0.25 ^b	2.50 \pm 0.15 ^a	4.17 \pm 0.21 ^a	4.17 \pm 0.24 ^c
WFGA1	8.67 \pm 0.26 ^a	9.08 \pm 0.23 ^a	7.83 \pm 0.21 ^{bc}	8.25 \pm 0.37 ^a	2.75 \pm 0.13 ^a	4.33 \pm 0.19 ^a	5.58 \pm 0.15 ^b
WFGA2	9.08 \pm 0.26 ^a	9.08 \pm 0.29 ^a	8.67 \pm 0.19 ^{ab}	8.83 \pm 0.27 ^a	2.42 \pm 0.15 ^a	3.67 \pm 0.28 ^a	5.17 \pm 0.21 ^b
WFGA3	8.67 \pm 0.33 ^a	9.08 \pm 0.26 ^a	7.67 \pm 0.28 ^c	8.08 \pm 0.19 ^a	2.67 \pm 0.14 ^a	3.67 \pm 0.14 ^a	4.83 \pm 0.21 ^{bc}
WFVB	8.75 \pm 0.25 ^a	9.25 \pm 0.25 ^a	9.17 \pm 0.27 ^a	8.67 \pm 0.26 ^a	2.58 \pm 0.15 ^a	4.25 \pm 0.22 ^a	7.42 \pm 0.15 ^a

Key: WFGA0- bread made from plain wheat flour, WFGA1- bread made from wheat flour with 1% gum Arabic, WFGA2- bread made from wheat flour with 2% gum Arabic, WFGA3- bread made from wheat flour with 3% gum Arabic, WFVB- bread made from commercial bread flour. Means followed by different superscript letters in the same column are significantly different ($p < 0.05$).

Principal component analysis was used in analyzing descriptive sensory data. It is a multivariate analytic technique which helps in reducing the variables down to a manageable size thus describing a sample using fewer dimensions. The variables are further grouped according to the factors that describe them (García-Gómez *et al.*,2022). The results from principal component analysis show the presence of 3 principal components with eigen values of above one for the sensory attributes of the bread containing gum Arabic. The three principal components explained a total of 72.7% of the variation in the bread samples as illustrated in Figure 3.

The first principal component loaded with more factors and accounted for 41.6% of the variability, while the second principal component was loaded with 16.6% and the third principal component loaded with 14.5%. The results from the loading matrix (Table 17) indicate that some attributes related more closely to each other than others due to the different treatments. These sets have high loadings in the same principal component. Attributes which were strongly loaded in principal component 1 were mainly crust hardness (0.82), crumb hardness (0.86), chewiness (0.81), cohesiveness (0.85) and sourness (0.68). Baked aroma (0.78) had positive coefficient in the second principal component while the third principal component had a positive coefficient on crust thickness (0.60) and sourness (0.81).

Table 17: Loading matrix coefficients of descriptive attributes of bread on principal components

Attribute	Prin1	Prin2	Prin3
Crust thickness			0.59943
Baked aroma		0.77624	
Crust hardness	0.82454		
Crumb hardness	0.85506		
Chewiness	0.80949		
Cohesiveness	0.85105		
Saltiness			0.80570
Sourness	0.67748		

The first principal component is mainly dominated by textural attributes and slightly by taste. Increase in the amount of gum Arabic resulted to increase in cohesiveness while increase in crust and crumb hardness was associated with absence of gum Arabic. An increase in chewiness was associated with absence of gum Arabic and also the commercial bread flour. Principal component two mainly comprised baked aroma intensity which was mainly

associated with the bread made from commercial bread flour. Principal component three which comprised of crust thickness and salty taste was mainly associated with bread containing 1% gum Arabic. Generally, the presence of gum Arabic and commercial improver influenced the texture, taste, aroma and the appearance properties which are some of the most important attributes in bread characterization (Guiné, 2022).

The hydrocolloid nature of gum Arabic led to the entrapping of water in the bread matrix which acts as a plasticizer thus modifying the textural properties (Mohammadi *et al.*, 2014). The baked aroma and sourness which were mainly associated with bread from commercial bread flour resulted from the action of amylases enzyme which speeded up the rate of reaction by the yeast during fermentation. This resulted to the formation of volatile compounds that contributed to the flavor and sour taste.

Varimax rotation was used to reduce the number of variables influencing each factor. It also determines the alignment showing the shared variance among factors loaded on the various principal components as illustrated in Figure 3. Each of the descriptors was aligned independently on principal components 1, 2 and 3 showing that there was no multicollinearity among the descriptors.

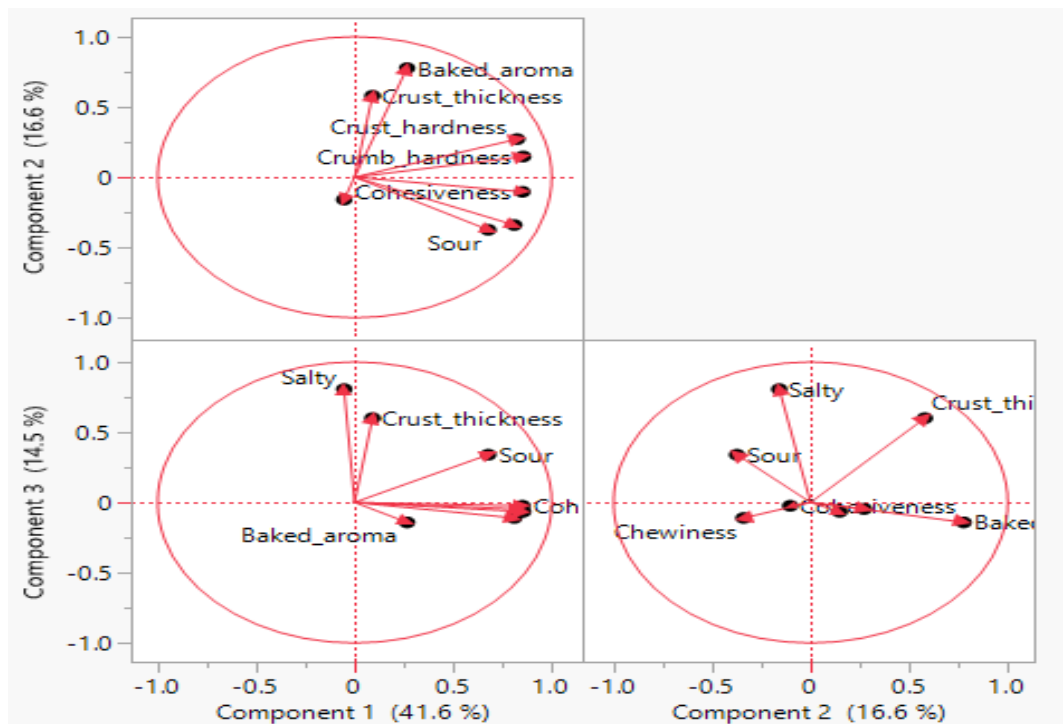


Figure 3: Plot of the loading factors 1,2 and 3 from descriptive sensory analysis of bread

b. Consumer Acceptability of Bread Containing Gum Arabic

Overall acceptance of food is a significant factor which is affected by the sensory quality of the food and the customer's perception of the food. The sensory properties scores of breads containing gum Arabic are shown in Figure 4. Addition of gum Arabic in bread significantly ($p < 0.05$) influenced the scores for colour (6.17-6.63), aroma (5.97-6.50), texture (5.70-6.50), taste (5.67-6.53) and overall acceptability (5.83-6.53). Wheat flour with 2 % gum Arabic had significantly higher ($p < 0.05$) scores across all the attributes while the bread made from plain wheat flour recorded significantly lower ($p < 0.05$) scores in all the attributes apart from the appearance.

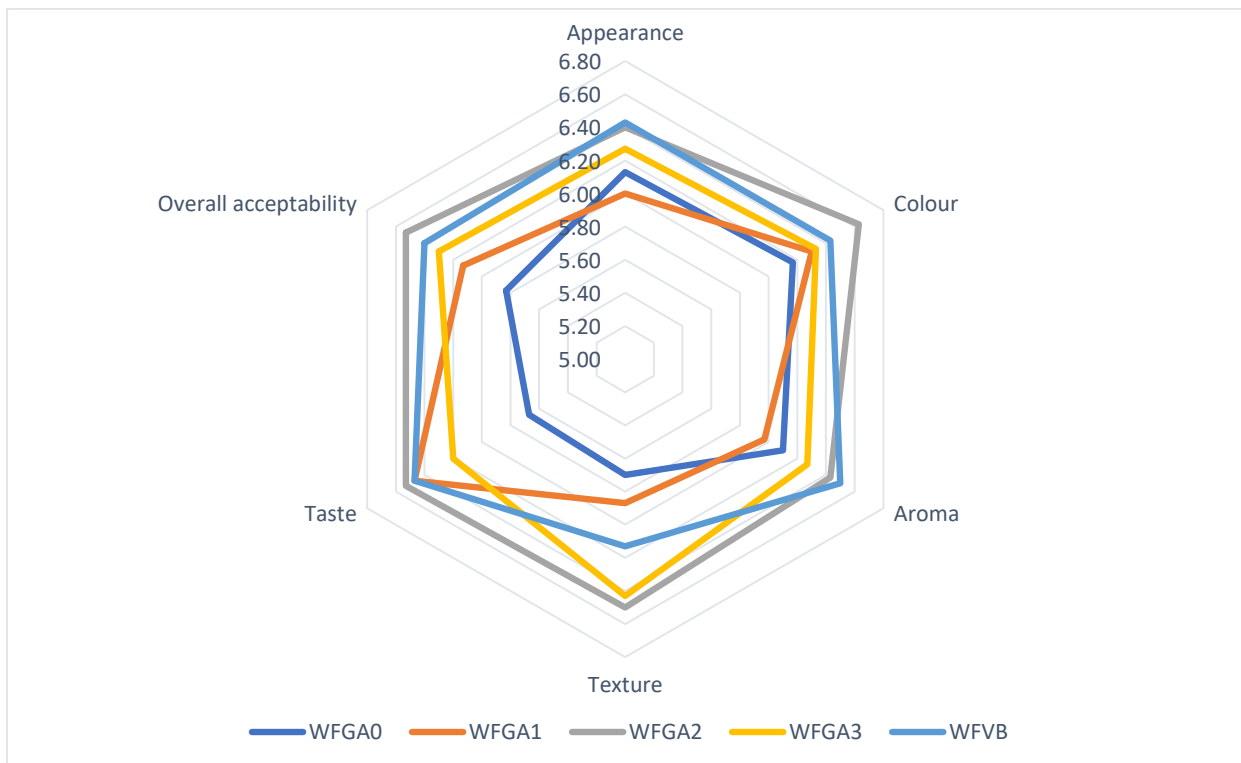


Figure 4: Consumer acceptability of bread containing gum Arabic. For each attribute, the relative intensity increases as it moves farther away from the center point

Key: WFGA0- bread made from plain wheat flour, WFGA1- bread made from wheat flour with 1% gum Arabic, WFGA2- bread made from wheat flour with 2% gum Arabic, WFGA3- bread made from wheat flour with 3% gum Arabic, WFVB- bread made from commercial bread flour.

Lack of significant ($p < 0.05$) difference on appearance scores among the different breads shows that all the breads samples had similar visual appealing characteristics. Colour which is one of the major palatability indicators in baked products was significantly higher ($p < 0.05$) in bread containing 2% gum Arabic (6.63). Aroma preference was significantly higher ($p < 0.05$) in bread made from commercial wheat flour (6.50) and was similar to bread made from wheat flour containing 2% gum Arabic (6.43) indicating that the bread samples had wholesome aroma which was highly acceptable. Texture was significantly ($p < 0.05$) influenced by addition of gum Arabic whereby more preference was recorded in samples containing higher levels of gum Arabic. This shows that bread samples containing gum Arabic had a relatively softer crumb and crust due to water retention ability and reduction of starch retrogradation in the samples (Mohammadi *et al.*, 2014). There was no significant ($p < 0.05$) difference between the bread containing 2 % gum Arabic and the bread from commercial flour in aroma, taste and overall acceptability.

4.4.2 Effect of gum Arabic on sensory properties of *Chapati*

The descriptive profiling of the 5 types of *Chapati* (Appendix V) yielded fifteen descriptors which were grouped into appearance, aroma, taste and texture to describe the *Chapati* as represented in Table 18 and 19.

Table 18: Lexicon for descriptive sensory analysis of *Chapati* appearance attributes

Attribute	Descriptors	Reference/ Rating scale
Appearance		
<i>Chapati</i> thickness	<i>Chapati</i> thickness as viewed in presence of light	Very thick- Greater than 4 mm (1) Very thin - Less than 2mm (10)
Evenness on the surface	Surface appearance	Uneven (1) Extremely even (10)
Uniformity of spots	Distribution of the spots on the surface	Not Uniform (1) Very uniform (10)
Layers	Visibility of distinct layers	No visible layers (1) Distinct visible layers (10)
<i>Chapati</i> colour description	Intensity of <i>Chapati</i> colour in the presence of light	White (1) Light brown/ Cream (10)
Colour of the spots	Intensity of spots colour in the presence of light	Burnt/Black (1) Brown (10)

Table 19: Lexicon for descriptive sensory analysis of *Chapati* aroma, texture and taste attributes

Aroma		
Baked aroma intensity	Aroma sensation associated with baked wheat	Weak baked wheat aroma after 3 minutes bake (1) Strong baked wheat aroma after 3 minutes bake (10)
Additional Aroma	Aroma sensation associated with barks of trees	Strong woody aroma/ fragrance (1) Weak woody aroma/ fragrance (10)
Texture		
Firmness	Force required to bite through the sample	Hard – force required to bite a cookie (1) Soft- force required to bite a sponge cake (10)
Chewiness	Number of chews before the sample is properly masticated	Large number - More than 40 chews (1) Small number- less than 20 chews (10)
Capacity of foldability	The flexibility of the sample to take different forms	Unfoldable- breaks easily on folding e.g. a biscuit (1) Easily folded- e.g., a piece of printing paper (10)
Tearability	Force required to tear through the <i>Chapati</i>	Untearable (1) Easy to tear (10)
Taste		
Salty	Degree of taste associated with iodized salt	Weak salty solution (1) Concentrated salty solution (10)
Sweet	Degree of taste associated with sugars	Weak sugary solution (1) Concentrated sugary solution (10)
Sour	Degree of taste associated with fermented products	Strong taste of fermented dough (1) Weak taste of fermented dough (10)

a. Quantitative Descriptive Analysis of *Chapati* containing Gum Arabic

Means scores for sensory properties of *Chapati* with different levels of gum Arabic (Appendix V) are shown in Table 20 and 21. Visibility of layers was significantly ($p < 0.05$) influenced by addition of gum Arabic with *Chapati* containing 1% gum Arabic (8.75) exhibiting significantly higher ($p < 0.05$) scores while *Chapati* from plain wheat flour (7.17) exhibited a significantly lower ($p < 0.05$) score. However, there was no significant ($p < 0.05$) difference on visible layers in the other samples. The colour of the spots was significantly higher ($p < 0.05$) and most preferred in *Chapati* made from commercial *Chapati* flour (9.33) while it was least preferred in *Chapati* containing 1% gum Arabic (8.67). Good quality *Chapati* should have a desirable colour with brown spots spread uniformly on the surface (Khurshid *et al.*, 2020). The results indicate that *Chapati* from commercial flour yielded the best colour attributes followed by *Chapati* containing 3% gum Arabic.

The *Chapati* aroma significantly ($p < 0.05$) increased with addition of gum Arabic with *Chapati* containing 3% gum Arabic (8.92) exhibiting the higher score. The degree of firmness was significantly lower ($p < 0.05$) in *Chapati* containing 2% gum Arabic (8.83) as shown by the high preference. This was due to the water retention capacity that was imparted into the matrix by the gum which inhibited retrogradation and yielded a softer and pliable *Chapati* (Pahwa *et al.*, 2016). Chewiness was least preferred in *Chapati* made from plain wheat flour (8.25) which shows it was chewier while *Chapati* containing 2% gum Arabic (9.08) was more preferred and less chewy. Reduced chewiness in samples containing gum Arabic indicate that it reduced the force required in mastication of the food. The capacity of foldability was significantly ($p < 0.05$) affected by the level of gum Arabic whereby there was an increase in capacity of foldability with addition of gum Arabic. This indicates that gum Arabic improved the mechanical characteristics of the *Chapati*. There was no significant ($p < 0.05$) difference among *Chapati* containing 2% and 3% gum Arabic and *Chapati* from commercial flour. There was no significant ($p < 0.05$) difference in tearability between *Chapati* containing 3% (8.25) and *Chapati* from commercial *Chapati* flour (8.25). This shows that less amount of force was required in tearing the *Chapati* due to the soft texture (Hemalatha *et al.*, 2022). Attributes such as *Chapati* thickness, evenness of the surface, uniformity of spots, colour, baked aroma intensity, saltiness and sugariness did not show significant ($p < 0.05$) differences among the different levels which shows that gum Arabic did not influence these attributes. Generally, addition of gum Arabic resulted to greater pliability, soft texture and easy to tear and little chewiness (Hemalatha *et al.*, 2022).

Table 20: Means scores \pm standard deviation of appearance properties of *Chapati* samples containing gum Arabic

Sample	<i>Chapati</i> Thickness	Evenness on the surface	Uniformity spots	of Layers	<i>Chapati</i> colour description	Colour of the spots
WFGA0	4.58 \pm 0.15 ^a	7.58 \pm 0.15 ^a	8.75 \pm 0.13 ^a	7.17 \pm 0.21 ^b	7.75 \pm 0.13 ^a	8.92 \pm 0.26 ^{ab}
WFGA1	4.50 \pm 0.15 ^a	7.67 \pm 0.14 ^a	8.83 \pm 0.24 ^a	8.75 \pm 0.13 ^a	8.83 \pm 0.24 ^a	8.67 \pm 0.26 ^b
WFGA2	4.67 \pm 0.14 ^a	7.50 \pm 0.15 ^a	9.00 \pm 0.28 ^a	8.08 \pm 0.26 ^a	8.50 \pm 0.15 ^a	9.08 \pm 0.26 ^{ab}
WFGA3	4.58 \pm 0.15 ^a	8.08 \pm 0.26 ^a	8.92 \pm 0.26 ^a	8.33 \pm 0.14 ^a	9.00 \pm 0.25 ^a	8.83 \pm 0.24 ^{ab}
WFCF	4.50 \pm 0.15 ^a	7.42 \pm 0.15 ^a	8.92 \pm 0.23 ^a	8.33 \pm 0.14 ^a	9.17 \pm 0.21 ^a	9.33 \pm 0.19 ^a

Key: WFGA0- *Chapati* made from plain wheat flour, WFGA1- *Chapati* made from wheat flour with 1% gum Arabic, WFGA2- *Chapati* made from wheat flour with 2% gum Arabic, WFGA3- *Chapati* made from wheat flour with 3% gum Arabic, WFCF- *Chapati* made from commercial *Chapati* flour. Means followed by different superscript letters in the same column are significantly different ($p < 0.05$).

Table 21: Means scores \pm standard deviation of aroma, texture and taste properties of *Chapati* samples containing gum Arabic

Sample	Baked aroma	Additional aroma	Firmness	Chewiness	Capacity of foldability	Tearability	Saltiness	Sugariness
WFGA0	8.42 \pm 0.15 ^a	6.50 \pm 0.15 ^c	8.08 \pm 0.29 ^b	8.25 \pm 0.13 ^b	6.58 \pm 0.15 ^c	7.42 \pm 0.15 ^b	3.58 \pm 0.15 ^a	3.50 \pm 0.15 ^a
WFGA1	8.08 \pm 0.23 ^a	8.00 \pm 0.21 ^b	8.08 \pm 0.23 ^b	8.50 \pm 0.15 ^a	7.42 \pm 0.15 ^b	7.33 \pm 0.22 ^b	3.50 \pm 0.15 ^a	3.58 \pm 0.15 ^a
WFGA2	8.25 \pm 0.13 ^a	8.08 \pm 0.23 ^b	8.83 \pm 0.17 ^a	9.08 \pm 0.26 ^{ab}	7.75 \pm 0.22 ^{ab}	7.92 \pm 0.19 ^{ab}	3.42 \pm 0.15 ^a	3.50 \pm 0.15 ^a
WFGA3	8.58 \pm 0.23 ^a	8.92 \pm 0.19 ^a	8.33 \pm 0.28 ^{ab}	8.58 \pm 0.15 ^{ab}	7.75 \pm 0.22 ^{ab}	8.25 \pm 0.18 ^a	3.42 \pm 0.15 ^a	3.50 \pm 0.15 ^a
WFCF	8.25 \pm 0.13 ^a	7.50 \pm 0.15 ^b	8.42 \pm 0.19 ^{ab}	8.42 \pm 0.15 ^b	8.33 \pm 0.14 ^a	8.25 \pm 0.22 ^a	3.25 \pm 0.13 ^a	3.42 \pm 0.15 ^a

Key: WFGA0- *Chapati* made from plain wheat flour, WFGA1- *Chapati* made from wheat flour with 1% gum Arabic, WFGA2- *Chapati* made from wheat flour with 2% gum Arabic, WFGA3- *Chapati* made from wheat flour with 3% gum Arabic, WFCF- *Chapati* made from commercial *Chapati* flour. Means followed by different superscript letters in the same column are significantly different (p<0.05).

The results from principal component analysis show the presence of 3 principal components with eigen values of above one for the sensory attributes of the *Chapati* containing gum Arabic. The three principal components explained a total of 61.7% of the variation in the *Chapati* samples as illustrated in Figure 5. The first principal component was loaded with more factors and accounted for 30.2%, while the second principal component was loaded with 17.0% and the third principal component loaded with 14.5%. The results from the loading matrix (Table 22) suggests that some attributes are related closely to each other resulting from the different treatments in the bread samples. Principal component 1 had attributes with positive coefficients such as layers (0.66), *Chapati* colour (0.81), additional aroma (0.61), capacity of foldability (0.48), and tearability (0.61). The second principal component had positive coefficients for uniformity of spots (0.65) and colour of the spots (0.69). The third principal component had a positive coefficient on saltiness (0.72) but a negative coefficient on chewiness (-0.74).

Table 22: Loading matrix coefficients of *Chapati* descriptive attributes on principal components

Attribute	Prin1	Prin2	Prin3
Uniformity of spots	-	0.65306	
Layers	0.66177		
<i>Chapati</i> colour description	0.80676		
Colour of the spots		0.69212	
Additional aroma	0.68132		
Chewiness			-0.73672
Capacity of foldability	0.47756		
Tearability	0.61016		
Salty			0.71713

The first and the second principal components are dominated with attributes related to appearance, colour, texture and aroma which are the most influential attributes of *Chapati* (Khurshid *et al.*, 2020). Besides, the third principal component is dominated by attributes related to the taste and texture. The texture properties such as capacity of foldability, tearability, and chewiness were mainly influenced by a unit addition of gum Arabic in different levels. This was brought about by the nature of gum Arabic to enhance the entrapment of water in the dough matrix thus leading to the modification of the textural properties of the final product (Pahwa *et al.*, 2016). The colour of the *Chapati* was influenced

by the addition of the gum Arabic which caused water redistribution and the commercial improver which influenced Maillard browning and caramelization leading to colour enhancement (Mohammadi *et al.*, 2014). Additional aroma was associated with gum Arabic at higher levels due to entrapping of aromatic compounds in the gum. Varimax rotation is a technique which was used in was used to reduce factors to manageable dimensions. It also determines the rotation of the axis to represent the shared variance among different factors loaded on the various principal components as shown in Figure 5. Each of the descriptors was aligned independently on principal components 1, 2 and 3 showing that there was no multicollinearity among the descriptors.

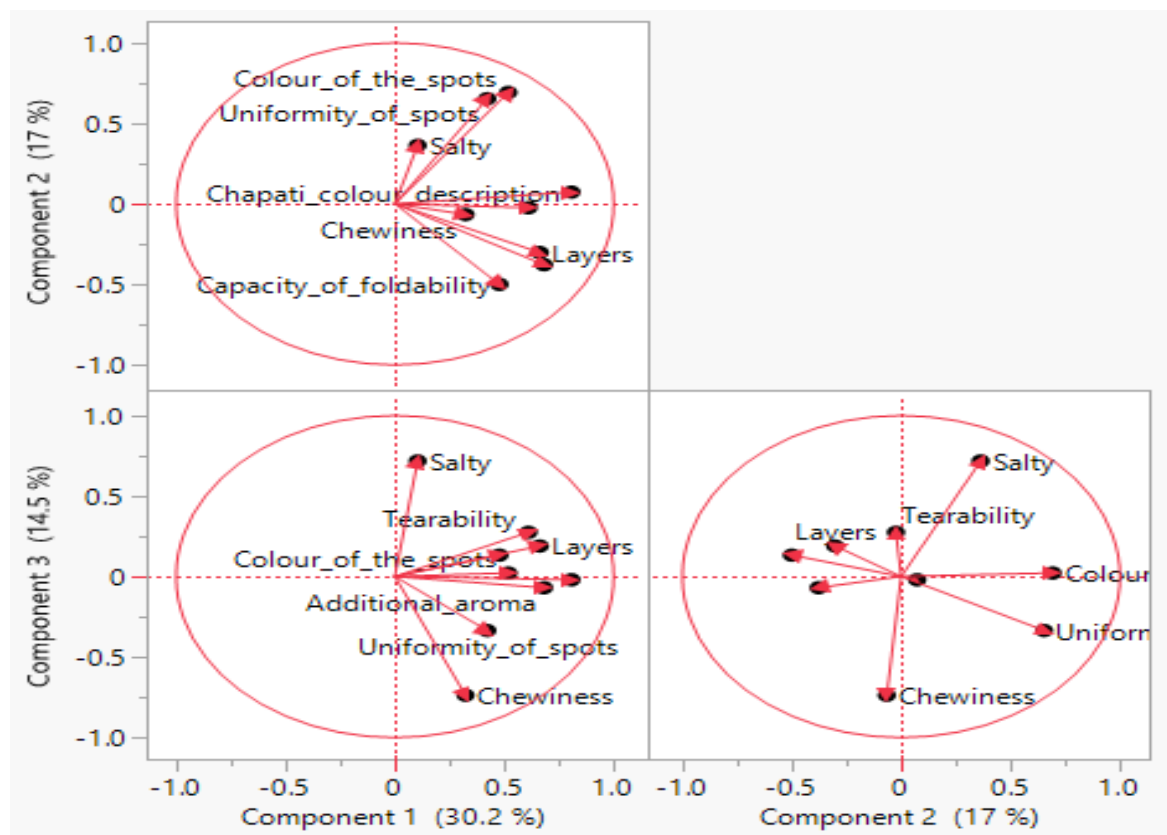


Figure 5: Plot of the loading factors 1,2 and 3 from descriptive sensory analysis of Chapati

b. Consumer Acceptability of Chapati Containing Gum Arabic

The sensory properties result of *Chapati* containing gum Arabic are shown in Figure 6. Addition of gum Arabic significantly ($p < 0.05$) influenced all the sensory attributes. The *Chapati* made from wheat flour with 3% gum Arabic recorded significantly higher ($p < 0.05$) scores in all the attributes apart from aroma. *Chapati* made from commercial flour (6.43) had significantly higher ($p < 0.05$) aroma. *Chapati* samples made from plain wheat flour had significantly lower ($p < 0.05$) scores across all the attributes. There was no significant ($p < 0.05$)

difference between *Chapati* made from wheat flour containing 3% gum Arabic and commercial *Chapati* flour in all the sensory attributes apart from aroma and texture.

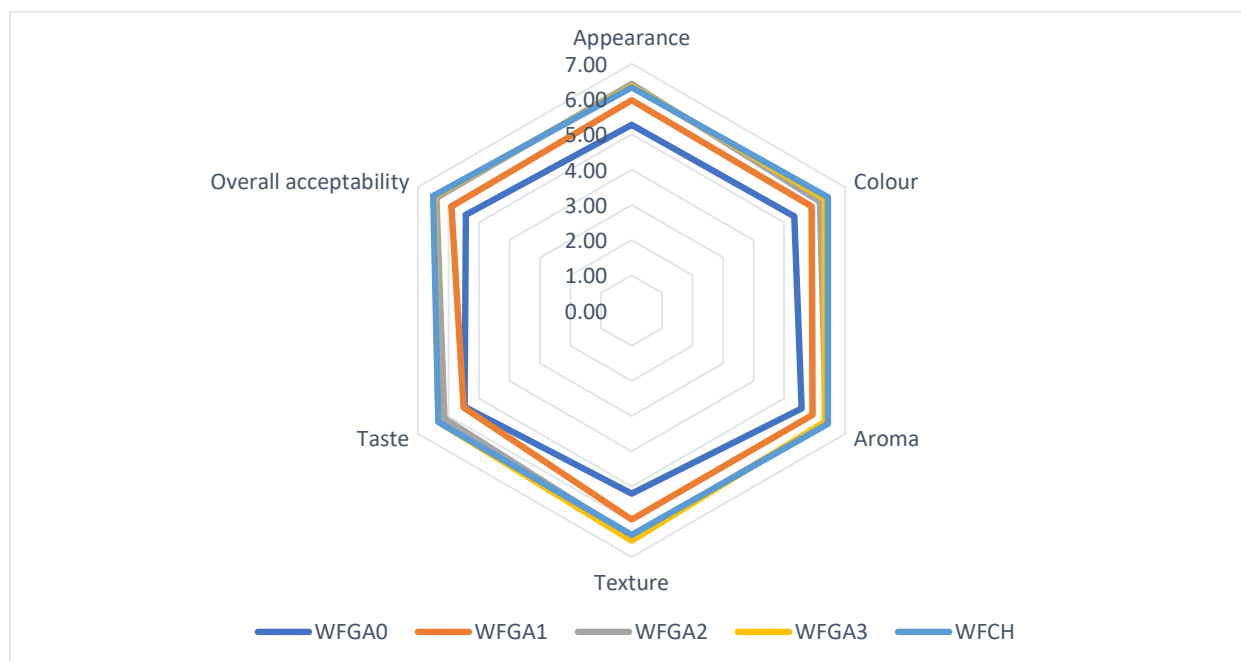


Figure 6: Consumer acceptability of *Chapati* containing gum Arabic. For each attribute, the relative intensity increases as it moves farther away from the center point

Key: WFGA0- *Chapati* made from plain wheat flour, WFGA1- *Chapati* made from wheat flour with 1% gum Arabic, WFGA2- *Chapati* made from wheat flour with 2% gum Arabic, WFGA3- *Chapati* made from wheat flour with 3% gum Arabic, WFCH- *Chapati* made from commercial *Chapati* flour

Chapati made from plain wheat flour recorded the significantly lower ($p < 0.05$) score for the appearance (5.27) which shows that addition of gum Arabic improved the visual appeal of the *Chapati* samples. Gum Arabic addition imparted desirable attributes in *Chapati* such as puffiness and visible layers. It led to desirable creamy colour with light brown spots uniformly distributed on the surface (Khurshid *et al.*, 2020). The aroma and taste increased with the addition of gum Arabic which indicates that it prevented the escape of volatile compounds and caused the retention of flavour compounds. Texture was significantly ($p < 0.05$) influenced by the addition of gum Arabic through the retention of water and reduction of starch retrogradation thus maintaining the soft and pliable characteristics desirable in *Chapati* (Pahwa *et al.*, 2016).

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The results from the current study indicated that:

- i. Gum Arabic modified the proximate composition of wheat flour by increasing moisture, fibre, ash and carbohydrate content but decreasing the protein and fat content. Gum Arabic also led to improved water holding capacity, oil holding capacity, emulsion capacity and emulsion stability of wheat flour.
- ii. Gum Arabic modified all Farinograph properties apart from consistency and extensograph properties. The pasting properties of wheat were modified resulting in reduction of Viscograph parameters except pasting temperature.
- iii. The use of gum Arabic improved the baking quality attributes by improving the specific volume of bread and textural profile of bread and the texture of *Chapati*.
- iv. The use of gum Arabic improved the sensory properties of bread and *Chapati* and the consumer acceptability of the products. Products containing gum Arabic scored higher in sensory properties compared to those without.

5.2 Recommendations

- i. Industrial use of gum Arabic as a dietary fiber is encouraged and also as a water binder, oil binder and as an emulsifier in the different applications of flours.
- ii. According to this study, an optimal gum Arabic concentration of 2% in wheat flour dough and 90 minutes proofing time is recommended for pan bread making due to the desirable strength and ability to hold gases. Gum Arabic concentration of 3% had the highest extensibility is recommended for flat breads such as *Chapati*.
- iii. The application of gum Arabic in dough production and final products processing is encouraged since it has proven to improve dough properties and those of the final products.
- iv. Further studies are recommended for optimization of gum Arabic in baking operations for different baked products that were not part of the study.

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APPENDICES

Appendix I: Score Sheet for Quantitative Descriptive Sensory Analysis for Bread

The sensory evaluation for bread was carried out using a line scale where; 1 was the lowest score while 10 was the highest score.

No. panelist..... Name of Panelist.....

Date.....

Please rinse your mouth before starting.

- Evaluate the product in front of you by looking at it, feeling it and tasting it.
- Assign an appropriate score (with 1 being the least and 10 being the most) for each of the listed parameters/components.

Instruction: - You are provided with coded samples, Kindly score and record each sample per your judgement of the attributes listed on the table in the appropriate box.

Sensory Attribute	Attribute	Descriptor	Scale and References						
			Min (1)	Max (10)	B525	Z287	C192	G327	J692
Appearance	Crust colour description	Intensity of crust colour in the presence of light	Pale brown (1)	Dark brown (10)					
	Crumb colour description	Intensity of crumb colour in the presence of light	Dark brown (1)	Cream (10)					
	Crust thickness	Crust thickness as viewed in presence of light	Very Thin (1)	Very thick (10)					
	Crumb cell distribution	Uniformity on distribution of crumb cells	Not uniform (1)	Very uniform (10)					
	Size of crumb cells	Area occupied by crumb cells	High percentage of cells	High percentage of cells					

			larger than a lentil (1)	smaller than a lentil (10)					
Aroma	Baked aroma intensity	Aroma sensation associated with baked wheat	Weak aroma after 5 minutes bake (1)	Strong aroma after 5 minutes bake (10)					
	Additional aroma	Aroma sensation associated with barks of trees	Strong woody aroma (1)	No woody aroma (10)					
Texture	Crust hardness	Force required to bite through the crust	Hard force—biting a cookie (1)	Soft force—biting a sponge cake (10)					
	Chewiness	Number of chews required for mastication	Greater than 20 chews (1)	Less than 10 chews (10)					

	Cohesiveness	Degree in which the sample holds together	Compact Biscuit type (1)	Crumble-Sponge cake (10)					
Taste	Salty	Degree of taste associated with iodized salt	Weak salty solution (1)	Concentrated salty solution (10)					
	Sweet	Degree of taste associated with sugars	Weak sugary solution (1)	Concentrated sugary solution (10)					
	Sour	Degree of taste associated with fermented products	Strong aroma of fermented dough (1)	Weak aroma of fermented dough (10)					

THANK YOU FOR YOUR TIME

Appendix II: Score Sheet for Quantitative Descriptive Sensory Evaluation for *Chapati*



The sensory evaluation for *Chapati* was carried out using a line scale where; 1 was the lowest score while 10 was the highest score.

No. panelist..... Name of Panelist.....
Date.....

Please rinse your mouth before starting.

- Evaluate the product in front of you by looking at it, feeling it and tasting it.
- Assign an appropriate score (with 1 being the least and 10 being the most) for each of the listed parameters/components.

Instruction: - You are provided with coded samples, Kindly score and record each sample per your judgement of the attributes listed on the left side of the table in the appropriate box.

Sensory Attribute	Attribute	Descriptor	Scale and References		Ratings				
			Min (0)	Max (10)	B115	Z582	C309	J256	G364
Appearance	<i>Chapati</i> thickness	<i>Chapati</i> thickness as viewed in presence of light	Very thick Greater than 4 mm (1)	Very thin Less than 2mm (10)					
	Evenness on the surface	Surface appearance	Uneven (1)	Extremely even (10)					
	Uniformity of spots	Distribution of the spots on the surface	Not Uniform (1) 	Very uniform (10) 					
	Layers	Visibility of distinct layers	No visible layers (1)	Distinct visible layers (10)					
Colour	<i>Chapati</i> colour description	Intensity of <i>Chapati</i> colour in the presence of light	White (1)	Light brown/ Cream (10)					
	Colour of the spots	Intensity of spots colour in the presence of light	Burnt/Black (1)	Brown (10)					
Aroma	Baked aroma	Aroma sensation associated with baked wheat	Weak baked wheat aroma	Strong baked wheat aroma					

	intensity		after 3 minutes bake (1)	after 3 minutes bake (10)					
	Additional Aroma	Aroma sensation associated with barks of trees	Strong woody aroma/ fragrance (1)	Weak woody aroma/ fragrance (10)					
Texture	Firmness	Force required to bite through the sample	Hard – force required to bite a cookie (1)	Soft- force required to bite a sponge cake (10)					
	Chewiness	Number of chews before the sample is properly masticated	Large number More than 40 chews (1)	Small number Less than 20 chews (10)					
	Capacity of foldability	The flexibility of the sample to take different forms	Unfoldable- breaks easily on folding e.g. a biscuit (1)	Easily folded- e.g., a piece of printing paper					

				(10)					
	Tearability	Force required to tear through the <i>Chapati</i>	Untearable (1)	Easy to tear (10)					
Taste	Salty	Degree of taste associated with iodized salt	Weak salty solution (1)	Concentrated salty solution (10)					
	Sweet	Degree of taste associated with sugars	Weak sugary solution (1)	Concentrated sugary solution (10)					
	Sour	Degree of taste associated with fermented products	Strong aroma of fermented dough (1)	Weak aroma of fermented dough (10)					

THANKYOU FOR YOUR TIME

Appendix III: Consumer Acceptability Sensory Evaluation for Bread

The sensory evaluation for bread was carried out using a seven-point hedonic scale.

Score sheet for a 7 Point Hedonic Scale Ranking where; 7= like extremely, 6 = like moderately, 5= like slightly, 4= neither like nor dislike, 3 = dislike slightly, 2=dislike moderately and 1= dislike extremely.

No. panelist..... Name of Panelist.....

Date.....

Instruction: - You are provided with coded samples, Kindly score and record each sample per your judgement of the attributes listed on the left side of the table in the appropriate box.

Attribute	Hedonic scale	Sample codes				
		B525	Z287	C192	G327	J692
Appearance	(1= dislike extremely to 7= like extremely)					
Colour	(1= dislike extremely to 7= like extremely)					
Aroma	(1= dislike extremely to 7= like extremely)					
Texture	(1= dislike extremely to 7= like extremely)					
Taste	(1= dislike extremely to 7= like extremely)					
Overall acceptability	(1= dislike extremely to 7= like extremely)					

THANKYOU FOR YOUR TIME.

Appendix IV: Consumer Acceptability Sensory Evaluation for Chapati

The sensory evaluation for *Chapati* was carried out using a seven-point hedonic scale.

Score sheet for a 7 Point Hedonic Scale Ranking where; 7= like extremely, 6 = like moderately, 5= like slightly, 4= neither like nor dislike, 3 = dislike slightly, 2=dislike moderately and 1= dislike extremely.

No. panelist..... Name of Panelist.....

Date.....

Instruction: - You are provided with coded samples, Kindly score and record each sample per your judgement of the attributes listed on the left side of the table in the appropriate box.

Attribute	Hedonic scale	Sample codes				
		B115	Z582	C309	J256	G364
Appearance	(1= dislike extremely to 7= like extremely)					
Colour	(1= dislike extremely to 7= like extremely)					
Aroma	(1= dislike extremely to 7= like extremely)					
Texture	(1= dislike extremely to 7= like extremely)					
Overall acceptability	(1= dislike extremely to 7= like extremely)					

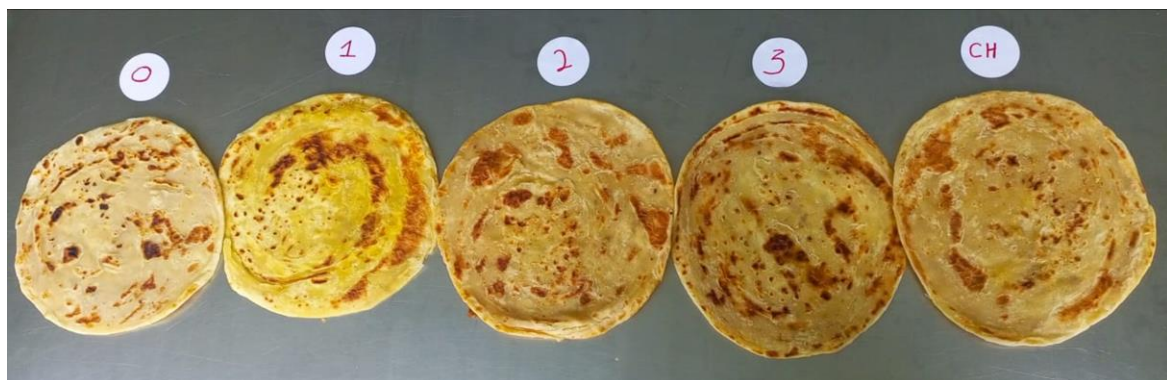
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Appendix V: Images of Bread and Chapati Samples containing gum Arabic



Baked bread samples

Key: 0%- bread made from plain wheat flour, 1%- bread made from wheat flour with 1% gum Arabic, 2%- bread made from wheat flour with 2% gum Arabic, 3%- bread made from wheat flour with 3% gum Arabic, VB- bread made from commercial bread flour.



Chapati samples

Key: 0- Chapati made from plain wheat flour, 1- Chapati made from wheat flour with 1% gum Arabic, 2- Chapati made from wheat flour with 2% gum Arabic, 3- Chapati made from wheat flour with 3% gum Arabic, CH- Chapati made from commercial Chapati flour

Appendix VI: ANOVA TABLES

a. proximate composition of wheat flour containing gum Arabic

Source	Degree of freedom	Moisture	Fat	Protein	Fibre	Ash	Carbohydrates
Sample	5	0.02***	0.14***	0.50***	0.09***	0.03***	0.26***
Replicate	4	0.00	0.00	0.00	0.00	0.00	0.00
Error	20	0.00	0.00	0.00	0.00	0.00	0.00
R2		0.87	0.97	0.93	0.98	0.90	0.98
Coefficient of variation		0.22	2.09	0.26	1.54	3.10	0.06

b. physicochemical properties of wheat flour containing gum Arabic

	Degree of freedom	WHC	OHC	EC	ES
Treatment	5	0.112***	0.063***	18.688***	39.298***
Replicate	4	0	0	0.287	0.399
Error	20	0	0	0.137	0.167
R2	—	0.99	0.992	0.972	0.983
C.V	—	1.486	0.874	0.742	0.856

c. extensograph properties of wheat flour dough containing gum Arabic

SOURCE	D.F	ENERGY	RES.TO. EXT	EXTENSIBILITY	MAX. BU	RATIO NO
SAMPLE	5	265.422***	72876.044***	1090.133***	98768.978***	9.012***
TIME	2	262.889***	23074.889***	388.722***	14917.722***	2.962***
REP	2	16.889	448.167	26.889	248.722	0.036
SAMPLE*TIME	10	99.178***	5125.600***	70.389***	1942.233***	0.808***
ERROR	34	7.026	216.677	5.869	227.624	0.029
R2	—	0.923	0.984	0.972	0.986	0.983
C.V	—	2.636	3.542	1.677	2.824	5.801

d. Viscograph properties of wheat flour dough containing gum Arabic

Source of Variation	Degree of Freedom	Pasting temp	Peak Viscosity	Min Viscosity	Final Viscosity	Breakdown	Setback
Sample	5	4.352**	2124.22***	783.633***	8622.14***	338.133***	4211.653***
Rep	4	1.508	12.133	2.867	49.033	4.117	29.133
Error	20	0.866	13.553	5.967	69.573	5.317	38.153
R²	—	0.616	0.975	0.971	0.969	0.941	0.965
C.V	—	1.321	4.714	5.473	5.158	6.89	5.276

f. Farinograph properties of wheat flour dough containing gum Arabic

ANOVA								
Source of Variation	Degree of Freedom	D.DEV.T	CONSISTENCY	WAC	S	M.T. I	F.Q. N	T.B. D
Treatment	5	27.76 ***	136.213 ^{NS}	0.321 *	11.265 ***	414.993 ***	3085.34 ***	33.914 ***
Rep	4	0.025	25.250	0.025	0.027	1.917	3.450	0.026
Error	20	0.020	79.930	0.062	0.049	7.877	22.090	0.089
R²	—	0.997	0.329	0.577	0.983	0.930	0.972	0.990
C.V	—	4.051	1.798	0.419	2.587	9.733	5.182	3.300

g. loaf specific volume of bread containing gum Arabic

Source of Variation	Degree of freedom	L.W	L.V	S. V	
Treatment		4	4093.61***	34963.43***	0.42***
Rep		4	14.89	189.83	0.00
Error		16	6.47	326.88	0.00
R²	—		0.99	0.96	0.98
C.V	—		0.64	1.35	1.46

h. textural profile analysis of bread containing gum Arabic


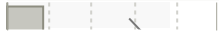


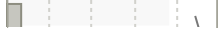
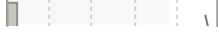
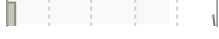
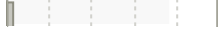
Source of Variation	Degree of freedom	Springiness	Cohesiveness	Gumminess	Chewiness	Resilience
Sample	4	0.003***	0.0068***	316599.784***	215127.967***	0.000***
Rep	4	0	0	7085.017	5519.65	0
Error	16	0	0	5096.262	3494.483	0
R ²	—	0.767	0.791	0.941	0.94	0.755
C.V	—	1.807	4.017	9.45	9.303	5.007

i. textural analysis of Chapati containing gum Arabic

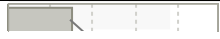

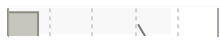
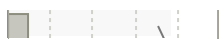
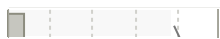

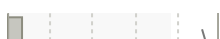
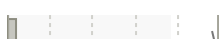

Source of Variation	Degree of freedom	Firmness
Treatment	4	71919.751***
Rep	4	450.88
Error	16	577.476
R ²	—	0.969
C.V	—	2.606

Appendix VII: Screen plots

a. for bread

Number	Eigenvalue	
1	3.331389	
2	1.324873	
3	1.163104	
4	0.789084	
5	0.557626	
6	0.353141	
7	0.281183	
8	0.199600	

b. for Chapati

Number	Eigenvalue	
1	2.715113	
2	1.530504	
3	1.303897	
4	0.843883	
5	0.678046	
6	0.656230	
7	0.592598	
8	0.357014	
9	0.322716	

Effect of Gum Arabic from *Acacia senegal* var. *kerensis* as an Improver on the Rheological Properties of Wheat Flour Dough

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Abstract

Dough improvers are substances with functional characteristics used in baking industry to enhance dough properties. Currently, the baking industry is faced with increasing demand for natural ingredients owing to increasing consumer awareness, thus contributing to the rising demand for natural hydrocolloids. Gum Arabic from *Acacia senegal* var. *kerensis* is a natural gum exhibiting excellent water binding and emulsification capacity. However, very little is reported on how it affects the rheological properties of wheat dough. The aim of this study was therefore, to determine the rheological properties of wheat dough with partial additions of gum Arabic as an improver. Six treatments were analyzed comprising of flour-gum blends prepared by adding gum Arabic to wheat flour at different levels (1%, 2% and 3%), plain wheat flour (negative control), commercial bread flour and commercial *chapati* flour (positive controls). The rheological properties were determined using Brabender Farinograph, Brabender Extensograph and Brabender Viscograph. Results showed that addition of gum Arabic significantly ($p < 0.05$) increased dough development time (1.44 - 6.45 minutes), water absorption capacity (59.34% - 59.96%), stability (6.34 - 10.75 minutes), mixing tolerance index (12.00 - 35.80), Farinograph quality number (48.60 - 122.20) and time to breakdown (4.33 - 12.05 minutes). However, there was no significant effect of gum Arabic addition on dough consistency (490 - 505 BU). In extensograph properties, energy was significantly ($p < 0.05$) higher in wheat flour containing 2% gum Arabic (108.44 cm²), while extensibility was significantly higher in wheat flour containing 3% gum Arabic (153.11 mm). Gum Arabic significantly ($p < 0.05$) decreased all the Viscograph parameters apart from the pasting temperature (69.82°C - 71.68°C). The findings of this study show that gum Arabic significantly ($p < 0.05$) enhanced the rheological properties of the dough.