

**ANALYSIS OF THE IMPACT OF GUM ARABIC FROM *Acacia senegal* var. *kerensis*
ON THE TECHNO-FUNCTIONAL PROPERTIES OF MAIZE AND CASSAVA
FLOURS AND STARCHES**

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for the Doctor of Philosophy Degree in Food Science of Egerton University**

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DECLARATION AND RECOMMENDATION

Declaration

This Thesis is my original work and has neither, wholly or in parts been presented nor concurrently been presented for the conferment of any degree in Egerton University or any other institution.

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DEDICATION

This thesis is dedicated to my spouse-Isaac, children, siblings and my parents the late Mr. & Mrs. Solomon Kiprop Cheptoo.

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ABSTRACT

Chemical, enzymatic, physical or natural modification of starches and flours of food crops to achieve particular, intended functional qualities is a common protocol in food processing. Unmodified flours and starches display limited functionality due to low resistance to shear stress, decomposition upon heating and high deterioration rate when subjected to different processing conditions. Hydrocolloids are currently being utilized to modify starches and flours due to the market demand for natural, safe and economical food ingredients. This study aimed at examining the effect of utilizing gum Arabic (GA) from *Acacia senegal* var. *kerensis* on the techno-functional qualities of cassava and maize flour and starch. Milled GA powder was substituted in both starch and flour of maize and cassava at 0 %, 0.5%, 2.0 %, 4.0 %, 6.0 % and 8.0 % g/g based on dry weight. The starch/flour-gum mixtures were analyzed for pasting properties using a Brabender Viscograph-E[®] at 85 rpm and 700cmg torque, textural properties were measured using Texture Analyzer[®] and the data analysed at 95% confidence level. The findings revealed that increasing the level of GA significantly decreased peak viscosity, final viscosity, breakdown and setback values in both maize and cassava starches. However, there was no significant effect of GA on the pasting temperature 71.8-72.1°C for maize starch and 68.7-68.9°C for cassava starch. Increasing the level of GA (0 % to 8%) in both cassava and maize flours significantly decreased the peak, final and setback viscosities. The breakdown viscosity of cassava flour reduced significantly (426 to 262 BU) while maize flour recorded a zero breakdown (7.5 to 0 BU). Unlike in starches, the pasting temperature in flours significantly decreased with increasing gum levels 64.2-63.6°C and 87.1-84.9°C for cassava and maize flour respectively. The degree of gel firmness (894g) and consistency (21060gs) was significantly greater in native maize starch than in native cassava starch (89g and 2095gs respectively) however as the levels of gum increased from 0.5 to 8% there was a significant reduction on the firmness and consistency of maize starch gels as compared to cassava starch gels that showed no marked difference. Increasing the level of GA substitution in both starches significantly decreased the bulk density but significantly increased water solubility index, swelling capacity, absorption index and water holding capacity (WHC) but no significant difference was observed for WHC in both flours. These findings demonstrate that gum Arabic can be used to modify flours and starches for specific applications in the food industry. This is the first time this type of empirical data is being reported on the techno-functional properties of maize and cassava starches and flours containing GA from *Acacia Senegal* var *kerensis*.

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LIST OF ABBREVIATIONS, ACRONYMS AND SYMBOLS

AG	Arabinogalactan
AGP	Arabinogalactan Protein Complex
ALC	Amylose Lipid Complex
AM	Amylose
ANOVA	Analysis of Variance
AP	Amylopectin
A/BE	Abbe Back extrusion
BD	Bulk density
Bd	Breakdown
BU	Brabender Units
C	Consistency
CaS	Cassava starch
MS	Maize starch
CPV	Cool Paste Viscosity
°C	Degree Celsius
DSC	Differential Scanning Calorimetry
FAO	Food and Agriculture Organization of the United Nations
GA	Gum Arabic
GC-MS	Gas Chromatography-Mass Spectrophotometry
GP	Glycoprotein
GRAS	Generally Recognized as Safe
KEFRI	Kenya Forestry Research Institute
HSD	Honestly Significant Difference
HPV	Hot Paste Viscosity
MLR	Multinomial Logistic Regression
MOALF	Ministry of Agriculture, Livestock and Fisheries
MVAG	Microvisco-Amylograph
OPT	Onset Pasting Temperature
PV	Peak Viscosity
Rg	Radius of gyration
rpm	Revolutions Per Minute

RVA	Rapid Visco-Analyzer
SAS	Statistical Analysis System
SB	Set Back
SSSEA	Soil Science Society of East Africa
TA	Texture Analyzer
<i>T_c</i>	Conclusion Temperature
<i>T_o</i>	Onset Temperature
<i>T_p</i>	Peak Temperature
<i>ns</i>	Not significant
µm	Micro meter
UK	United Kingdom
Var	Variety
WAI	Water Absorption Index
WSI	Water Solubility Index
WOC	Work of Cohesion
WHO	World Health Organization
XRD	X-ray diffraction

CHAPTER ONE

INTRODUCTION

1.1 Background Information

Maize (*Zea mays*) is one of the cereals with global importance. Commercial and industrial uses for maize grain exist in addition to its usage in human nutrition (Rubi, 2009). In Kenya, approximately 3.5 million small-scale farmers are involved in maize production accounting for 75% of the total maize crop while 1,000 large-scale farmers produce the remaining 25% of the total production. Although maize production in Kenya fluctuated substantially in recent past years, it tended to increase through 1970 - 2019 period ending at 3.4 million metric tonnes in 2019 (SSSEA, 2019). Wet milling, dry milling and nixtamalization are the three basic methods generally used to process maize grains industrially into value-added products leading to production of maize flour and maize starch among other products (Kaushal *et al.*, 2022). Maize starch mainly contributes up to 85% of the world starch requirements (Abotbina *et al.*, 2021; Bertolini, 2010). Starch being a major polysaccharide is a food ingredient that affects the texture, appearance and product shelf-life (Zhang *et al.*, 2010).

Another major source of starch in the world is cassava (*Manihot esculenta Crantz*). The amount of cassava produced globally was 278 million metric tonnes in 2018 and the Food and Agricultural Organization of the United Nations (FAO) projects that by the year 2025; about 62% of global cassava production will be from sub-Saharan Africa (Verma *et al.*, 2022). Being a climate smart crop, cassava has gained immense attention in Africa due to its significant contribution in addressing food insecurity. Currently, Kenya produces approximately 3.68 million metric tonnes of sweet potatoes, cassava, cocoyams, yams and irish potatoes. This is way below the country's potential (MOALF, 2019). Cassava is the second most extensively grown root crop in Kenya after Irish potatoes. Kenya has the potential to generate around two million metric tons of cassava per year. However, this yield has not been realized because current production of cassava is primarily on a smallholder basis mainly for domestic use (Opondo *et al.*, 2020). There has been a lot of focus on cassava due to its high productivity with substantial starch yield which accounts up to 30% of the fresh root and / or up to 80% of the root dry matter and high clarity (Nuwamanya *et al.*, 2010). The cassava flour diet may be augmented with cereal flours from maize, sorghum or millet during the preparation of traditional food to ameliorate the

food product's flavor and texture (Osungbaro *et al.*, 2010). According to Olatidoye *et al.* (2020) research is being done on partially substituting cassava flour for wheat flour when making bread, which will lower the high cost of importing wheat and enhance the usage of food crops that are readily available locally.

Heating an aqueous suspension of starch granules above a certain temperature, the granules undergo an irreversible order-disorder transformation where granule structure collapses via a process referred to as gelatinization (Wang *et al.*, 2018). The enthalpy change (ΔH) indicates fundamentally the disruption of long-range starch structural order during heating. Retrogradation is the process by which the disintegrated starch chains eventually reorganize into semi-ordered structures that differ from those of the original granules upon being cooled. Reducing or delaying the retrogradation process should receive a lot of attention because it frequently has a negative impact on the quality of goods high in starch. These events are often observed by use of pasting profiles and thermal analysis studies (Wang *et al.*, 2018; Wang *et al.*, 2016). Since gelatinization process is used largely in the food industry, the rapid determination of its parameters is extremely useful in process and product development as well as enhancing process efficiency (Bertrand *et al.*, 2019). Starch has distinctive thermal properties and functionality that have allowed its extensive use in various food products and industrial applications (Damodaran *et al.*, 2008). Reports indicate that native/ unmodified starches are limited in their application as their pastes are unstable with the changes of temperature, pH and food conditions hence they are likely to deteriorate and disintegrate (Hussain, 2015). Also, unmodified starches do not dissolve in water, are resistant to enzymatic breakdown and lose their functional properties easily. Therefore, in order to meet the current industrial demands native starch properties are improved by subjecting to various methods of modification. Special qualities like solubility, texture, adhesion, stability, and heat resistance to industrial temperature procedures are frequently present in modified starches (Sabounchi *et al.*, 2021).

Hydrocolloids are high molecular water soluble macromolecules. Different types of hydrocolloids are used to modify the pasting, physical and thermal properties of various native starches. This has been prompted by the expanding market need for affordable, secure and organic food ingredients (Hussain, 2015). Among the hydrocolloids; guar gum, locust bean gum,

alginates, carrageenan, gum Arabic and xanthan gum are most frequently employed as stabilizers and thickeners in the food sector (Šubarić *et al.*, 2011). An edible substance called gum Arabic (GA), which is a hydrocolloid, is exuded from the branches and stems of Acacia trees. Soluble fiber is abundant in the gum (Dauqan & Abdullah, 2013). Because of its strong solubility and ability to withstand acids, GA has the ability to be incorporated in various products including confectionery to improve productivity, durability, texture, retard sugar crystallization and extend the shelf life (Yadav *et al.*, 2007). Kenya is well known to be bestowed with trees that yield a substantial amount of gum however it exports only small amounts of gum. Approximately 400 metric tonnes (per annum) of gum Arabic is currently produced in Kenya (with an annual export value of USD 50 million) against a production potential estimated at 12,000 metric tonnes. <https://selfhelpafrica.org/ie/gumacacia/#> Accessed on 16th July 2024.

Functional and physicochemical properties have been shown to primarily influence the industrial application of flours (Falade & Okafor, 2015). Techno-functional attributes that are desired of cassava starch and flour have been shown to influence a lot their application in food product development and formulations (Chisenga *et al.*, 2019). According to Bashir and Aggarwal (2019) using biopolymers for modification of various characteristics of starch including water binding capacity, emulsion stability, swelling capacity, foaming capacity, bulk density, oil holding capacity is considered as an inexpensive, readily available and safe option for food production.

The present worldwide tendency of addressing the security of food and nutrition in relation to developing concerns and global economics served as the basis for this study. Using locally accessible, underutilized tree exudates with industrial value is becoming popular in order to satisfy customer demand for more natural ingredients. Prior research has demonstrated that the rheological and structural properties of starch and flour are altered via the addition of a hydrocolloid (Aboukzail *et al.*, 2017). Hydrocolloids have been widely used as additives to provide usefulness in the food sector because of their large molar mass and water-soluble characteristics. Not only do they increase the mouthfeel, flavor, and texture of items, but they also raise the overall quality of the final goods to satisfy production costs (Krstonošić *et al.*, 2019).

Past research efforts had been focused to clarify the role and potential usefulness of hydrocolloids in modifying the rheology and texture of starch-based food products (Alam *et al.*, 2009; Leite *et al.*, 2012). Addition of gum to brown rice batter modified the thermal and rheological properties in different ways based on the type and percentage of gum used as reported by Aboukzail *et al.* (2017). Thus, the objective of this research was to investigate the impact of gum Arabic from *Acacia senegal* var *kerensis* on native starches and flours for possible utilization in food production and processing as a binder and modifier for the improvement of native flour and starch characteristics.

1.2 Statement of the Problem

Industrial application of native starches and flours for different uses in foods is hampered due to breakdown, syneresis and loss of original texture inherent to the formulation and preservation of foods based on starch. Despite the versatility of native starch, it is faced with technical challenges or structural shortcoming hence ways to address such limitations becomes necessary. This has led to the search for ingredients which could be useful in modifying their functional properties in order to enhance application. Foods rich in starch are usually heated and cooled many times when they are not consumed. The starch retrogradation process, which is mostly responsible for the starching of bread and other starch-rich foods, is thought to have adverse effects, and such temperature-cycled treatment is expected to accelerate it. Consequently, there will be less consumer acceptance and shelf life, which will result in huge waste and result in major issues for food processors. This result to significant waste thereby posing major challenge to food processors as well as household food security. To withstand the rigors of manufacturing and improve the qualities of the finished product, modification is necessary. Therefore, to prepare food products with ideal properties, native flours and starches are commonly modified by either physical, chemical or enzymatic means. However, these methods have shortcomings including high cost and toxicity issues hence the need for clean label additives. Gum Arabic is generally recognized as safe additive with no aftertaste, it is also well known to possess special emulsifying and stabilizing properties hence ideal for starch and flour modification. Thus, the current study's objective was to investigate the role and potential usefulness of gum Arabic from *Acacia senegal* var. *kerensis* in pasting and physical modification of cassava and maize flours and starches. A thorough understanding of flour and starch pasting and texture is needed in order

to control its property functionality for food processing and can enhance new product development possibilities.

1.3 Objectives

1.3.1 General Objective

To generate data on the techno functional properties of maize and cassava flours and starches containing gum Arabic from *Acacia senegal* var. *kerensis* that could have a potential impact on food security.

1.3.2 Specific Objectives

- i. To determine the effect of gum Arabic levels on the pasting properties of maize and cassava flours and starches.
- ii. To determine the effect of gum Arabic levels on the textural properties of maize and cassava flours and starches.
- iii. To determine the effect of gum Arabic levels on the physical properties of maize and cassava flours and starches.

1.4 Hypotheses

- i. There is no significant effect of gum Arabic levels on the pasting properties of maize and cassava flours and starches.
- ii. There is no significant effect of gum Arabic levels on the textural properties of maize and cassava flours and starches.
- iii. There is no significant effect of gum Arabic levels on the physical properties of maize and cassava flours and starches.

1.5 Justification

The growing market demand for natural, safe, affordable, and clean-label food ingredients has led to a greater focus on and understanding of valuable natural sources of complex carbohydrate polymers, especially gums, which support the desired texture, quality, stability, and appearance of food products. Gums have been shown to offer substantial technological improvements in starches and flours (Sanchez *et al.*, 2002). According to reports, starch accounts for up to 90% of calories consumed on average in underdeveloped nations and more than 50% in western countries (Wang *et al.*, 2015). Desirable functional properties of flours and starches have been

shown to greatly influence their application in food product formulations and development. The use of starch in food is nearly universal e.g., as a thickener for soups, sauces, gravies, baby foods and pudding, as well as an ingredient for cakes, jellies, confectioneries, breads, noodles, canned and frozen foods (Bertrand *et al.*, 2019).

More efforts should be focused on utilization of natural ingredients to alter different flour and starch characteristics to satisfy growing consumer expectations and GA from *Acacia senegal* var. *kerensis* is a good option due to this beneficial attribute. By utilizing the gum, its industrial range of application is increased and the livelihood of the farmers growing this polymer is also improved. The study findings are critical as it could be used to inform policy especially at the County level on the importance of the gum. Owing to the special characteristics exhibited by GA including high solubility, low viscosity, low toxicity and desirable emulsifying properties, it is considered as one of the most widely used polysaccharide in the food industry particularly as stabilizer, thickener, emulsifier and film-forming and suspending agent (Patel & Goyal, 2015). The use of blends of flour and starch and gum has an economic benefit especially in developing countries like Kenya as it contributes to the reduction of the huge burden on importation of wheat flour and encourages use of locally grown crops as flour for various food production and industrial processes.

The current study establishes the impact of GA on functional characteristics of cassava and maize flours and starches hence outlining a protocol that could be embraced by the food industry. The study also could encourage the application of GA from *Acacia senegal* var. *kerensis* during cooking and processing of the said flours and starches hence enhance their applications in food preparation and during product development. Remarkably, this study is important in achieving Kenya Government's agenda on attaining 100% food and nutrition security by 2030. It helps in achieving the United Nations sustainable development goals (SDG) 2 that focuses on ending hunger, achieving food security and improved nutrition as well as promoting sustainable agriculture. Published work from this research study provides information for researchers working on this or related area of study.

1.6 Limitation of the study

This research focused on *acacia senegal* var. *kerensis* gum (hydrocolloid) as well as maize and cassava flours and starches. Within Kenya's dry and semi-arid regions, *Acacia senegal* cultivars

proliferate in regions receiving 200–800 mm of rainfall annually and high temperatures. Gum acacia have been reported to play a crucial function in dryland farming systems of biological nitrogen fixation, which restores the fertility of deteriorated soils. The gum from the variety *kerensis* was used without further purification. The study focused only on examining the effects of incorporating GA on pasting, textural and selected physical properties of the aforementioned flours and starches at substitution levels up to 8%.

1.7 Definition of Terms

Birefringence is a characteristic exhibited by starches in native form which tend to split rays of a polarized light into two that normally corresponds to their crystalline structure.

Hydrocolloids are macromolecules with a high molecular weight that dissolve in water, they have great affinity for water and thus by binding a large amount of water results to modification of the rheology of the watery systems they are introduced to.

Maltose cross is a central dark area that is seen in crystals and starch grains. These regions are transparent to the crossed polarized light and one is seeing the background through the crystals.

Modification of starch involves altering its structure by either physical, chemical, enzymatic or by use of additives. Modification processes augment the properties of native starch by enhancing their techno functional characteristics and morphological attributes thus expanding the industrial value (Saboonchi *et al.*, 2021).

Native refers to products in their natural, unmodified state, without any chemical alterations or processing beyond what is naturally occurring.

Setback is an indicator of the cooked flour's propensity to solidify upon cooling as a result of amylase retrogradation (Adeniyi *et al.*, 2010).

Retrogradation is a process that occurs when disaggregated starch chains gradually assemble into semi-ordered structures that are distinct from those in native granules during the chilling process.

CHAPTER TWO

LITERATURE REVIEW

2.1 Starch Chemistry

Starch, a storage carbohydrate in plants, is a major food supply for humanity. It develops as semi-crystalline granules in the form of seeds, rhizomes, roots, and tubers, each of which has special qualities. The components of starch are amylose and amylopectin, which are present in the form of granules of varying sizes and shapes, some degree of crystallinity, and amorphous aligned layers with a birefringence pattern (Maizeejo-Ramírez *et al.*, 2018). When native starch is observed in a polarized light using an optical microscope usually a maltese cross / birefringence pattern is often seen extending the 'arms' from the hilum generally assumed to be the start of growth of the granule (Figure 2.1) (Bertoft, 2017). It has been observed that the chemical makeup and component arrangement of starches varies throughout sources, which affects their thermal properties (Maizeejo-Ramírez *et al.*, 2018). The manufacture of starch occurs as a result of amylose and amylopectin the two polymers that differ in structure. The linear polymer (amylose) is composed of units of D-glucose linked through α -D- (1-4) linkages while amylopectin (branching polymer), is composed of α -D- (1-4) linked glucose segments containing glucose units in α -D (1-6) branches (Bertolini, 2010). Both macromolecules account largely for the functionality of starch during industrial processing and cooking.

Amylopectin is the predominant component by weight, on the other hand amylose makes up roughly 15-30% of the weight of most typical starch granules, there are some exceptions. Waxy starches as the name denotes have waxy appearance of the endosperm in waxy cereals hence consist of very little or no amylose content (Bertoft, 2017). The precise arrangements and proportions of amylose and amylopectin molecules influence the formation of a starch granule (Alcázar-alay & Meireles, 2015). The zones of starch granules which are crystalline are a result of the linear branches of amylopectin patterns and produce specific X-ray diffraction (XRD) patterns which designate a series of about 9 nm to 10 nm within the structure of the granule. They have been reported to be key in the recognition of various plant sources of starches (Magallanes-Cruz *et al.*, 2017; Perez & Bertoft, 2010). The degree of structural order of starch granules in native state usually range from 15% to 45% and therefore these granules show a maltese cross when observed under polarized light as reported by Perez and Bertoft (2010).

Figure 2.2 show the two main types of XRD diagrams exhibited by the granules; the A type normally revealed by cereal starches and the B type for tuber and amylose - rich starches. Most legume starches and also from cereals grown in specific conditions of temperature and hydration are characterized by C-type (Vh) diffraction diagram, which has been shown to be a mixture of A and B type diagrams (Buleon *et al.*, 1998).

Research has shown that the structural characteristics of A type and B type starch crystallites may be compared at the molecular level. The double helices in these starches are left-handed, almost perfectly six-fold structures, with a crystallographic repeat distance of about 1.05 nm. As a result, it is also thought that a key component influencing the general granule qualities is the crystal shape. In contrast to starches with the B-type crystal form, which exhibits a reverse order, the authors found that the gelatinization temperature in starches with the A-type crystal form typically tends to increase with increasing overall crystallinity of the granule (Buleon *et al.*, 1998).

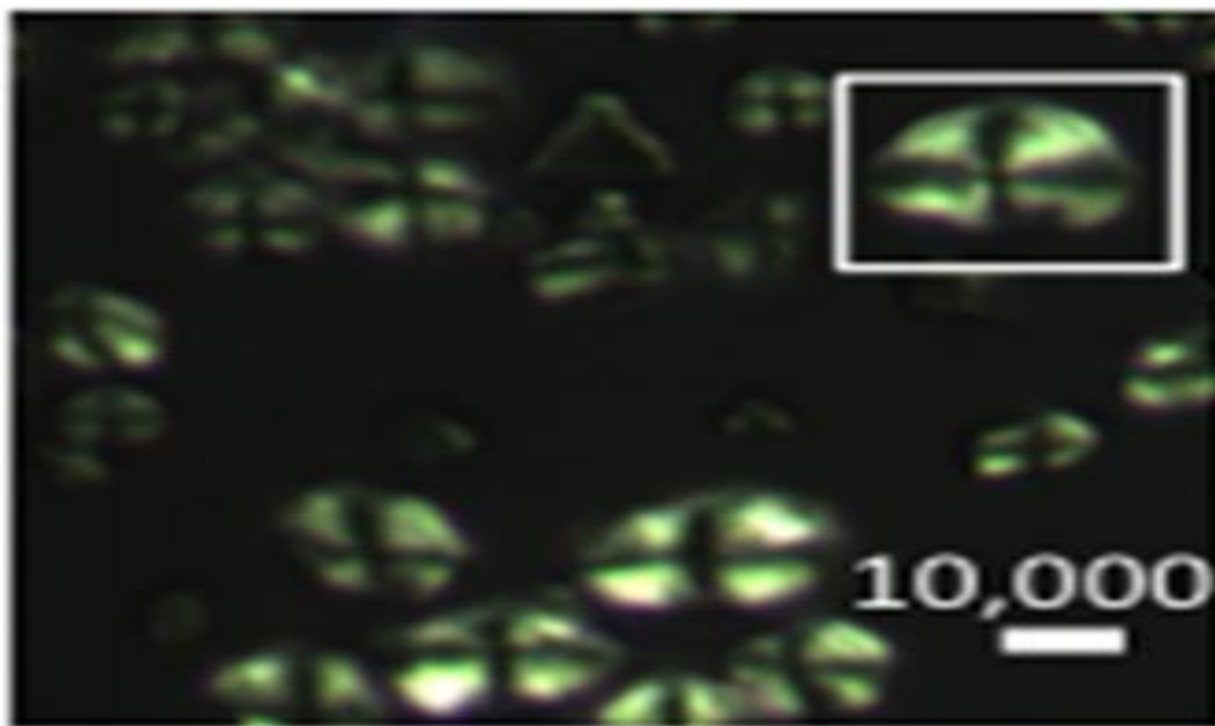


Figure 2.1: Under polarized light, maize starch granules display the "Maltese cross," a sign of a radial arrangement within the starch granule

Source: Bertoft (2017)

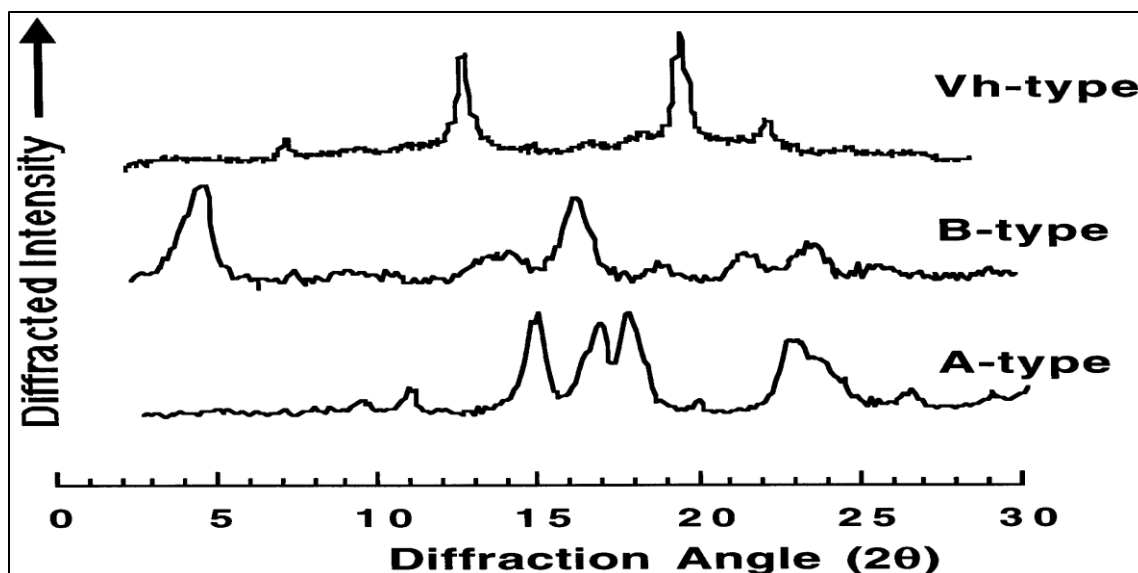


Figure 2.2: X-ray diffraction diagrams of A-, B- and Vh-type starch

Source: Buleon *et al.* (1998)

The pasting characteristics of starch are influenced by the various physical and chemical features of amylose (AM) and amylopectin (AP), each of which plays a unique role. This has been linked to the fact that starch granules with high amylose content display high levels of deterioration and absorb very little water content during cooking whereas for the waxy starches (high amylopectin content) denote high peak viscosity and not prone to high retrogradation (Magallanes-Cruz *et al.*, 2017). To create structures with certain functions, researchers have examined the chemistry of starch and altering technologies due to the relationship between structure and functionality (Bertolini, 2010).

In spite of the fact that starch is a great ingredient to change the consistency and texture of food. It has been demonstrated that the molecular architectures and makeup of the starch or flour affect its functionality. This comprises of amylose/amylopectin ratio, phosphorus content, starch molecular weight, granule size and the chain length distribution (Fallahi *et al.*, 2016). The use of knowledge pertaining the physical chemistry of starch is in modifying component interactions hence phase behaviour and dynamics that determine starch contribution to food structure and ultimate quality.

2.2 Effect of Starch Structure on Thermal Properties

Recent research have shown that the relationship between the structural traits and functional qualities of starches from various botanical sources has consistently provided essential information for optimizing industrial applications (Bashir & Aggarwal, 2019; Egharevba, 2019). Series of events that occur when starch granules are heated in water and are associated with changes in the swelling power, viscosity and gelatinization capability, which are often found near the starch supply and are in responsible of the gel lattice structure's creation. Those changes do occur in cooking as well as during industrial process where flour or starch is used as the raw material therefore it is imperative to comprehend the influence of starch structural characteristics on the thermal properties during heating processes (Maizeejo-Ramírez *et al.*, 2018). The rheological characteristics of starch pastes and gels have been demonstrated to be significantly influenced by the ratio of amylose to amylopectin (BeMiller & Whistler, 2009). According to Nawaz *et al.* (2020) and Tako *et al.* (2014) hydrogen bonding may lead to the intermolecular connection between the O-6 of amylose and the OH-2 of amylopectin molecules (Figure 2.3).

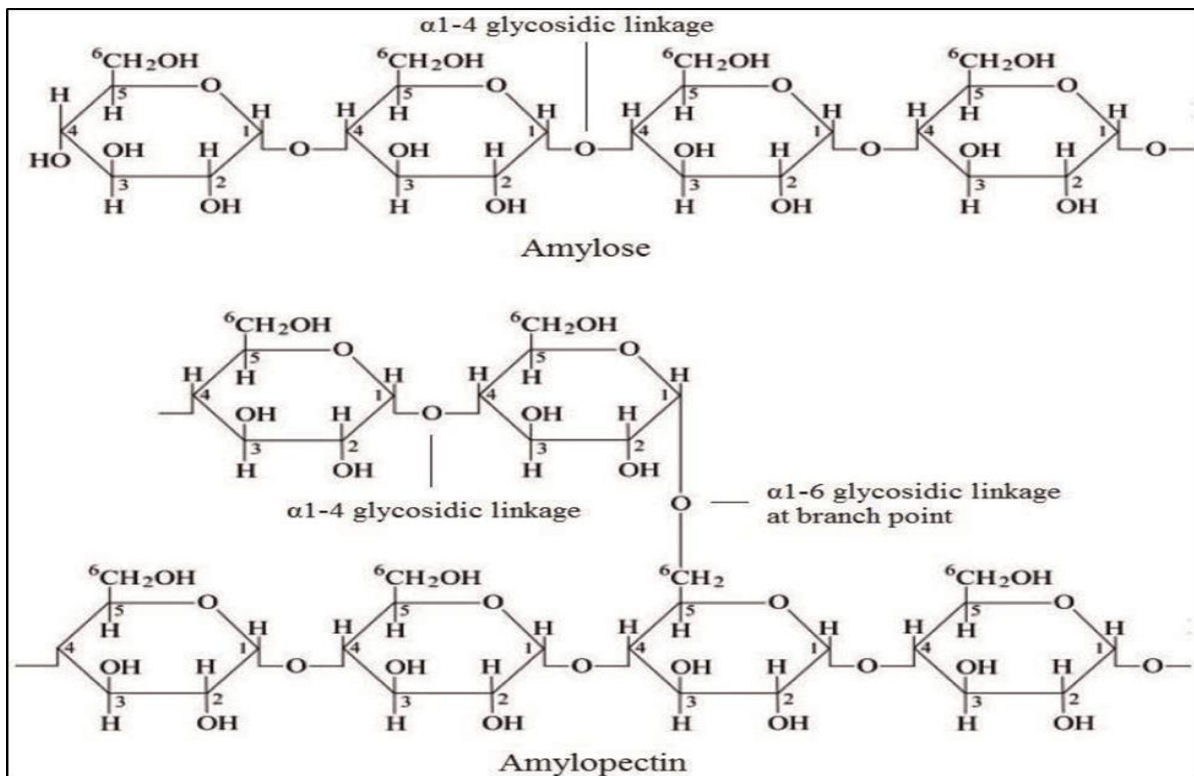


Figure 2.3: Structure of Amylose and Amylopectin

Source: Nawaz *et al.* (2020)

Amylopectin is also the principal constituent responsible for the swelling capacity and viscosity development of the starch paste after the starch granules are gelatinized and expand. The presence of very long branches in amylopectin molecule has been reported to significantly affect the pasting characteristics of starch. Waxy cereal starch exhibits a lower pasting temperature as compared to their normal starch counterpart due to lack of amylose and amylose lipid complex (ALC) in the former (Ai *et al.*, 2013). The unique feature can be attributed to the fact that the long branch chains of the starch associate with one another to prevent the scattering of starch granules as well as the viscosity breakdown (Zhu & Xie, 2018).

When held for an extended length of time, amorphous starch molecules in the aqueous media often recrystallize to form double-helical crystallites and lose their ability to bind water. This phenomenon is referred to as starch retrogradation or deterioration that commonly occur when bread stales and the separation of water from soups and sauces with starch as the thickener (Ai *et al.*, 2013). This process is generally enhanced by increasing the following aspects (i) levels of starch in the paste (ii) the amylose content (iii) the branch chain length of amylopectin then storing the starch paste at a temperature of 0 - 5°C (Wang *et al.*, 2015). Normal cereal starches produce a paste or gel that tends to have a greater affinity for retrogradation than that from tuber and root starches. This observation can be explained by the usual cereal starch granules' modest swelling, which allows starch chains to be close to one another for improved retrogradation (Ai *et al.*, 2013).

According to reports, the branched structure of amylopectin with short branch chains means that it takes several days or months for the retrogradation of amylopectin polymer to produce crystallites with a low dissociation-temperature of roughly 40°C to 60°C. In contrast, the linear shape of the amylose molecules causes them to retrograde more quickly and form crystallites with a higher dissociation temperature of roughly 130°C to 170°C (Ai *et al.*, 2013; BeMiller & Whistler, 2009). Elimination of water and syneresis may occur as seen in certain products such as jam and jelly when there is a slow increase in the interaction between hydrophilic polymers with time (Chandel *et al.*, 2022). Syneresis has been shown to be caused by difference in osmotic pressure between the matrix of the polymer and the surrounding solution. According to Damodaran *et al.* (2008) the pastes of common native maize starch will harden and the

corresponding gels generally will be rubberlike, cohesive and mostly prone to moisture exudation (syneresis).

2.3 Functional Properties of Starch in Foods

Functional properties have been defined as those parameters that determine the selection of starches for different applications as well as the end use of food materials for various food products (Ubwa *et al.*, 2012). According to reports, variations in swelling power, viscosity, and gelatinization capacity can affect how well starch granules interact with water and hydrate the resultant mixture at high temperatures. These effects can differ based on the source of the starch (Maizeejo-Ramírez *et al.*, 2018). Commonly those changes do occur in cooking and industrial process where flour and starch are utilized as the raw materials hence it is important to understand the effect of adding GA on the functional characteristics of selected flours and starches. Gum Arabic, a hydrocolloid, is expected to interfere with the ionic interactions and bond linkages in the presence of water. Because of this, the metabolic reactions that occur in the flours and starches are disturbed in their proper sequence.

Generally, in theory gelatinization refers to an irreversible process that result to splitting of the intermolecular bonds of starch molecules when subjected to high heat and moistened condition. This has been shown to greatly impact the rheological characteristics such as the supposed viscosity and thus the functionality of the materials being manufactured. Changes in starch can be facilitated by its capacity to hydrate and swell and as a matter of fact an increase in viscosity (η) as a result of gelatinization has been attributed to be the main purpose of the utilization of starch in various applications (Fallahi *et al.*, 2016). The ability of starch to dissolve in water in presence of heat, swell, produce a viscous paste and the amount of amylose leaching out during gelatinization are pertinent factors that indicate the importance of starch properties (Bertolini, 2010; Maizeejo-Ramírez *et al.*, 2018).

Flour and starch functional properties are vital in various aspects in food production such as for moisture control, viscosity, texture, uniformity, stability, mouth-feel and durability of the final products (Wang *et al.*, 2018). The structure of amylose and amylopectin starch polymers at a molecular level and their environmental interactions during gelatinization and retrogradation processes determine starch functionality. It has been reported that starch solutions can be stored

at 4°C and 25°C for a day leading to occurrence of retrogradation after the formation of new intermolecular hydrogen bonding (Tako *et al.*, 2014).

The structural, physical, chemical and functional properties of native starch have been documented to be impacted by a number of variables, including high pressure and temperature, high or low acidity, mechanical stress, phosphates, synthetic polymers, and some cationic compounds (Damodaran *et al.*, 2008; Nawaz *et al.*, 2020). Treatment of starch using heat in aqueous medium as reported by Nawaz *et al.* (2020) has been found to cause transformation of amorphous state of starch to crystalline form leading to gelatinization of starch. Also starch properties are altered when it interacts with water and oil; breakdown of the bonds linking amylose-amylopectin occurs when it absorbs water, can also lead to loss of crystalline nature and swelling of starch granules. The aforementioned factors have aided in the enhancement of starch functional quality to yield better results while being used in diverse food and industrial production (Nawaz *et al.*, 2020). Elkhalfa *et al.* (2007) found that the addition of guar gum and gum Arabic in different concentrations improved the functional properties of sorghum flour. Furthermore, it has been shown that blending of hydrocolloid with wheat and high-quality cassava flour has a significant effect on the functional and pasting properties of bread (Dudu *et al.*, 2019; Olatidoeye *et al.*, 2020).

2.4 Starches and Flours of Choice

The structure and properties of starch are crucial for quality of the food products. Starch has been widely utilized as an important industrial ingredient for many diverse applications. Starches with industrial significance have been reported to be majorly from maize, potato, cassava, wheat and rice (Yazid *et al.*, 2018). Maize has been demonstrated to be the cereal with the highest production worldwide utilized primarily for human consumption and for industrial purposes (Rubi, 2009). Cassava is a major root crop attributed to food security across sub-Saharan Africa (Githunguri *et al.*, 2017). In Kenya, Maize and cassava flour are commonly used to produce indigenous foods including porridge and *Ugali*. The maize starch granule polyhedral shape and diameter is between 5µm and 25µm. The granule size correlates with some physicochemical and functional properties of the starch molecule. These may include temperature and enthalpy, gelatinization, paste clarity, retrogradation and syneresis, enzymatic susceptibility, paste viscosity, gel properties, solubility and swelling power (Alamri *et al.*, 2012; Rubi, 2009). The

effect of maize flour on these functional properties is different from maize starch though very little information is available.

Starch from sources (such as rice and maize) with small granules have been reported to be difficult to gelatinize and this has been attributed to their more compressed structure at molecular level while tuber/root starch sources (such as potato and cassava) usually participate in gelatinization more readily and do exhibit more functional characteristics (Fallahi *et al.*, 2016). According to Fallahi *et al.* (2016) the lowest thermal stability was observed for the potato extrudate. Generally, it is expected that starches from cassava and potato can contribute better in the formation of a sticky structure and the generation of more enlarged extrudates. However, starch in its native form has restrictions in terms of structural functionality and industrial application and therefore to achieve the desired properties, modification becomes necessary (Zhu & Xie *et al.*, 2018).

The gelatinization temperatures of root and tuber starches are generally reported to be lower than those of cereal starches though reports indicate that the rheological properties of maize starch containing higher amylopectin content (waxy) closely resemble those of cassava starch (Horstmann *et al.*, 2017). It has been demonstrated that starches from roots, tubers and waxy cook readily to give greatly swollen and fragile granules which easily break down and weaken during stirring. The common cereal starches are associated to very slow cooking, lesser degree of swelling as well as exhibiting a moderate resistance against viscosity breakdown upon agitation. Studies have shown that maize starch pastes and maize solutions tend to retrograde relatively fast as compared to cassava starch that exhibits low tendency towards retrogradation (BeMiller & Whistler, 2009; Horstmann *et al.*, 2017). Chisenga *et al.* (2019) suggested that amylose content should be the primary basis for selecting flours or starches from different botanical sources for industrial applications. This is because starches with similar amylose contents exhibit similar functionalities, but, variations in the structural properties; starch granule size and crystallinity, degree of polymerization; chain length of amylopectin structures would likely induce differences in starch functionalities.

2.4.1 Maize Flour and Starch

Maize is the most important staple in Kenya that is grown across a wide range of agro-ecological zones accounting for about 40 percent of daily calories. Maize flours for food use have been characterized by a broad range of quality parameters (Rubi, 2009). In Kenya either flour or grain are the most common maize preparations used. According to Wafula *et al.* (2022) maize consumption in Kenya stands at 400 grams per person per day, with 98 kg annual consumption per capita. The major flour preparations include porridge which can either be soft (*uji*) or stiff (*ugali*) furthermore the main grain products are *githeri* and *muthokoi*. *Uji* (Swahili word for soft or thin porridge) refers to a kind of gruel typically eaten for breakfast which can be made from different cereal flours or their mixtures, usually maize with millet or sorghum and can either be fermented or not (Wanjala *et al.*, 2016). Maize is also used in production of both indigenous such as *busaa* and industrial alcoholic beverages (Middleton *et al.*, 2022; Wafula *et al.*, 2022).

Globally, the maize plant has been shown to be the primary source of commercial starches this is because maize starch represents more than 85% of global starch (Abotbina *et al.*, 2021). Various functional properties including dispersibility, water absorption capacity, retrogradation, viscosity, swelling power, solubility index among others determine the application of flour and starch in food production and in the industry, which may vary considerably based on the type of crop as well as the influence of ecology and agronomy (BeMiller & Whistler, 2009; Yazid *et al.*, 2018). The flour and starch composition and molecular structures such as the ratio of amylose/amylopectin, starch molecular weight, granule size, the chain length distribution and phosphorus content greatly impact on these functional properties (Oluwole *et al.*, 2016). Upon heating flours in excess water, the slurry rich in starch component transforms into porridge as a result of gelatinization of starch (Wanjala *et al.*, 2016). Oluwole *et al.* (2016) assessed a few functional properties of flours made from commonly consumed Nigerian food crops, such as millet, sorghum, rice, and maize. They discovered that each parameter studied by the flours' functional properties revealed a unique characteristic that could be useful for food application processes.

Maize is one of the most important grains in the world, its grain is utilized both for human sustenance and has numerous industrial uses (BeMiller & Whistler, 2009). The percentage of amylose and amylopectin ranges from 20% to 25% (amylose) and from 75% to 80% for

amylopectin. Research has indicated that the amount of amylose present in starch significantly affects its thermal, pasting, gelling, and digestive qualities. Because amylose molecules can entangle with amylopectin when lipids are present, this helps to keep starch granules coherent during heating and shearing. The high temperature of gelatinization (often conclusion temperature up to 130°C) that promotes the production of bigger starch granules is said to be caused by the presence of long-chain double-helical amylose crystallites in high-amylose maize starch (90% amylose) (BeMiller & Whistler, 2009; Zhu & Xie, 2018). According to Yazid *et al.* (2018) maize has been used to a great extent for the manufacturing of syrup, particularly high fructose corn syrup intended for industrial use. Maize is also a good source of starch for thickening agent particularly in infant formula. The physical characteristics of maize starch are significantly influenced by the presence of lipids in this starch. According to reports, the solubilization of potato and cassava starches is the highest, whereas that of maize starch is lower due to the presence of lipids that bind with the amylose molecule to form amylose-lipid complexes that prevent granule swelling (Ai *et al.*, 2013).

2.4.2 Cassava Flour and Starch

Cassava, sometimes referred to as tapioca, manioc, or yuca, is a versatile root crop that has become well-known in Africa. It is also a climate-smart crop that has significant economic value in reducing food insecurity. It is the second most widely grown root crop in Kenya after Irish potatoes. Studies have shown that Kenya has a huge potential to produce more than 2 million metric tonnes of cassava every year. However, this projected overall yield has not been realized and this has been attributed to the current status where cassava production is predominantly on a smallholder basis mainly for home consumption (Opondo *et al.*, 2020). Though it is produced in large quantities in Kenya's Western, Coastal, and Eastern areas, cassava is cultivated almost everywhere in the country, but it is only used for human consumption (Githunguri *et al.*, 2017).

Cassava produces relatively higher units of energy per hectare as compared to most tropical food crops. Worldwide cassava ranks fifth after wheat, rice, maize and potatoes though it comes second to Irish potato as an important source of food among the non-cereal crops. Cassava is key in the manufacture of gluten-free flour, animal feed, confectionary products as well as a substitute of sucrose in beverages. Furthermore, it is rich in gluten-free carbohydrates which help to prevent gluten intolerance and food allergies. Owing to the high amount of fiber content,

cassava is quite helpful in reducing cholesterol level. It is also a rich source of vital minerals including calcium, manganese, iron among others which are beneficial for pregnant women (MOALF, 2019).

Studies have shown high capability of cassava flour to be utilized as a raw material in the food industry and with this regard Nilusha *et al.* (2021) reported that there is dire need for characterization of cassava flour properties in order to ensure its efficient and diverse applications in industry. Extraction of starch from cassava root is relatively easier as compared to that of cereals (Costa *et al.*, 2018). In addition to the above qualities, cassava flour and starch are considered inexpensive products with unique and desirable physical, chemical, physicochemical, pasting and thermal properties. The versatility of cassava starch is not only highly demanded in the food industry but also for pharmaceutical use (Drunkler *et al.*, 2012; Yazid *et al.*, 2018). According to BeMiller and Whistler (2009), high molecular weight of its amylose in combination with low lipid and protein contents and low proportions of amylose (17%) makes cassava a distinct native starch suitable for direct use in food and industrial applications. For a considerable amount of time, cassava starch has been acknowledged as the preferred starch for making baby food due to its minimal taste contribution and physical attributes including stability and texture (Costa *et al.*, 2018).

According to Nuwamanya *et al.* (2010) starch comprises the main constituent of the cassava root and consequently plays an important role in its use as a food and commercial crop. The starch used may be altered such that it survives the processing conditions and improve the physical properties of the finished product. For the production of specialty products, it is also considered an excellent beginning material for modification. With special emphasis on its lack of flavor (bland) contribution to food systems, cassava starch is typically used as a thickening and stabilizer by other food applications, allowing for immediate detection of the flavor of the food itself (BeMiller & Whistler, 2009). In the food industry, the use of natural gums and starch in combination has been widespread (BeMiller, 2011).

2.5 Starch Modification

Cereals, root and tuber crops as well as legumes are the major sources of flour and starch utilized for human nutrition and industrial application. In native (unmodified) state, however, starch is rarely consumed as it displays limited functionality in the food industry which can be attributed

to low resistance to shear stress, disintegration upon heating, high deterioration rate and possible separation of liquid from a gel including poor solubility and processing behavior (Neelam *et al.*, 2012). Therefore, in order to meet the current industrial demands starch properties are improved by subjecting to various methods of modification. The main aim for this modification is to correct the aforementioned limitations and thus enhance its flexibility as well as fulfil the requirements or demands of the consumer (Kaur *et al.*, 2016; Neelam *et al.*, 2012). As starch is a naturally occurring polymer, it is typically used with food ingredients to prevent deterioration, extending their shelf life and improving their appearance. Starch functional value can be altered when subjected to hydrolysis by acids or/ and enzymes resulting in decomposition of the amylose and amylopectin polymers thus altering the surface structure and granules properties leading to starch modification. Modification processes can augment the properties of native starch by enhancing their techno functional characteristics and morphological attributes thus expanding the industrial value (Saboonchi *et al.*, 2021).

Modifications are generally achieved using several methods *vis-à-vis* physical means comprising treatments such as osmotic pressure, deep freezing and thrashing; chemical methods, which primarily consist of starch derivatizations like etherification, esterification and crosslinking, oxidation, cationization, and grafting; enzymatic degradation techniques; and genetic modifications, which entail genetically-engineered techniques targeting the different enzymes involved in starch biogenesis (Neelam *et al.*, 2012). Various combinations of moisture, pressure, shear, temperature, and radiation are used as physical ways to treat the natural starch. These modifications are inexpensive, safe, and easy to do. Since these methods don't require chemical or biological agents, people tend to prefer using them for food (Ashogbon & Akintayo, 2014; Saboonchi *et al.*, 2021). Starch properties can be altered physically resulting in changes in the particle size, surface characteristics, index of solubility as well as functional properties such as water absorption, swelling capacity, pasting and gel formation. Such modifications instantly impact on the functionality, sensitivity and application of the modified starch for various industrial usage (Nawaz *et al.*, 2020). The physical and chemical modification methods commonly employed are shown in Figure 2.4.

Modification of starch via chemical method involves changing the effective group of starch without physical altering of the particle size, shape and molecule distribution. These alterations

contribute immensely to starch behaviour, thermal and paste characteristics (Lopez *et al.*, 2010). The majority of the food industry use these modifications since they are essential to the functionality of the starch characteristic. Each of the glucose units in amylose and amylopectin polymers has three reactive hydroxyl groups accounting to the major sites for chemical alteration in starch. Starch chemical modification changes the physical characteristics including salting and thermal decomposition, that work by stabilizing the inter and intra particle adhesion of starch molecules (Nawaz *et al.*, 2020; Pérez & Bertoft, 2010). Chemical methods of modification give diverse options for the functioning of starch hence widen the field of application remarkably as compared with physical modifications. In addition to being expensive, those treatments may have negative environmental effects (Fan & Picchioni, 2020). Furthermore, according to Egharevba (2020) more studies for greener modification processes has been given attention due to chemical residues concerns in starch products and the attention to environment for hazardous chemicals used in some of the processes.

The capability of hydrocolloids to alter the rheology of a food system has resulted to a wide application by food processors (Yamul & Navarro, 2020). Several studies have shown that some hydrocolloids when blended with starch yielded improvements in the paste and gel properties including stability and functionality of starch without the requirement of chemical modifications (Alam *et al.*, 2009; da Silva Costa *et al.*, 2020; Kim *et al.*, 2013). Modified starch has been reported to be utilized entirely in all food processing sectors including industry for beverages, baked goods, infant food, canned food, and confectionery. The modified starch's specificity, utility and functional quality for a range of dietary and food industry formulation are influenced by starch modification processes (Chakraborty *et al.*, 2022).

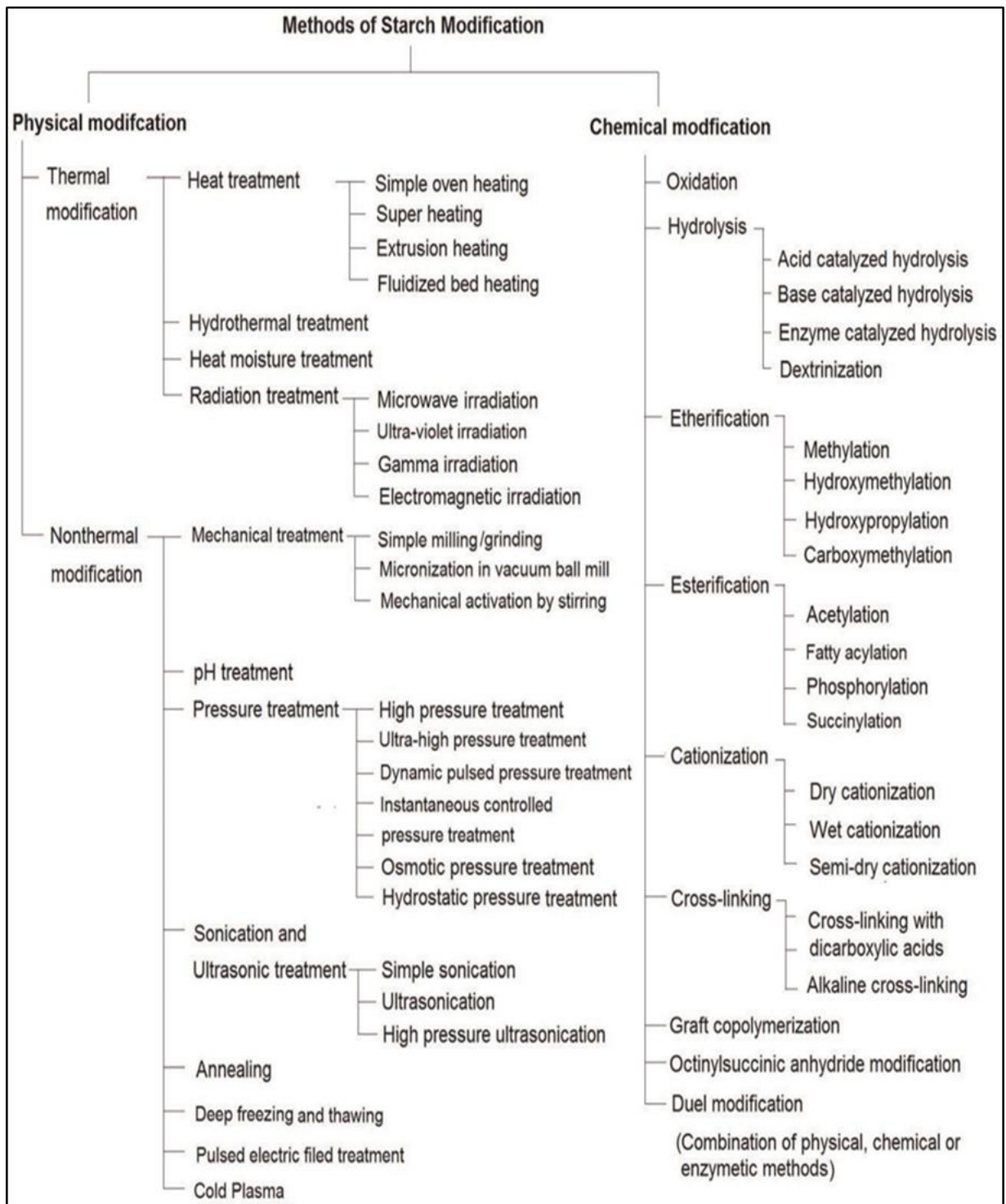


Figure 2.4: Methods of physical and chemical modifications of starch

Source: Nawaz *et al.* (2020)

2.6 Gum Arabic

Gum Arabic (GA) is a natural polysaccharide extracted from exudates of *Acacia senegal* and *Acacia seyal* trees (Figure 2.5) that is rich in non-viscous soluble fiber and is a commonly used food hydrocolloid (Patel & Goyal, 2015). *Acacia senegal* tree is able to survive all but the most severe of droughts in arid and semi-arid habitats in sub-Saharan Africa. It has been reported that about 90% of the total GA produced worldwide comes from *Acacia senegal* which is cultivated as a cash crop in agroforestry systems in Sudan. Sudan is recognized as the major producer of this gum and exports slightly above 80 percent to the world market (Lelon *et al.*, 2020). According to Wekesa *et al.* (2009) varietal differences in *A. senegal* are based on variation in natural distribution as well as differences in morphological characteristics. Three different varieties of *A. senegal* recognized in Kenya are var. *senegal*, var. *kerensis*, and var. *leiorhachi*. In Kenya, the primary source of commercial GA is *Acacia senegal* var. *kerensis*. Although the variety *senegal* has not been commercially produced, it grows in regions with comparatively more rainfall and occasionally produces gum when tapped (Muga *et al.*, 2021).

Previous studies have shown that *Acacia senegal* var. *kerensis* is the primary source of commercial gum Arabic in the arid regions of Kenya; in the absence of plantations, it grows naturally. Apart from gum Arabic production, it has been shown to enhance soil stabilization and soil fertility through biological nitrogen fixation thus contributing to the environmental conservation. Thus, *A. senegal* can provide a potential solution to land degradation in the ASALs. Promotion and utilization of the gum can offer alternative livelihoods to the pastoralists and agro-pastoralists thus contribute to soil fertility and protection of these fragile ecosystems (Wekesa *et al.*, 2013).

2.6.1 Production of Gums and Resins in Kenya

Seven ASAL Counties—Marsabit, Wajir, Garissa, Mandera, Turkana, Samburu, and Isiolo—are the primary producers of gums and resins. In Kenya, December through March and June through September are the main gum collection seasons. Gum Arabic's value addition is restricted to grading and grinding the product before shipment (Muga *et al.*, 2021). The different botanical sources, poor tapping methods and harvesting period, edaphic conditions as well as climatic factors have been reported to be the main factors affecting quality of Kenyan gums and these are critical with respect to their application (Lelon *et al.*, 2020).

Table 2.1: Potential Production of Gums and Resins in Kenya

County	Gum Arabic	Myrr	Frankincense	Hagar (Opoponax)
Isiolo	6,818.8t			3,752.2t
Samburu	4,771.9t			
Turkana	4,700t			
Wajir		644.8t	1,800t	1,978.5t
Garissa				1,959t
Total	16,290.7t	644.8t	1,800t	7,689.7t

Key t =tonnes

Source: Muga *et al.* (2021)

Gum arabic is also one of the hydrogels that are capable for soil modification. Studies showed that increase in soil organic carbon resulted in high level of nitrogen in gum arabic (Lelon *et al.*, 2020; Muga *et al.*, 2021). The main obstacles to the gums and resins in Kenya's drylands reaching their full potential, according to Muga *et al.* (2021), have been identified and categorized as ecological and climatic issues, socioeconomic factors, technological barriers and policy, as well as institutional barriers.

According to studies, with the exception of a little portion of the total volume produced that is treated for essential oils, the majority of gums and resins produced in Kenya (Table 2.1) are exported in raw form, without processing (Muga *et al.*, 2021; Vellema *et al.*, 2014). Efforts are put in place to curb the key challenges facing the sub-sector. Currently, pastoralists are encouraged to extract gums from trees in order to diversify their economic activities as a supplement for their income. To increase the quantities collected per day, better collection techniques such as tapping as well as increased use of postharvest techniques including drying, cleaning and sorting could improve the value of gum in return create more of an incentive to collect larger quantities. Furthermore, keeping records and review of traditional ecological knowledge is critical in enhancing the development of gum Arabic which has numerous industrial applications especially in food industries. In consequence, when the knowledge of local people is involved in the planning process will improve the likelihood in bringing about rural development and livelihoods diversification among them. Also assisting in the development

of the gum Arabic market would give an opportunity for people to be self dependent (Vellema *et al.*, 2014; Wekesa *et al.*, 2013).

2.6.2 Structure of Gum Arabic

Three main sections of polysaccharides and proteins are usually obtained from the hydrolysis of the high molecular weight polysaccharides in GA: arabinogalactan (AG), arabinogalactan protein (AGP), and glycoprotein (GP). This is due to the salts of calcium, magnesium, and potassium. These fractions are distinct in terms of their molecular weight and chemical makeup (Castellani *et al.*, 2010). The side chains of GA are made up of two to five 1, 3-linked β -D-galactopyranosyl units connected to the main chain by 1, 6-linkages, whereas the core of GA is made up of 1, 3-linked β -D-galactopyranosyl units (Musa *et al.*, 2018).

It has been demonstrated that the arabinogalactan fraction, which makes up 88% of the total gum weight, has a low molecular weight (Mw, ~300 KDa) and a low protein content—roughly less than 1%. The arabinogalactan protein fraction, which makes up around 10% of the gum overall, has a protein concentration of roughly 10% and a high molecular weight (Mw) of about 1500 KDa. Approximately 2% of the gum is made up of glycoproteins, which have the largest protein concentration (between 20% and 50%) and the lowest molecular weight (around 250 KDa). According to reports, AGP is the most interfacially active component of the aforementioned fractions (Castellani *et al.*, 2010). The emulsifying qualities of GA are mainly the result of the AGP component (Musa *et al.*, 2018). According to Castellani *et al.* (2010), this fraction (AGP) has amphiphilic properties due to the integration of hydrophilic polysaccharide fragments with hydrophobic protein chains. As a result, it has the ability to generate a viscoelastic film that decreases the tension between the oil and water interface when adsorbed on the oil in water interface.



Figure 2.5: (a) Tree with gum Arabic exudates (b) granules of gum Arabic

Source: Patel and Goyal (2015)

2.6.3 Properties of Gum Arabic

Moisture, total ash, volatile matter, and internal energy are the qualities of GA that are defined as quality characteristics. These attributes were evaluated in relation to gums extracted from the *Acacia senegal* species and its variations in Sudan (Table 2.2). These characteristics have been used to distinguish between different raw gums, most of which are added to food (FAO, 1990). Gum Arabic has been determined as a naturally occurring product complex made up of a combination of hydrophilic and hydrophobic protein components (Dauqan & Abdullah, 2013). While the hydrophilic carbohydrate component in food items prevents flocculation and molecular coalescence through electrostatic and steric repulsions, as an emulsifier, the water-resistant protein fraction adsorbs onto the oil droplet surface. It has been demonstrated that hydrophilic carbohydrates and hydrophobic proteins dissolve more easily in GA when there is a higher moisture content. The precise concentrations of heavy metals in the grade of GA have also been identified using the cationic constitution of the ash content. According to Castellani *et al.* (2010) the volatile matter of GA controls the properties and degree of polymerization found in sugar compositions like arabinose, galactose, and rhamnose, which have potent emulsifying qualities and are used as binders and stabilizers in the production of a variety of confectionery products as well as cough syrups in the pharmaceutical industry. It has been demonstrated that the protein content and trace amounts of lipids in GA are primarily responsible for its emulsifying action.

Table 2.2: International specifications of quality parameters of gum Arabic (GA)

Property	Range	
Moisture content (%)	13 – 15	
Ash content (%)	2 – 4	
Internal energy (%)	30 – 39	
Volatile matter (%)	51 – 65	
Optical rotation (Degrees)	(-26) – (-34)	
Nitrogen content (%)	0.26 – 0.39	
Cationic composition of total ash (550°C)	Copper (ppm)	52 – 66
	Iron (ppm)	720 – 2490
	Manganese (ppm)	69 – 117
	Zinc (ppm)	11 – 45

Source: FAO (1990)

According to reports, GA is an intricate blend of macromolecules with varied sizes and composition. It is mostly composed of carbohydrates, including D-galactose and L-arabinose, which make up around 97% of the mixture, and proteins, which make up less than 3% (Castellani *et al.*, 2010). In Samburu and Marsabit Counties, the impact of soil chemical characteristics on gum Arabic elementary compositions from *Acacia senegal* variety *kerensis* has been investigated (Table 2.3) (Lelon *et al.*, 2020). The gum arabic quality was shown to be significantly impacted by the chemical features of the soils. According to the experiments, gum pH differed ($p < 0.05$) with soil pH at every site. The little variations in the chemical makeup of GA are mostly influenced by the location of origin, weather, harvest time, tree age, and techniques used during processing, like spray dyeing (Castellani *et al.*, 2010; Lelon *et al.*, 2013). Numerous studies including the most recent one carried out by Lopez-Torrez *et al.* (2015), have revealed certain variations in the GA's chemical makeup derived from *Acacia senegal* and *Acacia seyal*. According to Table 2.3, the results demonstrated that the amino acid content of both *Acacia* gums was the same with *A. senegal* having a larger protein level (2.7%) than *A. seyal* (1.0%).

Table 2.3: Chemical characteristics of gum Arabic and soils

Sites	Soil chemical properties				Chemical properties of gum Arabic			
	pH	Organic carbon (%)	N (%)	P (ppm)	pH	Organic carbon (%)	N (%)	P (ppm)
Sereolipi	6.3	0.2	0.3	21.3	4.54	0.03	0.23	700.2
Merrile	6.0	0.3	0.3	6.4	4.52	0.15	0.31	705.2
Laisamis	6.6	0.7	0.4	4.5	4.50	0.06	0.32	412.2
Logologo	6.7	1.4	0.8	4.2	4.51	0.07	0.32	412.2

Key: N= Nitrogen; P= Phosphorus

Source: Lelon *et al.* (2020)

2.7 General Physicochemical Properties of Gum Arabic

Gum Arabic is an assorted material comprising of both hydrophilic and hydrophobic affinities (Patel & Goyal, 2015). The physicochemical responses of GA can be addressed putting into consideration the ratio of interactions that are hydrophilic and hydrophobic. Moreover, the structure of GA is closely related to its functional properties which in turn have an influence on such factors as solubility, consistency, degree of interaction between an emulsion's water and oil, including its capacity to coat and shield tiny particles for a variety of beneficial purposes (Montenegro *et al.*, 2012).

2.7.1 Solubility and Viscosity

Gum Arabic can dissolve readily in water though as compared with other gums it has relatively low viscosity hence large quantities may be necessary to achieve high viscosity. On the other hand, because of their high viscosity, most gums may not dissolve in water at quantities higher than 5%. According to reports, GA can dissolve easily in water at a 50% w/v concentration, resulting in the formation of a fluid solution with an acidic pH of about 4.5. GA typically has a compact hydrodynamic volume that is very modest due to its highly branched structure, and only at high concentrations does GA form a viscous solution (Montenegro *et al.*, 2012). Patel and Goyal (2015), describes GA as one of the most widely used polysaccharides in the industry as it possesses desirable characteristics such as high solubility nature, low viscosity and low toxicity

in addition to excellent emulsifying properties. Furthermore, due to its moisture regulation and film forming properties it has been reported to be beneficial to bakery products with regards to processing, texture and the period the product can remain sound.

2.7.2 Emulsifying Properties

Gum Arabic is widely utilized as an emulsifier in the flavor and essential oil industries due to its exceptional emulsifying characteristics (Montenegro *et al.*, 2012). Emulsion stability index has been used to determine the stability of emulsion (Hosseini *et al.*, 2015). Therefore, according to Mugo *et al.* (2020) *Acacia senegal* var *kerensis* gum (3.17%) and *Acacia senegal* var. *senegal* (16.53 %) gum shows that GA from *Acacia senegal* var. *kerensis* makes a more stable emulsion since the increase in droplet size is small although has a large particle size (3.27) compared to *Acacia senegal* var. *senegal* gum (1.044). Correspondingly the high emulsion stability could be accounted for by the high arabinogalactan protein content in gum Arabic.

Table 2.4: Biochemical composition of *A. senegal* and *A. seyal* gums on a dry basis

Component	<i>A. Senegal</i>	<i>A. seyal</i>
Total dry matter (mg g ⁻¹)	889.0±0.27	893.0±0.02
Sugars ^a	940.0	950.0
Galactose (%) ^b	35.8±1.20	36.9±1.05
Arabinose (%) ^b	30.3±2.50	47.6±0.60
Rhamnose (%) ^b	15.5±0.35	3.0±0.30
Glucuronic acid (%) ^b	17.4±1.15	6.7±0.40
4-O-Me-glucuronic acid (%) ^b	1.0±0.05	5.8±0.55
Proteins (mg g ⁻¹)	27.0±0.01	10.0±0.04
Minerals (mg g ⁻¹)	33.0±0.24	40.0±0.07

Key: ^aThe total sugar content was obtained by subtracting proteins and minerals from 1000 mg g⁻¹ on a dry basis; ^bThe sugar composition was evaluated by GC-MS. Values are mean ± standard deviation.

Source: Lopez-Torrez *et al.* (2015)

2.7.3 Molecular Association

Polysaccharides are commonly recognized to have a propensity to combine in aqueous media, leading to a variety of interactions even at the molecular level. Because of their effects on molecular weight, shape, and size—which determine how molecules interact with water and other molecules—these molecular connections have been demonstrated to have the power to significantly alter how molecules perform in a given application (Montenegro *et al.*, 2012). The same study also found that several factors, such as hydrogen bonding, hydrophobic association, an association mediated by ions, and electrostatic interactions, are determined by the concentration and presence of protein components that do affect the ability to form larger molecule complexes.

The molecular weight parameters of *Acacia senegal* varieties have been evaluated by Mugo *et al.* (2020). The results of this study demonstrated that the molecular weight of GA from *Acacia senegal* var. *kerensis* was almost double that of *Acacia senegal* var. *senegal* gum used as a standard. The R_g has been described as a measure of the size of the particle with reference to the mass distribution of the particle, taken as the average distance from the center of the gravity to the chain segment. The results further found R_g value to be 25 and 40 nm for *Acacia senegal* var. *senegal* gum and *Acacia senegal* var. *kerensis* gum respectively, this shows that *Acacia senegal* var. *kerensis* gum has the tendency to form a moderate gel as compared to *Acacia senegal* var. *senegal* gum.

2.7.4 Toxicological effect of Acacia gum

Studies have shown that high intake of dietary fiber such as GA is associated with beneficial effects on fat metabolism. It also promotes satiety, alters glycaemic index, affect gastric depletion as well as secretion of gut hormone thus assist in weight management (Ali *et al.*, 2009). The authors suggest that GA has anti-inflammatory and antioxidant properties that guard against damage to the kidneys, liver, and heart. Apart from its capacity to alleviate the deleterious consequences of chronic renal malfunction in humans, it has also been demonstrated to mitigate some biochemical, physiological, and behavioral effects in rats (Ali *et al.*, 2009; Ali *et al.*, 2011).

In a petition, the Joint Expert Committee on Food Additives (JECFA) of the Food and Agriculture Organization and the World Health Organization (FAO/WHO) assessed the permissible daily consumption of acacia gum. From the review the gum was found to be technologically effective but should be used at the lowest level necessary to achieve this effect. The expert committee did not place a limit on gum acacia's dietary use beyond the standard that it should be used within the confines of good manufacturing practice (FAO, 1990). The agency concludes that acacia may be safely used as emulsifier, stabilizer or thickener in alcoholic beverages at a use level that should not exceed 20 percent in the final beverage.

<https://www.federalregister.gov/documents/2005/02/17/05-3026/food-additives-permitted-for-direct-addition-to-food-for-human-consumption-acacia-gum-arabic>. Accessed 17th July 2024

2.8 Applications of Gum Arabic in Foods

Hydrocolloids such as xanthan, methyl cellulose, tragacanth, GA, galactomannans, gellan, alginate have been applied in different food formulations as additives to provide the appropriate viscosity and mouth feel, such as salad dressings, soups, gravies, sauces, and toppings. In order to provide the appropriate texture, they are also used in a variety of food products, including ice cream, jams, jellies, gelled desserts, cakes, and sweets (Saha & Bhattacharya, 2010). Gum Arabic has been reported to provide the greatest economic value due to its extensive usage in various sectors particularly in food, pharmaceutical and cosmetic industries (Dauqan & Abdullah, 2013). According to Patel and Goyal (2015), GA has found extensive application in the food sectors due to its edibility, strong water solubility, generally recognized as safe (GRAS) status, absence of aftertaste among other advantageous qualities. Furthermore, the study revealed that due to its desirable emulsifying, stabilizing, binding and shelf-life enhancing properties GA has found application in many foods. Musa *et al.* (2018) demonstrated that acacia gums are distinct among the various hydrocolloids known in that they are widely used in the food industry because they allow for modification and control, especially of the rheological characteristics of aqueous systems for food by acting as thickening agents, suspending and binding agents as well as bringing about stability.

The potential for applying GA from *Acacia senegal* var. *kerensis* in food products has been demonstrated by a number of research. According to reports, gum Arabic possesses the water-

binding qualities needed for it to serve as a binder in low-fat yogurt (Mugo *et al.*, 2020) and enhancing the way cooked extended beef rounds are processed and their sensory qualities (Mwove *et al.*, 2016). imilar findings were made by another earlier study that examined the impact of GA from *Acacia Senegal* var. *kerensis* on the physico-chemical and baking properties of wheat-plantain composite flour. This study discovered that the gum significantly improved the overall textural qualities of bread by producing softer and more springy bread (Soibe *et al.*, 2016). Correspondingly the present study sought to determine the effect of this gum variety on various properties of maize and cassava flours and starches with a view of enhancing their industrial application.

According to Alam *et al.* (2009) Arabic and guar gums have been applied in baking to affect some properties for example both gums were added into wheat dough to lower hardness, slow aging of bakery products, to improve texture and enhances specific volume of bakery products. Mugo *et al.* (2020) also reported that an increase in viscosity of yoghurt by addition of the GA hence suggesting that GA participated as a copolymer with milk casein. The same study also demonstrated that *Acacia senegal* var. *kerensis* gum was better in enhancing viscosity of yoghurt as compared to *Acacia senegal* var. *senegal* gum. A report from another study showed that by heating gum Arabic from *Acacia senegal*, the proteinaceous components aggregate, producing a hydrogel form with improved mechanical properties and water binding capabilities, resulting in an increase in cook yields while decreasing the extractable moisture of beef rounds (Mwove *et al.*, 2016).

Shahzad *et al.* (2019) investigated the effects of hydrocolloids on the pasting, viscoelastic, textural, and thermal properties of sweet potato starch. Arabic, xanthan, cress seed, fenugreek, flaxseed, and okra gums were tested at concentrations ranging from 0.5% to 2.0%. According to the study, the flow behavior index decreased with the addition of gum, and this was visible with an increase in gum concentration. However, contradictory results were reported for gum Arabic and cress seed. These studies show that starch and gum mixes exhibit increasing non-Newtonian behavior as the gum content increases. The consistency coefficient (k) was also demonstrated to decrease with the addition of any gum as well as with increasing concentration of gums, except for xanthan gum at 25°C. Other studies have also reported that increasing the concentration of guar gum improved linearly the overall acceptability of bread, while the hardness of biscuits

increased significantly by GA addition, and this was attributed to the highly branched structure of gum Arabic, as well as its ability to associate with other components by forming links (China *et al.*, 2020). These data were found to correspond to Ziobro *et al.* (2016) remark that gums are one of the most commonly utilized additions to improve the texture and appearance of non-wheat flour compositions.

2.9 Effect of Hydrocolloids on Starch Functionality

Previous studies have shown that the nature of starch structure determines its application in various fields including biomedical and industrial due to its distinct functional properties. Starch is made up of amylose and amylopectin polymers, which have a poor solubility in water and a low ability to absorb oil and water. It also shows good pasting, viscosity, gelatinization and swelling power abilities. These studies further reported that the functional properties of starch can be enhanced by modifying a number of the physicochemical factors to augment its nutritional and industrial significance (Bashir & Aggarwal, 2019; Nawaz *et al.*, 2020). Islam *et al.* (2012) reported that the functional properties especially for flours are extremely vital as far as the product's information is concerned since it shows the amount of water necessary to make the greatest dough. It also displays the qualities and behavior of flour with the addition of water..

Hydrocolloids have been defined as water soluble macromolecules of high molecular weight which alter the rheology of aqueous systems to which they are added into and this operation is accomplished by binding a huge quantity of water. Hydrocolloids alter the pasting qualities of starch in various ways, which can be related to numerous elements such as the ionic charges of both starches and hydrocolloids, as well as the molecular structure of hydrocolloids (Saha & Bhattacharya, 2010). Large amount of starch is usually used in preparations that involve hydrocolloids as potential additives to carry out reaction with starch in presence of water resulting in modification of its physicochemical properties (Shahzad *et al.*, 2019). Consequently, this interaction between gums and starch has been of great concern to food scientists. Hydrocolloids (gums) are used in the food industry because they improve stability, alter textural character, and reduce the retrogradation rate of starch (Puri *et al.*, 2014). They have been shown to have wide application in the food industry since they influence the texture or the organoleptic properties of food products. Furthermore, hydrocolloids have also been reported to play a critical role in keeping the desired characteristic of texture as well as stabilizing products upon long

storage. Therefore, blends of starch and gum are valuable for utilization in a wide range of food products (Shahzad *et al.*, 2019).

The effects of different hydrocolloids have been studied, for example the effects of guar, xanthan, Arabic, carboxy methyl cellulose (CMC) and tragacanth gums on the gelatinization behaviour of hard wheat flour have been investigated by Alam *et al.* (2009). Their results showed that guar and xanthan had the ability to significantly lower the gelatinization temperature, improve peak viscosity, increase the breakdown during cooking, promote the stability during cooling as well as reduce the tendency to setback. Gum Arabic was shown to lower the peak viscosity, reduced breakdown during heating and thus provided increased stability during cooking. These results also revealed that retrogradation of starch could be decreased at early stages of storage by adding gums.

Effects of improved viscosity in flour / starch - hydrocolloid combinations are widely regarded to originate from the modification in granule swelling and leaching of amylose during gelatinization because it impacts granule distortion, including starch-hydrocolloid interactions in the continuous phase. Bustillos-Rodríguez *et al.* (2019) examined the process of gelation of maize starch dispersions at 4% with added galactomannans ranging from 0.1 to 0.5% by using constant stress rheometry, upon addition of galactomannans a rapid increase in gelation kinetics was displayed that resulted in slightly higher G' (loss modulus) values for the final networks as compared to starch alone. Mixed gels had higher $\tan \delta$ values, indicating fewer elastic networks, although their G' values were slightly more frequency-dependent. There is a need for more organized and foundational work on structure formation, pasting, and functional qualities in flour and starch - hydrocolloid gels. According to previous studies, such investigations constitute the basis for measuring and managing both the structure and texture of processed and designed products comprising flour and starch (BeMiller & Whistler, 2009; Bustillos-Rodríguez *et al.*, 2019).

Recent study by Borries-Medrano *et al.* (2018) evaluated starch viscosity as well as its hydrolysis on wheat starch and flour by the addition of different gums such as gum Arabic, guar gum and locust bean gum. This study finding demonstrated that GA significantly reduced all the viscosity parameters of the pastes whereas guar gum and locust bean gum both increased pasting parameters such as peak and final viscosity in the developed pastes. Furthermore, among the

textural qualities studied, galactomannans increased gel hardness and gel strength, which was linked to the re-association of comparable molecules in the system. Quality control of starch gel products is heavily reliant on the strength and stability of the gel's structural organization as well as its texture during storage (Song *et al.*, 2008). It is critical to assess the influence of GA from the variety accessible in Kenya on the textural qualities of flours and starches of maize (staple crop) and cassava, a climate smart crop, in order to enhance their industrial applicability.

According to Shahzad *et al.* (2019), hardness of sweet potato gels significantly increased with the addition of gum Arabic as compared to other gums. Furthermore, the hardness had a strong correlation with the setback values. The increase in hardness was attributable to the establishment of hydrogen bonds between the starch polymers and gum macromolecules, which resulted in the gel firmness. da Silva Costa *et al.* (2020) indicated that the blending of guar gum and xanthan gum with arrowroot starch was an option to boost the stability and improve the textural features of starch gels.

2.10 Rheological and physical Properties of Starch

Rheological and physical properties have been reported to influence the application of starch and starch-based products. The key functional features of starch are pasting and the viscosity of the starch paste (Balet *et al.*, 2019). According to these authors, the gelatinization process occurs before pasting, which involves granular swelling and amylose molecule leaching. Pasting causes complete disruption of the starch granules, usually at a temperature higher than that of gelatinization. Researchers have demonstrated that pasting imposes the formation of a viscous gel that can be measured by observing changes in viscosity based on rheological principles.

Another property of starch that involve the re arrangement and re-association of the amylose and amylopectin chains in the gelatinized starch back into an ordered crystalline structure is commonly referred to as retrogradation (Balet *et al.*, 2019; Beckles & Thitisaksakul, 2014). The physiochemical as well as the functional properties of the different cereal starches has been shown to influence the molecular, crystalline and granular differences of the starches (Li *et al.*, 2017). Chakraborty *et al.* (2022) discovered that the structure, texture, and palatability of starch-based foods are primarily influenced by functional qualities such as starch swelling and gelatinization behavior.

2.10.1 Rheological properties

Rheology has been defined as the study of material behavior in terms of deformation and flow upon application of forces which can routinely be measured by various instruments particularly a rheometer. The chemical structure of starch, starch concentration, pasting conditions, and storage conditions, particularly temperature and time, all have an impact on the rheological properties of flour/starch pastes and gels (Ai & Jane, 2015). The rheological properties describe the behavior of materials subjected to shearing forces and deformation, also known as viscoelastic complexes (Alcázar-alay & Meireles, 2015). According to these authors, starch exhibits a variety of deformation and flow characteristics that are proportionate to applied stress, which are known as starch's rheological properties. Pasting qualities, viscosity of starch paste, and rheological parameters of starch gel are all important.

Rheological properties of starch pastes are reported to determine their potential application especially as thickeners, binders or as gelling agents. Ojewumi *et al.* (2019) demonstrated that the rheological properties of maize and cassava starch studied depended largely on three main factors i.e. temperature, shear rate and thickness of the gel. Cassava starch was shown to have more substantial rheological property than that of maize starch at equal concentration. Furthermore, aqueous gels of cassava and maize starches displayed a pseudoplastic or shear thinning material which is usually known to be a typical Non-Newtonian fluid. According to Wang *et al.* (2017) rheological properties of food are taken to closely relate to food processing, storage and ultimate taste, and these are normally regarded as crucial aspects with reference to the quality of starch and starch-based foods. Furthermore, the authors discovered that the interactions between the dispersed and continuous phases affect the rheological properties of the gelatinized starch systems.

A controlled, clearly defined deformation or tension is usually applied to a material in order to measure rheological properties over a period of time, and the resulting force response is analyzed to give an indication of material parameters such as stiffness, modulus, viscosity, hardness, strength, or toughness (Alcázar-alay & Meireles, 2015; Martinez, 2015). The general aims of these researchers in measuring the rheological properties were to: obtain a quantitative description of the material's mechanical properties, information related to the molecular structure and composition of the material, as well as the evaluation and simulation of the material's

performance throughout processing with the purpose or intention of predicting the quality of the finished products. Some of these objectives are in tandem with the current study's goals in which the effects of a hydrocolloid on such properties of flour and starch have been evaluated.

2.10.2 Physical Properties

Physical properties can be defined as those characteristics of a product that explain how the different components in food act during preparation and processing as well as their effects on the final food products especially with regards to appearance, texture and palatability (Awuchi *et al.*, 2019). These properties have been reported to be affected by the food composition such as energy source, lipids, proteins, water content, fiber and other food additives that are added to food, as well as how these ingredients are organized in flours and other foods. Water absorption capacity, oil absorption capacity, emulsion activity and stability, foam capacity and stability, swelling capacity, solubility, water retention, emulsification, cohesion, adhesion, and hydration are a few of the physical characteristics (Awuchi *et al.*, 2019; Chandra & Samsher, 2013).

The molecular average weight of starch polymers (amylose and amylopectin) and their molecular arrangement within the granule influences starch functionality even though it comprises an excellent raw material to alter food texture and uniformity. Starch can be thought of as the main ingredient in many food formulations, because it provides significant nutritional and functional qualities for the food industry (Bashir & Aggarwal, 2019; Bertolini, 2011). The properties of food ingredients apart from the feature of nutrition which has a great impact on its application have been referred to as the food functionality. According to recent studies, a food material's functional characteristics dictate how it is used and applied for different food products (Hasmadi *et al.*, 2020). The results of these studies show that bulk density, one of flour's functional qualities, can be utilized to measure how heavy a flour sample is. The oil absorption capacity (OAC), another property is taken as the flavour retaining capacity of flour which is a crucial element in food formulations also, it has been shown to be highly related to the starch molecular ability to combine with lipids especially in cassava flour.

The acceptability of starch, flour, protein or paste as an ingredient in food preparation is dictated solely by their functional attributes which in turn depend on certain factors that cause interaction between salts, acids, gums, carbohydrate, fat among other components that influence the quality

of the finished products as explained by Onyeneke (2019). According to Chandra and Samsher (2013), the swelling capacity (defined as starch measurability to take up water and swell) of flours and starches can be influenced by the size of the particle, species including the method of processing or other unit operations.

In another study as reported by Onyeneke (2019) milling a variety of dry cassava chips produced flour which upon analysis exhibited higher bulk density, lower oil and water absorption capacities, high swelling index as well as higher gelatinization temperature. Being a remarkable functional property required in various foods particularly those involving dough handling, water absorption capacity (WAC) can be influenced by starch granules having loose connection of amylopectin and amylose with weaker associative forces that maintains the granular structure. While WAC is critical aspect in baking processes as well as in bulking and stability of products oil absorption capacity (OAC) is also essential as it contributes to enhancement of palatability whereas retaining the food product's taste (Iwe *et al.*, 2016). Oil absorption capacity has been shown to be advantageous in structural association in food especially in flavor retention, palatability enhancement and prolonging shelf life of bakery or meat products, baked goods, pancake including soup mixes where fat absorption is desirable (Onyeneke, 2019).

2.10.3 Gelatinization

Prior to consumption by humans or for its application in materials, flour or starch is frequently subjected to heat in the presence of water, undergoing an order to disorder change, a process generally referred to as gelatinization (Wang *et al.*, 2016). Gelatinization is sometimes characterized as the process in which starch converts from an organized semi-crystalline granule to an amorphous state, culminating in the loss of the 'maltose' cross (Ai & Jane, 2015). Gelatinization of starch therefore, is evoked by several food processing operations such as the hot extrusion of cereal based products, baking process of bread and pastries as well as cooking of sauces and fillings, correspondingly previous studies have reported great variations in gelatinization properties for different starches (Schirmer *et al.*, 2015; Tako *et al.*, 2014). Generally, most starches have been shown to display gelatinization temperatures ranging between 60 and 80°C where higher gelatinization temperatures are exhibited by A-type starch than B type (Zhu & Xie, 2018). However, few exceptions have been identified in a recent study.

Starches with an extremely high quantity of amylose exhibit significantly higher gelatinization temperatures (Ai & Jane, 2015).

Schirmer *et al.* (2015) characterized the factors associated with the variations and progress of heat induction into the raw material properties and process or applied product parameters in order to gain a thorough knowledge of these gelatinization changes. The gelatinization process is said to depend on the characteristics of the starch granules including the composition, morphology, molecular architecture amongst others particularly from the raw material properties side. Furthermore, the extent of gelatinization is dependent on the addition of water that is the ratio of starch to water which is of notable interest. Food additives that compete for water with starch or interfere with the creation of starch chains have been found to have the capacity to influence the degree of retrograded starch (Wang *et al.*, 2015).

2.10.4 Retrogradation

Starch retrogradation is a term used to define the process in which gelatinized starch undergoes a disorder-to-order transition (Wang *et al.*, 2016). Reports have shown that water plays a crucial role in starch thermal processing and subsequent storage of foods (Wang *et al.*, 2015). The quality and nutritional qualities of starch-based products are heavily influenced by the changes that occur during cooking, processing and subsequent storage. Similarly, these changes have been shown to be responsible for the functionality of starch in terms of uptake of water, granule swelling as well as the development of a viscoelastic paste during heating, followed by the assembly of dispersed starch chains during cooling and gel formation (Fallahi *et al.*, 2016; Tako *et al.*, 2014).

Several variables such as the molecular ratio of amylose to amylopectin, moisture content and the structures of the amylose and amylopectin molecules determine the degree of starch retrogradation. As a result, these variables are reported to determine the botanical source of starch, temperature, and the presence and concentration of other additions, notably salts and surface-active chemicals (Damodaran *et al.*, 2008). Starch retrogradation has been greatly associated with undesirable effects particularly staling of bread as well as other foods rich in starch and this has decreased the durability and acceptance by customers of the items, resulting in significant waste, creating considerable issues to the food industry (Wang *et al.*, 2015). Furthermore, the degree of starch retrogradation is influenced by the temperature and the length

of storage; the common conditions are isothermal storage at 4°C, 25°C or 30°C or temperature cycling between 4 and 25°C or 30 °C and these temperatures are optimal for starch retrogradation (Wang *et al.*, 2015).

From their comprehensive review, Wang *et al.* (2015) illustrated that the type and quantities of carbohydrate largely determines the degree to which starch retrogradation is hindered. The competition for water between starch and the other polysaccharides further explains the processes that inhibit the degradation of starch. According to Ai *et al.* (2013) the single-helical complex of amylose and lipids could limit the swelling thus hampering the scattering of starch granules during heating by doing so starch granules are retained closely thus facilitating faster retrogradation. Studies have shown that in order to preserve and maintain the quality of starchy foods throughout the storage period, a thorough comprehension of the retrogradation behavior of starch is critical (Wang *et al.*, 2016; Zhu & Xie, 2018).

2.10.5 Pasting

When starch granules are constantly heated in the presence of water and shear pressures are applied, the following events occur: increased granule swelling, more leaching of soluble components, particularly the amylose portion, and total granule disruption. These processes have been shown to result in starch paste production with subsequent viscosity development, a process generally referred to as pasting (Damodaran *et al.*, 2008). Various equipments have been employed to measure the variations in viscosity and paste properties. These include; rapid visco-analyzer (RVA), amylograph or a brabender viscograph. It has been shown that the viscosity analysis typically starts at a temperature between 30°C and 50°C and this have been reported to lie just below the gelatinization temperature of starch (Schirmer *et al.*, 2015).

In Figure 2.6, a description of a viscosity measurement is given that shows a heating and cooling temperature profile. Schirmer *et al.* (2015) explains that swelling and partial rupture of the granules is usually initiated when the applied temperature exceeds the starch granule gelatinization temperature resulting to an increase in viscosity. The pasting temperature was determined during the heating process as the temperature at which the viscosity begins to increase. The peak viscosity constitutes the balance or the point of stability between the starch granule swelling and its rupture. Additional reports indicate that during a holding period at high

temperature of about 95°C mechanical shear stress do occur and this can cause further destabilization of starch granules and subsequent amylose leaching (Singh *et al.*, 2010; Zhu & Xie, 2018).

According to Singh *et al.* (2010) shear thinning or a breakdown in viscosity occurs and is contributed by amylose lixiviation which happens frequently in the direction of flow. The viscosity has been reported to increase until it reaches the final viscosity once the heated starch solution has been cooled whereas the term "setback viscosity" describes the viscosity that recovers as the heated starch suspension cools. Recent study has demonstrated that starch pasting properties are key parameters for quality approximation in both cereal and starch root crops (Maizeejo-Ramírez *et al.*, 2018). Additionally, it has been demonstrated that starch with a higher percentage of amylose exhibits a lower peak viscosity and a higher pasting temperature, especially in the presence of lipids. This phenomenon has been linked to amylose's inhibition of starch granule swelling during heating and shearing (Ai *et al.*, 2013). Waxy cassava and maize starches as reported by Santos *et al.* (2021) have been shown to exhibit high potential for industrial application due to their specific viscosity characteristic and also can be employed as an alternative particularly for different foods requiring stability during freezing. Research has demonstrated that gums have a crucial role in regulating the physical and chemical characteristics of food, enhancing its moisture content and preserving its overall quality while it is being stored (Soibe *et al.*, 2016).

2.10.6 Textural properties

Food texture is an essential quality characteristic apart from the taste as it gives appearance that appeals and satisfaction of the consumers (Nasaruddin *et al.*, 2012). Starch from different sources either modified or non-modified is known to contribute to the textural properties of various foods and has versatile industrial applications including thickening, encapsulation, adhesive, gelling and water retention agent (Egharevba, 2019). In the food industry, modified starch in particular has been widely used as a thickening, stabilizer, fat substitute, and textural modifier (Chakraborty *et al.*, 2022). Numerous research has additionally been carried out detailing the application of modified starch to improve food product textures (Chakraborty *et al.*, 2022; Clasen *et al.*, 2018). The ability of a gel structure and texture to be stable during storage has been shown to be a very critical factor for quality control determination of starch gel foods

(da Silva Costa *et al.*, 2020). The combination of natural starch and gums is used in the food industry today to improve the eating quality, retain moisture more effectively and change and regulate the texture and water mobility of food (Song *et al.*, 2008).

Texture modifiers with anti-staling effects are intended for the increases in the general acceptability and economic value of food products. Investigations have been carried out to explain the various reactions that occur in starch- gum mixtures, a study by Ishihara *et al.* (2010) suggest the potential usage of GA and soybean soluble polysaccharide (SSPS) as novel texture modifiers for cooked rice.

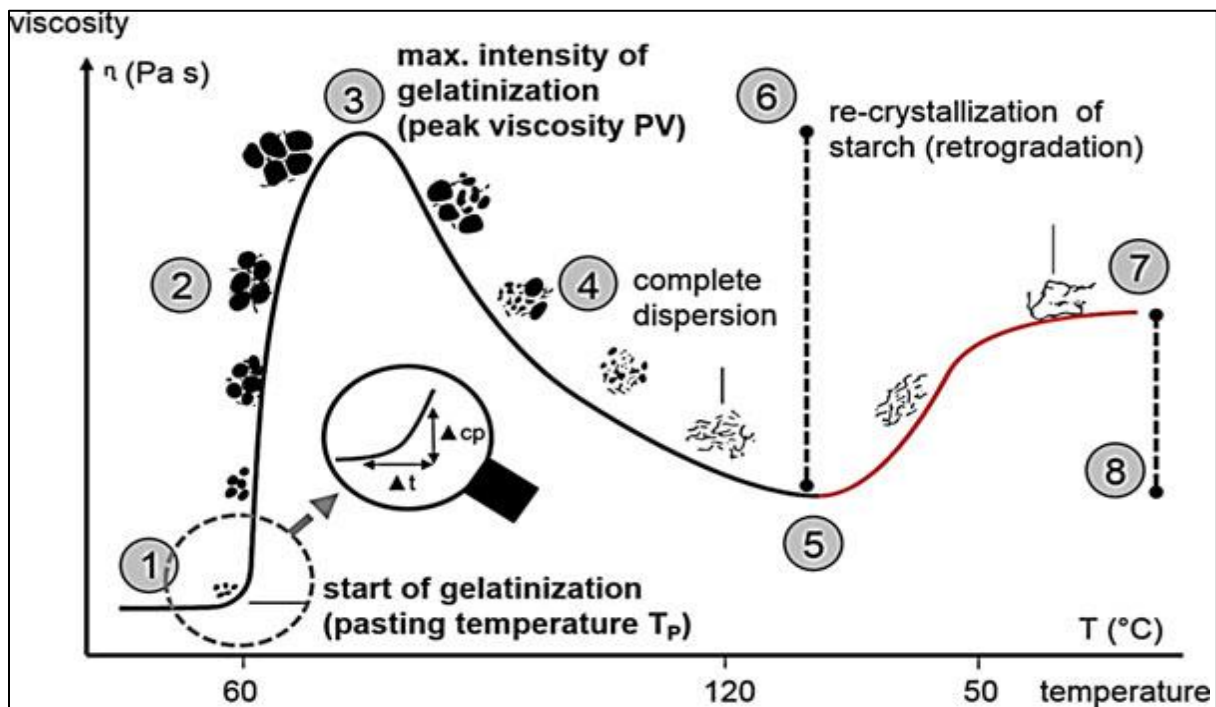


Figure 2.6: Measurement of starch viscosity with excess amount of water

Key: (1) Gelatinization onset (TP, pasting temperature), (2) hydration of starch granules, (3) maximum intensity of gelatinization (PV, peak viscosity), (4) enzymatic and shear destruction of starch granules, (5) minimum viscosity (HPV, hot paste viscosity), (6) viscosity loss (B, breakdown), (7) final viscosity (FV) and (8) paste hardening (S, setback).

Source: Schirmer *et al.* (2015)

2.11 Methods Used to Study Flour and Starch Properties

Various methods have been employed to analyze flour and starch properties. Previous studies have reported that the molecular and physicochemical structure of starch cannot be determined directly since starch is contained predominantly within a structural and chemical complex of food matrix (Schirmer *et al.*, 2015). The amount of amylose in a granule has a significant impact on the physicochemical and functional characteristics of starch. Variations in the geographical origin and growth conditions can cause this content to fluctuate even within a single botanical variety (Alcázar-alay & Meireles, 2015). Differential scanning calorimetry (DSC) has been widely used to analyze and characterize the change in state from one phase to another including crystal formation, phase transition from solid to liquid and rubbery state (Subaric *et al.*, 2011). It is possible to measure variations in the viscosity properties of starch using an amylograph, viscograph, or rapid visco-analyzer (RVA) (Balet *et al.*, 2019) while the textural properties of the starch and flour gels can be measured using texture analyzer systems (Borries-Medrano *et al.*, 2018). Wang *et al.* (2015) demonstrated that the functional characteristics of starch and flour influence the final foods' shelf life, nutritional value, and acceptability by consumers. Hence, it is imperative to assess the influence of gum Arabic the Kenyan variety on these properties.

The viscosity of starch is its main characteristic. There have also been reports of other rheological properties like as texture, transparency or clarity, shear strength, and retrogradation tendency. It has been demonstrated that each of these characteristics is crucial to the economic uses of starch (BeMiller & Whistler, 2009). "Paste properties" are the broad terms used to describe the changes in starch that result in granule rupture following heating in excess water (Alcázar-alay & Meireles, 2015). Viscosity variations in starch paste have typically been examined or evaluated using amylographs or viscometers, which can be of the rotating type, capillary flow, orifice, falling ball and rotating type (Schirmer *et al.*, 2015).

2.11.1 Instrumental Texture Analysis

Instrumental texture has been defined as a category of physical properties that is acquired from the structure of food as well as the interaction of its constituent ingredients. The back-extrusion method has been described as the most appropriate for quality control since it is considered to be a relatively simple, cheap and rapid method for characterizing food. The back-extrusion set-up on the texture analyzer is as shown in Figure 2.7. Since the back-extrusion operation is not

affected by free liquid the probe required may not be cleaned after usage as well as the cell need not be dried. Nevertheless, while in operation the plunger must go down in parallel with the back-extrusion cup to ensure a consistent circular width. This compression-extrusion test is applicable to a broad range of food products particularly those that flow under pressure such as viscous liquids, gels, fats as well as fresh and processed fruits and vegetables (Nasaruddin *et al.*, 2012).

2.11.2 Pasting properties

Different instruments have been used to study the pasting properties of flour or starch. These instruments include the Ottawa Starch Viscometer, Brabender Visco-Amylograph, Consistometer and the more recently developed is the Rapid Visco Analyser (RVA) (Balet *et al.*, 2019). According to these researchers, when a flour-water suspension is subjected to a heat-hold-cool-hold temperature cycle, the RVA tool simulates the cooking process of cereal. Furthermore, it is reported that during RVA analysis the pasting process is usually observed in a starch/flour and water slurry subjected to agitation and heat leading to swelling of the starch granules and total disruption following gelatinization hence the development of a gel. The pasting properties of flour or starch have been widely measured using the RVA which depicts the viscosity parameter as a function of temperature and time (Schirmer *et al.*, 2015).

The RVA separates the pasting behavior into three distinct periods as explained by Alcázar-alay and Meireles (2015) and Schirmer *et al.* (2015) which include: (i) a regulated heating phase that raises the suspension's temperature from room temperature to a peak that is usually set at 95 °C. (ii) a cooling phase that brings the temperature down to about 50°C and (iii) an isothermal phase that keeps the suspension at the highest temperature needed for analysis. Throughout the examination, the suspension is sheared, and it typically demonstrates a peak in viscosity that appears after gelatinization, rises as the granules inflate, and then decreases in viscosity as a result of granule breakage and polymer rearrangement (Alcázar-alay & Meireles, 2015; Martinez, 2015).

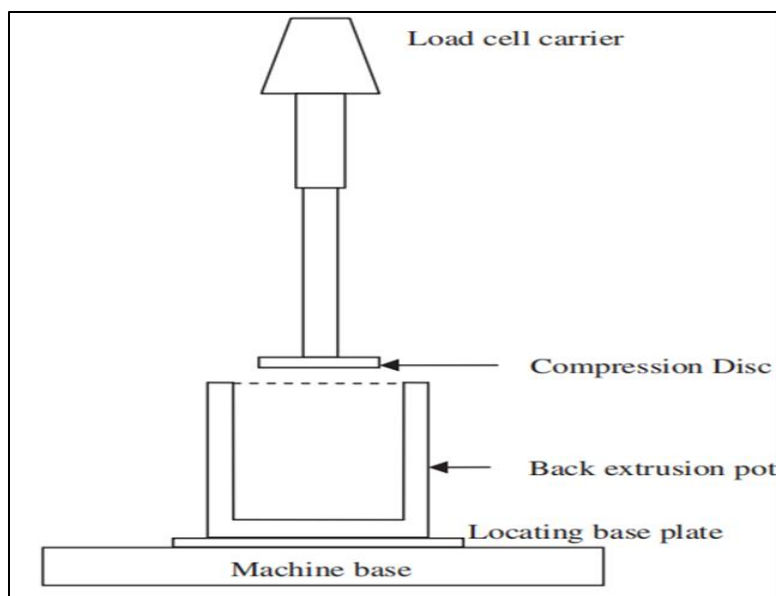


Figure 2.7: Back extrusion set-up on the texture analyser

Source: Nasaruddin *et al.* (2012)

The RVA has been shown to be an ideal tool for fingerprinting the viscosity, hydration and degree of cook of broad range of food products (Wang *et al.*, 2015). The pasting properties of the flour/starch/hydrocolloid blends can also be determined using the Brabender microvisco-amylograph (MVAG). Brabender Microvisco-Amylograph is a relatively new device that combines the amylograph and viscograph principles. According to earlier research, the MVAG was first created in response to the need for the huge sample sizes needed for the Brabender viscograph and amylograph. Other benefits of the MVAG include higher heating/cooling rates (1.5–10°C/min), better sample temperature measurement precision, an integrated self-optimizing temperature control unit, shorter test times, and easier handling (Hammed *et al.*, 2016).

The Brabender viscograph working principle entails heating up the sample within a rotating stainless-steel bowl and cooling down both under regulated conditions. Combined with the viscograph windows software, the integrated, self-optimizing temperature controller allows programming and storage of any temperature profiles with heating or cooling rates of between 0.5 to 3 °C/min. Finally, a measuring sensor extending into the sample is deflected in conformity with the viscosity of the sample in the bowl and this deflection is generally measured as torque. The parameters measured include the peak viscosity (PV), hot paste viscosity (HPV), end of cooling, final viscosity (FV), breakdown (Bd) and setback (SB) values all reported in Brabender

units (BU) (Brabender, 1998; Hammed *et al.*, 2016). According to Hammed *et al.* (2016) a relationship between the change in viscosity and the availability of water for starch gelatinization was demonstrated by the positive correlation found between the MVAG values and the DSC parameters. It has been discovered that Brabender setback, and breakdown in particular, are helpful in describing the thermal characteristics of dough.

2.12 Research Gap

Unmodified starch and flour lack vital qualities *vis a vis* viscoelastic behavior and structural stability hence limiting their industrial application as well as household food production. Current modification methods to improve such desirable characteristics are faced with short comings with regards to cost and safety concerns. This has resulted in growing consumer demand for natural ingredients. The use of hydrocolloids / gums has been on the rise to improve the functionality of native flour and starch to meet the desired qualities. Several types of hydrocolloids have been tested however very few, if not none, has focused on incorporating these hydrocolloids in flours and starches from maize and cassava to improve on their functionality. Gum Arabic, a naturally harvested hydrocolloid from *Acacia senegal var kerensis* species has drawn the interest of food processors because of its superior food-stabilizing, emulsifying and binding qualities. Consequently, the goal of this research is to help solve the limitation of native starches and flours thus contributing to food security by utilizing GA from *Acacia senegal var kerensis*, a Kenyan variety. This will promote utilization of locally available food crops and gum Arabic consequently improving livelihood of the farmers. Furthermore, evaluating these properties could also form the basis for augmenting household food production and industrial processes. A summary of the research gap has been provided in Figure 2.8.

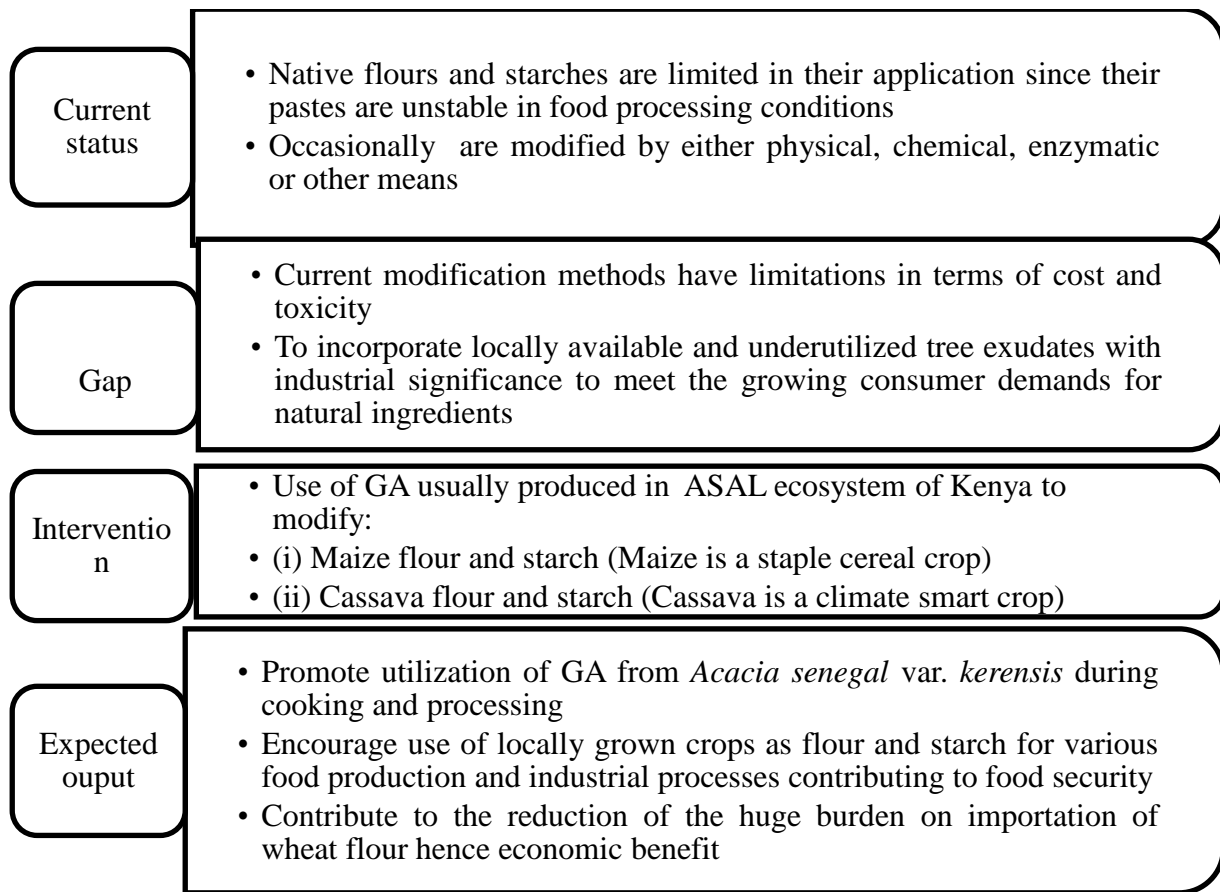


Figure 2.8: Summary of research gap

2.13 Conceptual Framework

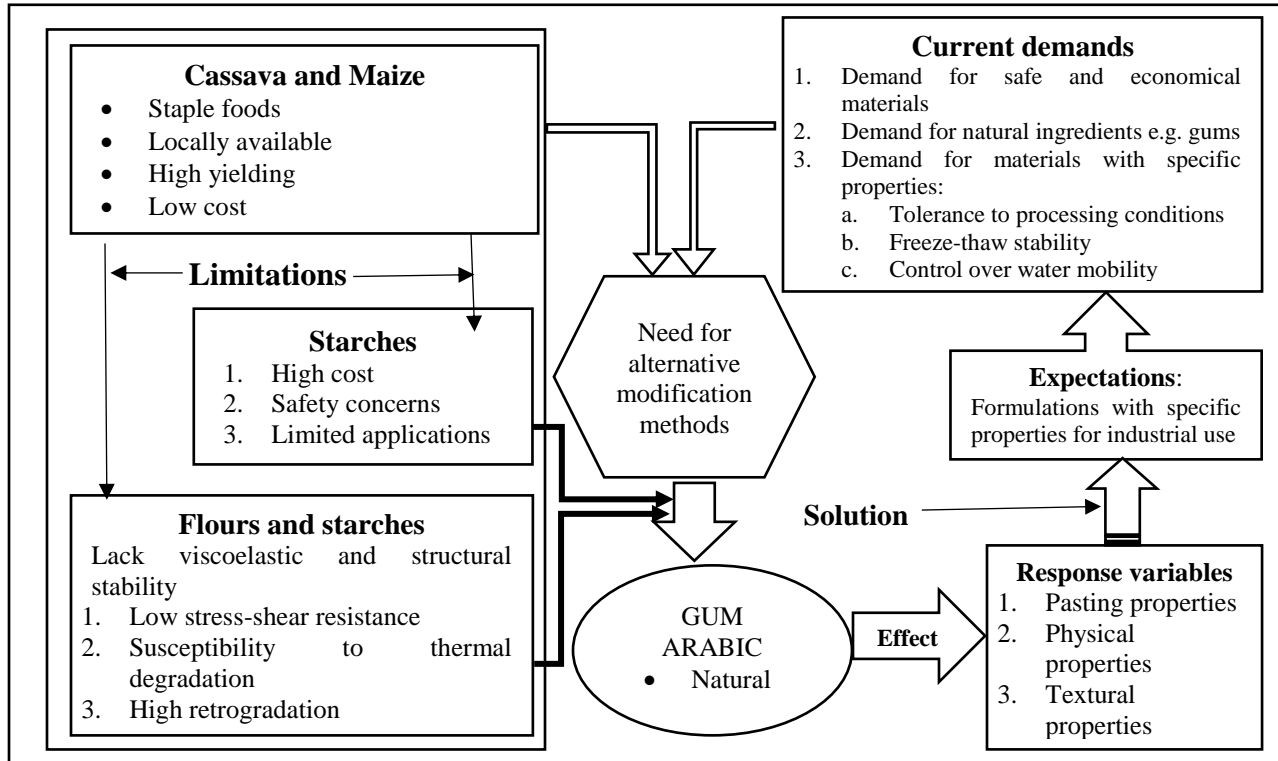


Figure 2.9: Conceptual framework

CHAPTER THREE

INFLUENCE OF GUM ARABIC FROM *ACACIA SENEGAL* VAR. *KERENSIS* ON THE MODIFICATIONS OF PASTING AND TEXTURAL PROPERTIES OF CASSAVA AND MAIZE STARCHES

Abstract

The use of hydrocolloids to modify the properties of native starches has been on the rise due to the market demand for natural, safe and economical food ingredients. The study of the effect of gum on the viscosity of starch system is important for the product and process development. *Acacia senegal* var. *kerensis* gum Arabic's effects at different levels (0 %, 0.5%, 2.0%, 4.0%, 6.0% and 8.0 %) was investigated on the pasting and textural properties of maize and cassava starches was investigated. Blends were prepared by substituting the starches with gum, whereas native maize and cassava starches were used as control. The objective of replacing starch with gum was to modify the starch properties as an alternative to chemical and enzymatic modification. The pasting properties of the starch-gum mixed systems were determined using the Brabender viscograph while the textural properties (firmness, consistency, cohesiveness and work of cohesion) were determined using Texture Analyzer. Results showed that the levels of gum Arabic used significantly decreased all the viscosity parameters (peak viscosity, final viscosity, break down and setback values) of both starches. However, gum Arabic had no discernible impact on the onset pasting temperature (71.8 °C - 72.1 °C) and (68.7°C - 68.9 °C) for maize and cassava starch respectively. The degree of gel firmness and consistency was higher in maize starch than in cassava starch and the effect of level of gum addition differed with each starch. The results indicate that gum Arabic significantly changed the pasting and textural properties of maize and cassava starches due to strong interaction between the gum and the starches hence could play a major role in controlling retrogradation and determining starch end use functionality.

3.1 Introduction

Starch is the main source of energy in the human diet and the most abundant polysaccharides mainly obtained from cereals and tubers. Starch is gaining biggest attention as compared to other carbohydrate polymers and the abundant production of starch has a bright future in sustainable food supply to the world (Mahmood *et al.*, 2017). Starches with industrial significance are from

maize, potato, cassava, wheat and rice (Yazid *et al.*, 2018). However, studies have indicated that native maize and cassava starches generally have limited functionality due to low shear stress resistance, susceptibility to thermal degradation, high retrogradation rate and syneresis. As a consequence, this has reduced maize and cassava starch applications in food systems and industries. Therefore, to meet the demanding technological needs of today, the properties of starch are altered by a variety of modification methods. Starch modification is particularly aimed at correcting one or some of the aforementioned shortcomings which in turn will enhance its versatility and satisfy consumer demand (Neelam *et al.*, 2012). Therefore, to improve the functionality of native starches different means of modification become necessary *visa viz* physical, chemical, enzymatic and other methods that includes use of natural additives. But due to market demands for economical, safe and natural food ingredients, different types of hydrocolloids are being extensively used to modify properties of different native starches such as pasting and texture (Hussain, 2015). But little information is available on how gum Arabic from *Acacia senegal* var. *kerensis* modifies such properties.

Cereal grains contain 60 to 70% starch and an excellent source of energy, vitamin and minerals including fat soluble vitamin E, which is an essential antioxidant (Oluwole *et al.*, 2016). Maize or maize (*Zea mays*) is one of the cereals of worldwide importance whose grain is used for human consumption and its starch has important industrial applications (BerMiller & Whistler, 2009). Cassava (*Manihot esculenta* Crantz) is one of the root crops that has gained attention in developing world because of its economic importance in addressing food insecurity (Opondo *et al.*, 2020). The advantage associated with cassava starch is that it is not only easily extracted using simple methods but also it is versatile in functionality as compared to starches from other sources due to its clear paste with a bland taste and relatively high viscosity and low cost (Sharma *et al.*, 2009). When modified cassava starch has widespread usage in the food industry including utilization in bread, cakes, extruded cereals, beverages and sauces (Chen *et al.*, 2015). Maize starch contributes about 70% of the world starch requirements (Bertolini, 2010). It has extensively been used for syrup production especially high fructose maize syrup for industrial needs. Maize also produces high amylose starch; it has an elevated level of gelatinization temperature compared to other types of starch and maintains its resistant starch content during

baking, mild extrusion and in further food processing techniques (Bertolini, 2010; Yazid *et al.*, 2018).

Hydrocolloids are rich in hydrophilic groups that have good water binding ability thus can alter the rheology of aqueous systems to which they are added (Mahmood *et al.*, 2017). Hydrocolloids (gums) are utilized in food industries since they improve stability, modify textural profile and reduce the retrogradation rate of starch. According to Borries-Medrano *et al.* (2018) for starch to perform better and for products to be of higher quality without adding more calories, starch and gums must be blended. Researchers have indicated that the following variables affect the mechanisms of hydrocolloid modification on the pasting properties of starch: (1) the ordered arrangement of molecules in the continuous phase (2) the hydrocolloid's properties in the continuous phase (3) the swelling of starch granules in the hydrocolloid-starch system, as well as (4) the interactions between the swollen starch granule and its fragments, the continuous phase and dispersion phase interaction and any electrostatic interactions between the hydrocolloid molecules and the starch granules (Chaisawang & Suphantharika, 2006; Marta *et al.*, 2020).

Gum Arabic (GA) or acacia gum is obtained from various species of acacia tree and has been reported to be an encapsulating, emulsifying and thickening agent (Varela *et al.*, 2016). High-molecular-weight polysaccharides and their calcium, magnesium and potassium salts make up the majority of gum Arabic. These polysaccharides and proteins hydrolyze to produce three main fractions: arabinogalactan (AG), arabinogalactan protein (AGP), and glycoprotein (GP). These fractions differ in terms of molecular weight and chemical composition. AGP is the fraction that is thought to be the most interfacially active among them, and it is mainly responsible for GA's emulsifying qualities (Castellani *et al.*, 2010). Acacia gum is widely used in the food industry mainly to impart desirable qualities because of its influence over viscosity, body and texture of products (Saha & Bhattacharya, 2010). Studies have shown that starch-gum Arabic blends have the ability to retain flavor thus provides an opportunity to extend its application in edible/biodegradable film formation (Mahmood *et al.*, 2017; Varela *et al.*, 2016). However, the extend of modifications caused by gum Arabic from the *Acacia senegal* var. *kerensis* on pasting properties of starches remains unreported.

Several recent studies have investigated starch - hydrocolloid combination aimed at overcoming the deficiencies of native and modified starches (Hussain *et al.*, 2020; Singh *et al.*, 2016). The

properties of native starch were changed to a certain degree by the addition of hydrocolloids /gums in all of these studies. The study of Chen *et al.* (2015) found that addition of gum Arabic (GA) into a tapioca starch suspension resulted to a reduction in the swelling power, solubility index and the peak viscosity. This demonstrates that GA can be used as a stabilizer and viscosity controlling agent in the food industry. According to Singh *et al.* (2016) low concentrations of GA can beneficially be used to improve the rheological behavior of tapioca starch. Observation made by Varela *et al.* (2016) depicted that mixing wheat or potato starch with Arabic gum did not have any significant effect on the viscosity and pasting properties of the starch-hydrocolloid blends. The recognition of pasting properties of starches have been shown as a vital measure of the processing conditions of foods and their constituents. Such understanding enables a processor to optimize pressure, temperature and shear limits to attain a product of required uniformity and attributes (Kaur *et al.*, 2018). Pasting and textural properties of starches are very important variables for food product development mainly for modifying texture and stability of the products.

The purpose of this investigation was to assess the impact of adding gum Arabic from *Acacia senegal* var. *kerensis* on the pasting and textural properties of maize and cassava starches. The findings from this study supply scientific data for expanding the applied range of GA in the food industries. Accordingly, a better understanding of the effects and interactions of this hydrocolloid on cassava and maize starches could be beneficial for its utilization to improve storage stability and textural quality of cassava and maize starch-based foods.

3.2 Materials and Methods

3.2.1 Materials

Native (unmodified) cassava and maize starches were acquired from Ingredion Holding LLC, Nairobi, Kenya. *Acacia senegal* var. *kerensis* gum was obtained from the Kenya Forestry and Research Institute (KEFRI), Nairobi, Kenya.

3.2.2 Sample preparation

Gum Arabic from *Acacia senegal* var. *kerensis* was prepared at Egerton University Food processing plant. Before the gum was ground into flour or tiny particles, it was sorted to remove any dirt, bark fragments, or foreign objects. It was then sealed properly in thermopak containers

and kept until the analyses were completed. In order to perform pasting measurements, formulations of starch and gum mixture was prepared to make 40g slurries. Different amounts of gum Arabic (0 %, 0.5%, 2.0 %, 4.0 %, 6.0 % and 8.0 % g/g on dry weight basis) were applied by replacing the amount of starch. The levels of gum Arabic that was added in flour or starch of maize and cassava were determined in pre-trial experiments. The gum was used without further purification. The 0% level (native / unmodified starch) was used as the control. A shaker was used to fully mix the samples in order to create a uniform starch-gum combination. Using a fast moisture meter set at 105°C, approximately 3g of the starch-gum mixture and native starches from maize and cassava were obtained to confirm the moisture content. Following the measurement of each sample's moisture content, a correction of up to 14% was applied, and the precise quantity of starch and water was measured and vigorously mixed into a slurry.

3.2.3 Determination of pasting properties

A Brabender Viscograph - E (Brabender GmbH & Co. KG, Duisburg, Germany) was used to measure the pasting characteristics of starch at a speed of 85 rpm and a torque of 700 cmg, as stated by Onyango (2014). In brief, 40g of starch and starch-gum mixture (adjusted to 14% moisture content) and 420 ml of distilled water were introduced to the dry, empty Viscograph-E canister to create slurries. The mixture was thoroughly stirred and the canister was then fitted into the Brabender Viscograph as per manufacturer's instructions. The slurry was heated from 30°C to 93°C at a rate of 1.5 °C/min; held at 93°C for 15min; cooled to 30°C at 1.5°C/min and finally held at 30°C for 15min. Resistance to stirring was recorded as viscosity in Brabender Units (BU). The pasting temperature (°C), peak viscosity (BU), breakdown viscosity (peak viscosity minus trough viscosity, BU), setback viscosity (final viscosity minus trough viscosity, BU) and final viscosity (BU) (as indicated in Figure 3.1) were determined with the aid of Viscograph - E correlation software connected to a computer.

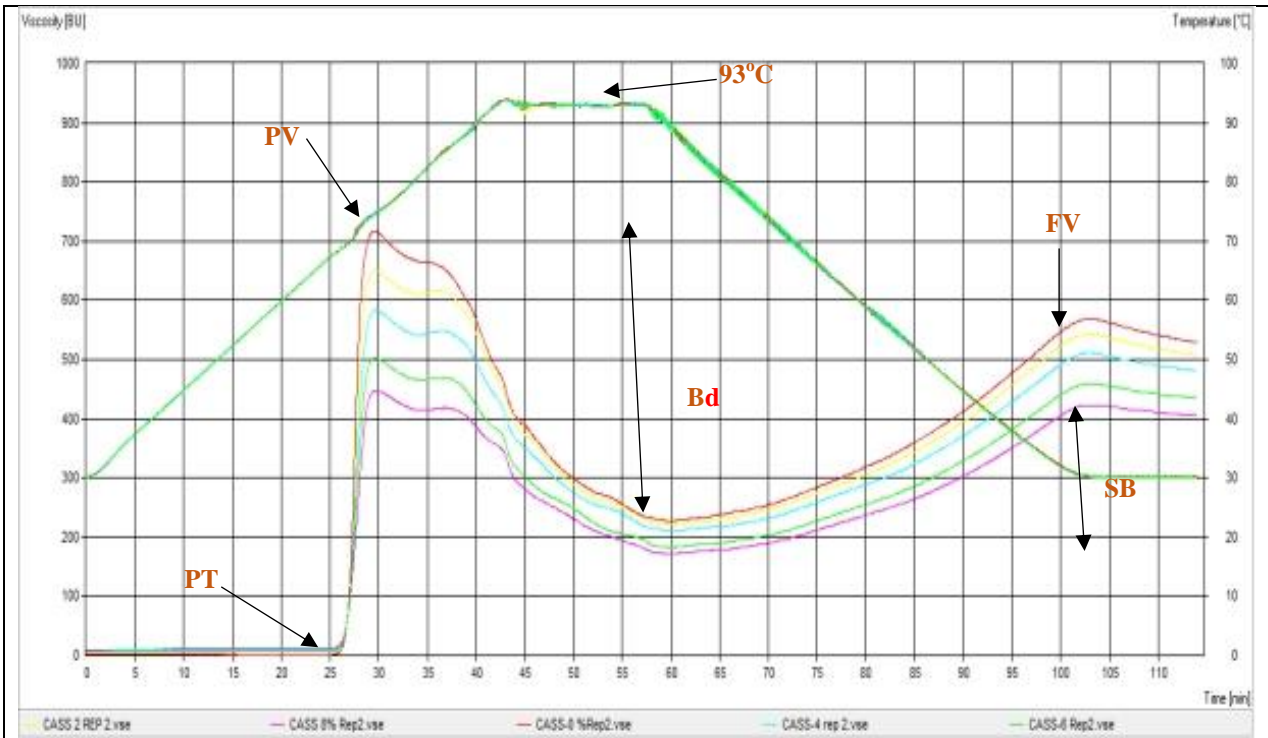


Figure 3.1a: Viscograms of cassava starch (CaS) - gum blends

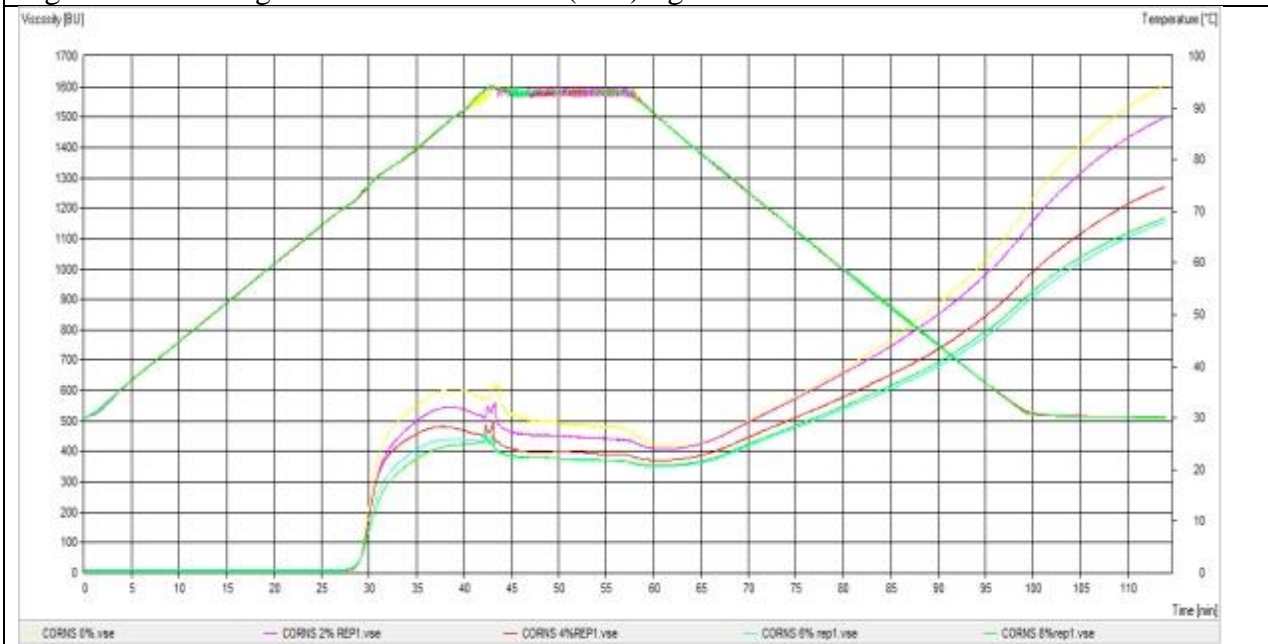


Figure 3.1b: Viscograms of maize starch (MS) - gum blends

Figure 3.1: Viscograms of gum Arabic effect on pasting properties of cassava and maize starches

Key: CaS is cassava starch; MS is maize starch

3.2.4 Determination of textural properties

The textural properties of the starch and starch-gum gels were determined by using back extrusion tests as described by Onyango (2014). Approximately 80g of the slurries obtained from the Brabender Viscograph - E were poured into 50mm diameter A/BE back extrusion containers (Stable Micro Systems, Surrey, UK). Back extrusion force was measured using TA. XT - *plus* Texture Analyzer (Stable Micro Systems, Surrey, UK) at the following TA settings: mode of measurement: force; load cell: 50kg; height calibration: 80mm; disc diameter: 45mm; pre-test speed: 1mm/s; trigger force: 10g; post-test speed: 10mm/s; data acquisition rate: 200pps; penetration distance: 30mm. Firmness (maximum positive force, g), consistency (area of the positive region of curve, g's), cohesiveness (maximum negative force, g) and work of cohesion (area of the negative region of the curve) were determined using Texture Analysis software.

3.2.5 Statistical Analysis

Samples were analyzed in triplicate and data obtained was analyzed statistically utilizing version 9.1 of SAS software (SAS Institute and Cary, NC). Analysis of variance (ANOVA) was carried out to study the effect of gum Arabic on the pasting and textural properties. Pearson's correlation was done to establish the strength of relationship between pasting and textural properties. Tukey's honestly significant difference (HSD) test was used in post-hoc analysis at $P < 0.05$.

3.3 Results

3.3.1 Pasting properties of maize and cassava starches

Analysis of Variance (ANOVA) showed that the type of the material (maize flour or starch and cassava flour or starch), substitution level of gum arabic in the materials and their interaction significantly affected the pasting properties (As shown in Appendix III part A). The pasting behaviors of maize and cassava starches are shown in Table 3.1. Maize starch (MS) displayed a significantly higher onset pasting temperature, final and setback viscosity values as compared to that of cassava starch (CaS) which displayed a higher peak and breakdown viscosity values.

Table 3.1 :Pasting properties of maize and cassava starches

Starch	Onset pasting temp (PT)	Peak viscosity (PV)	Final viscosity (FV)	Breakdown (Bd)	Setback (SB)
Cassava	68.78±0.03 ^b	602.25±0.82 ^a	481.75±4.79 ^b	382.50±4.34 ^a	260.58±9.89 ^b
Maize	71.79±0.02 ^a	539.92±1.25 ^b	1426.26±6.19 ^a	117.67±7.70 ^b	645.00±3.25 ^a

Key: Means with the same letter along the column are not significantly different at $p < 0.05$

Table 3.2 displays the impact of gum Arabic quantity on the pasting properties of maize starch (MS) and cassava starch (CaS). Gum Arabic decreased significantly the viscosity parameters at higher substitution levels but no effect observed on the onset PT (68.85 to 68.65 °C) and (72.05 to 71.85 °C) for CaS and MS, respectively. Native maize and cassava starch (control samples) exhibited highest PV values 723.50 BU and 636.50 BU respectively. With increasing substitution levels of GA, the peak viscosity (PV) values for CaS decreased significantly whereas for MS, although there was a marked reduction, no significant difference can be observed at higher gum levels (4, 6 and 8%). The same trend can be observed for the FV, Bd and SB where a significant decrease with increasing substitution level of GA can be observed, though at lower levels (0.5 and 2%) the viscosity parameters showed no discernible variations from the control sample (0% GA).

3.3.2 Effect of gum Arabic level in starch material on textural properties

Analysis of Variance (ANOVA) showed that the type of the material (maize flour or starch and cassava flour or starch), substitution level of gum Arabic in the materials and their interaction significantly affected the textural properties (As shown in Appendix III part B). The effect of GA on the textural properties of maize and cassava starches is shown in Figure 3.2. Gum Arabic had a significant effect on the firmness, consistency and work of cohesion of both MS and CaS gels. However, there was no significant effect of GA on the cohesiveness of both starch gels though 8% GA level had the highest value (-652.10g) and 0.5% had the least value (-1082.08g) for MS gel while 6% GA level had the highest value (-128.41g) and 0% had the least value (-146.28g) for cassava starch gels. As the levels of gum increased from 0.5 to 8% there was a significant reduction on the firmness of MS gels as compared to CaS gels that showed no marked difference at lower (0 %, 0.5%, 2%) and higher (6% and 8%) gum substitution levels. The firmness of CaS containing 8% gum was the highest (94.32g), while it was the lowest in sample containing 2%

gum (78.93g) however, in the case of MS gels, the gum significantly reduced the firmness with 8% gum having the lowest value (618.42g) while the control 0% gum had the highest value (894.90g). There was a significant reduction in the consistency of MS gels as the levels increased from 0.5% to 8% however, there was no significant effect in the consistency of CaS gels as the level increased from 0% to 2.0% but as the level of GA was increased to 6% the consistency of the starch increased though no difference was observed between 6% to 8% GA level. Similarly, the presence of GA in CaS gels showed a slight increase in the work of cohesion. In the case of MS gels such changes were not found, however, a significant decrease in values of this parameter was observed for samples with 0.5, 4 and 6% GA levels.

Table 3.2: Pasting profile of cassava and maize starches at different concentrations of gum Arabic

Starch	GA %	OPT (°C)	PV (BU)	FV (BU)	Bd (BU)	SB (BU)
Cassava	0.0	68.85±0.05 ^a	723.50±7.50 ^a	528.00±0.00 ^a	484.00±5.00 ^a	293.00±3.00 ^a
	0.5	68.90±1.10 ^a	704.50±3.50 ^a	533.50±3.50 ^a	463.00±4.00 ^a	295.50±4.00 ^a
	2.0	68.75±0.05 ^a	657.00±6.00 ^b	514.50±6.50 ^a	421.00±4.00 ^b	281.00±4.00 ^a
	4.0	68.75±0.05 ^a	578.50±4.50 ^c	477.50±3.50 ^b	360.00±2.00 ^c	257.00±1.00 ^b
	6.0	68.65±0.05 ^a	502.00±1.00 ^d	433.50±1.50 ^c	301.50±4.50 ^d	227.00±5.00 ^c
	8.0	68.65±0.05 ^a	448.00±0.00 ^e	403.50±1.50 ^d	265.50±0.50 ^e	210.00±2.00 ^c
Maize	0.0	72.05±0.05 ^a	636.50±1.50 ^a	1633.00±5.00 ^{ab}	157.00±9.00 ^a	716.00±5.00 ^{ab}
	0.5	72.00±0.00 ^a	619.50±0.50 ^a	1764.50±6.50 ^a	132.00±2.00 ^{ab}	812.00±2.00 ^a
	2.0	71.95±0.05 ^a	559.00±4.00 ^b	1479.00±2.00 ^b	130.50±5.50 ^b	669.50±1.50 ^b
	4.0	71.95±0.05 ^a	498.00±1.00 ^c	1259.00±2.00 ^{bc}	110.00±0.00 ^{bc}	560.00±1.00 ^c
	6.0	72.00±0.00 ^a	463.50±0.50 ^c	1187.50±0.50 ^c	91.50±4.50 ^c	536.00±2.00 ^d
	8.0	71.85±0.05 ^a	463.00±3.00 ^c	1237.00±7.00 ^c	85.00±7.00 ^c	576.00±3.00 ^{bc}

Key: Means with the same letter along the column within the same starch source are not significantly different at p<0.05. OPT= Onset pasting temperature; PV= peak viscosity; FV= final viscosity; Bd= breakdown viscosity; SB= setback viscosity; BU=Brabender units; GA= Gum Arabic.

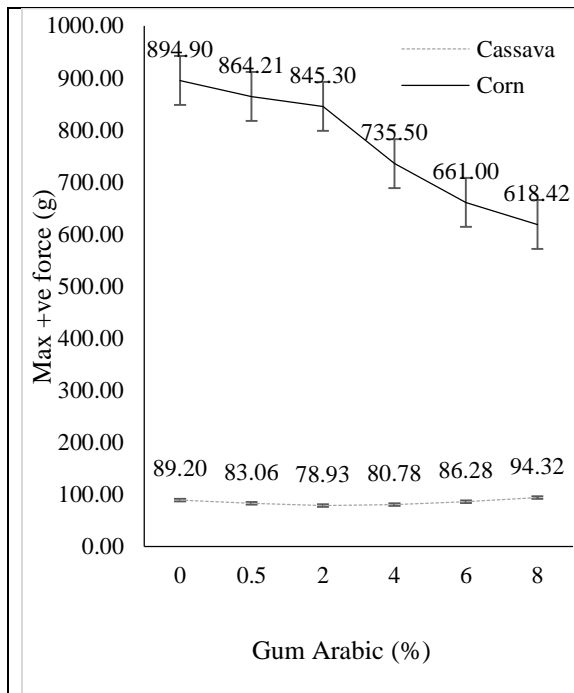


Figure 3.2a: Effect of gum Arabic on Firmness of maize and cassava starches

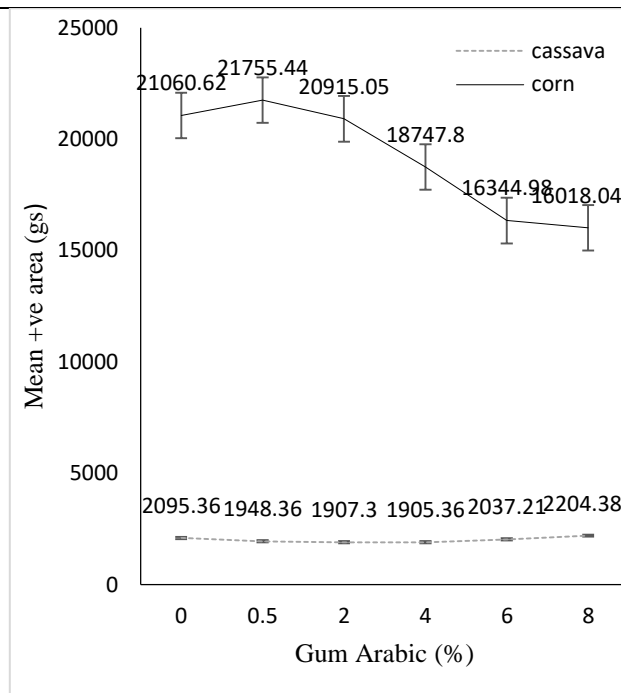


Figure 3.2b: Effect of gum Arabic on consistency of maize and cassava starches

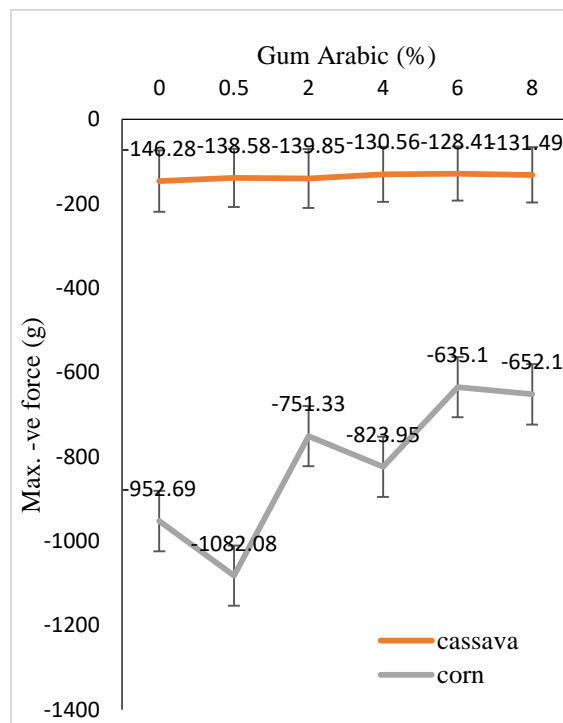


Figure 3.2c: Effect of gum Arabic on work of cohesiveness of maize and cassava starches

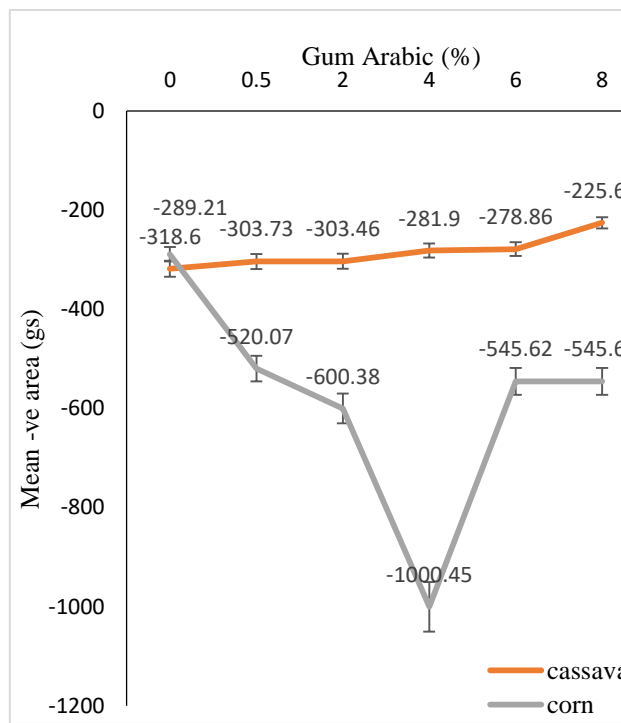


Figure 3.2d: Effect of gum Arabic on work of cohesion of maize and cassava starches

Figure 3.2: Textural behaviour of cassava and maize starch gels containing gum Arabic

3.3.3 Effect of gum Arabic on the relationship between pasting and textural properties of maize and cassava starches

Correlation relationship between textural and pasting properties of maize and cassava starches with gum Arabic is shown in Table 3.3. All the properties showed medium to strong positive and negative significant correlation coefficients except peak viscosity which exhibited a non-significant relationship with all properties except breakdown viscosity. Starches cohesiveness and work of cohesion textural properties significantly had a strong negative correlation with onset pasting temperature, final viscosity and setback viscosity but showed significantly positive correlation with breakdown viscosity. On contrary, firmness and consistency had a significant positive correlation with onset pasting temperature, final viscosity and setback viscosity but showed significantly negative correlation with breakdown viscosity. Firmness and consistency of starches were significantly positively correlated ($r = 0.999$) while cohesiveness and work of cohesion had a significantly medium positive correlation ($r = 0.582$). Among pasting properties, only breakdown viscosity that exhibited a significant negative correlation with onset pasting temperature ($r = -0.895$), final viscosity ($r = -0.806$) and setback viscosity ($r = -0.776$).

Table 3.3: Correlation coefficients of textural and pasting properties of maize and cassava starches with gum Arabic

	Firmness	Consistency	Cohesiveness	WOC	OPT	PV	FV	Breakdown	Setback
Firmness	1.000	0.999***	-0.969***	-0.597**	0.979***	-0.222 ^{ns}	0.984***	-0.866***	0.969***
Consistency		1.000	-0.972***	-0.624***	0.983***	-0.239 ^{ns}	0.983***	-0.875***	0.966***
Cohesiveness			1.000	0.582***	-0.943***	0.170 ^{ns}	-0.970***	0.822***	-0.958***
WOC				1.000	-0.659***	0.372 ^{ns}	-0.523**	0.617***	-0.508*
OPT					1.000	-0.300 ^{ns}	0.952***	-0.895***	0.938***
PV						1.000	-0.105 ^{ns}	0.671***	-0.059 ^{ns}
FV							1.000	-0.806***	0.997***
Breakdown								1.000	-0.776***
Setback									1.000

Key: WOC= Work of Cohesion; OPT=Onset Pasting Temperature; PV= Peak Viscosity; FV= Final Viscosity; ***= Significance level is $p = 0.001$; **= Significance level is $p = 0.01$; *= Significance level is $p = 0.05$; ns = Not significant at $p < 0.05$.

3.4 Discussion

3.4.1 Effect of GA on the pasting properties of cassava and maize starches

The process of pasting occurs when starch granules are heated continuously in the presence of excess water resulting to granule swelling and additional leaching of dissolved starch polymer molecules. The cohesive forces in the swollen granules become excessively weakened and the structure of the paste collapses (Bermiller, 2011). Swelling of granules accompanied by leaching of amylose has been shown to lead in an increase in viscosity. Granules may sometimes rupture during further heating resulting in a decrease in viscosity. Pasting temperature (PT) is an indicator of minimum energy required to cook food products containing starch. It is also a point where viscosity starts to increase (Shahzad *et al.*, 2019). Cassava starch swells to a greater extent than MS as depicted by the peak viscosity though MS is more stable than CaS as depicted by the final, break down and set back viscosities as shown in Table 3.1. This difference may be attributed to the higher amylose content (25%) with lipids in MS that form a complex restricting swelling as compared with CaS with relatively lower amylose content (17%). This agrees with previous study by Ai and Jane (2015) that reported that starch consisting of a larger amylose-content particularly with the presence of lipids displays a higher PT and a lower PV because amylose restricts the swelling of starch granules during heating and shearing. Similarly, according to Damodaran *et al.* (2008), tuber (potato) and root (tapioca /cassava) starches have weak intermolecular bonding and swell greatly to give high viscosity pastes however, the viscosity decreases quickly if shear force is applied since the highly swollen granules tend to break easily. The functional properties of starches may vary depending on their source, structure, grain size, grain shape, amylose content, chain length of amylopectin and methods of extraction (Hussain *et al.*, 2020).

Numerous writers have noted that the inclusion of hydrocolloids modifies starch's pasting characteristics (Bawa *et al.*, 2020; Chen *et al.*, 2015; Mahmood *et al.*, 2017). The current findings demonstrated that the pasting temperature (68°C and 72°C for CaS and MS respectively) was unaffected by GA's addition. This illustrates that, as indicated in Table 3.2, the gum had no effect on the rate of gelatinization. Lufti *et al.* (2017) reported similar results where acacia gum (GA) had neither positive nor negative effect on the pasting temperature of water chestnut starch. The high pasting temperature of MS indicates that it's more resistant against swelling than CaS and this can be attributed to the amylose lipid complex in the former. According to Bermiller (2011) native potato and tapioca starches have weak

intermolecular bonding and gelatinize easily to produce high- viscosity pastes that thin rapidly with moderate shear. Peak viscosity (PV) has been described as the point at which maximum swelling of starch granule is observed (Shahzad *et al.*, 2019). Maize starch depicted a relatively lower PV (539 BU) than cassava starch (602 BU) and this may be due to greater swelling of the granules of CaS as compared to MS (Table 3.1). As shown in Table 3.2, the coating of starch granules with GA resulted in limited granule swelling and decreased granule association, thus explaining the reason for the decrease in PV in the current study. Chen *et al.* (2015) made a similar finding and showed unequivocally that adding GA to tapioca starch significantly ($P<0.05$) reduced its peak viscosity, relative breakdown, and total setback values. This could be beneficial for stability during storage. Previous study by Song *et al.* (2008) reported similar findings where GA and xanthan gum levels showed reduced starch pasting capabilities for maize and wheat. Contrary findings were reported by Saleh *et al.* (2016) whose results indicated a significant increase in pasting viscosities of the starch analyzed as a result of hydrocolloids addition regardless of type and ratio of hydrocolloids added.

The change in the PV during heating clearly indicated that starch gelatinization occurred upon heating. It was also evident from the current study that a strong impact existed on the addition of GA to the MS and CaS dispersions. The GA presumably covered most of the starch granules and promoted granules association which restricted swelling of the granules and limited the increase in viscosity during pasting. According to Shahzad *et al.* (2019), the addition of gum Arabic to sweet potato starch caused the maximum reduction in the peak viscosity and even though GA exhibited the least pasting temperature, it depicted the highest setback among the other gums thus can significantly reduce retrogradation process. Most of the hydrocolloids frequently used have been shown to increase the viscosity but the hydrocolloids with lower molecular mass more often may lead to a decrease in the viscosity as observed by Alamri *et al.* (2012) and Qiu *et al.* (2015) for okra and maize fiber gum respectively. This situation have demonstrated to be useful with regards to viscosity control of mixture /dispersions.

The reduction in peak viscosity may be attributed to the retardation of granule destruction and leaching of amylose especially when the negatively charged starch solution was heated with anionic gums. Also, such effects can be due to interactions between leached amylose molecules and the gum used as explained by Shi and BerMiller (2002) and BerMiller (2011).

The effect of GA on final viscosity of starches was also established in the present study. The final viscosity (FV) has been described as the measure of the stability of gelatinized starch and its capacity to cool and solidify into a paste or gel (Shimelis *et al.*, 2006). This study's findings showed a decrease in the FV for both starches (maize and cassava) at 8% gum concentration though MS had significantly higher FV value than CaS (1237 BU and 403 BU respectively) as shown in Table 3.2. This suggests that foods with reduced viscosity can benefit from the addition of GA. The present results are consistent with those of previous studies that showed a reduction in FV at different concentrations when a hydrocolloid was added (Alamri *et al.*, 2012; Bawa *et al.*, 2020).

During pasting a considerable continued granule swelling and leaching of starch polymer (primarily amylose) molecules do usually occur. During the 93°C hold as shown in Figure 3.1, the fragile swollen granules break or disintegrate under force (the shear conditions of the instrument) resulting to a decrease in viscosity to a trough viscosity a process frequently referred to as the breakdown. Breakdown (Bd) viscosity measures the variation between peak and trough viscosities; this parameter is associated with the granules' resistance to heat and mechanical shear during continuous heating (Ribotta *et al.*, 2010). The addition of GA in the present study demonstrated that an interaction occurred between the gum and both starches and thus affected the swollen starch granules. The reduced Bd upon the addition of GA indicates that the swelling and shear-thinning of starch was retarded during pasting. Low breakdown value of starch granules has been suggested to be more stable during cooking and by extension a stronger cross-linking within the starch granules is evident as explained by Shimelis *et al.* (2006). As a result, maize starch is more stable than CaS, as shown by the values in Table 3.2 and Figure 3.1. This can be explained by the fact that MS granules are tighter and more resistant to breaking down than CaS granules, which are more brittle when exposed to mechanical stresses. Furthermore, less starch granule rupture is linked to reduced breakdown, which might ensure a more stable cooked paste (Shimelis *et al.*, 2006).

Table 3.2 illustrates how the setback values significantly ($p < 0.05$) reduced as the GA concentrations increased, with CaS and MS recording lower setback values of 210 BU and 576 BU, respectively. Consequently, CaS can resist retrogradation tendency as compared to MS due to low setback value. Based on this finding, starch-based products' storage qualities may be enhanced by the inclusion of gum Arabic, which could delay retrogradation. Bawa *et al.* (2020) reported comparable observations for starch-*Agbagoma* pectin mixtures and

Alamri *et al.* (2012) for the starch of rice and sorghum. When the mixture cools during pasting, a phenomenon known as "setback" occurs, during which there is evidence of some degree of reassociation between the starch molecules (Sharma *et al.*, 2009) also according to these authors a greater resilience to retrogradation is indicated by a lower setback viscosity. Correspondingly, Chen *et al.* (2015) similarly found that GA lowered the PV and swelling power leading to a delay of retrogradation. A decrease in the amount of amylase-amylose interactions, which are essential for starch retrogradation, has been associated with the competition of hydrocolloids and amylose molecules, which have a tendency to form an intermolecular bond during cooling (Leite *et al.*, 2012).

3.4.2 Effect of GA on the textural properties of cassava and maize starches

Cassava and maize starches showed variation in textural parameters as shown in Figure 3.2, which may be attributed to differences in starch granule size, shape and amylose content. Maize starch gels displayed higher firmness values as compared to CaS gels which agrees with the fact that the crystalline size and association within the maize granules are of a higher order of magnitude than that in cassava granules (Bermiller & Whistler, 2009). According to Bermiller and Whistler (2009), cassava (tapioca) starch produces clear, cohesive pastes that gel slowly with time while native maize, rice and wheat starches form opaque, gelled pastes that have a slight cereal flavour. The firmness of CaS gels slightly decreased as a result of replacement of starch with gum Arabic (GA) however, it increased at higher levels used (8%) though it showed no significant difference with the native CaS (0%) (Figure 3.2). This slight increase in the firmness of the gels at high gum concentration may be attributed to augmented effective concentration of starch by the binding of water molecules by the macro-molecules of the gum. On the other hand, the firmness of maize starch gels was significantly decreased with addition of GA ($p < 0.05$). This can be attributed to the fact that the strongly swollen granules usually become softer, fragile and disintegrate often resulting to a decrease in starch firmness.

A previous study reported similar results where the addition of hydrocolloids, particularly xanthan gum and GA, decreased the hardness of the pastes compared with that of the native maize starch (He *et al.*, 2014). The firmness reduced further for maize starch gels when the amount of GA was increased and this agrees with previous studies that suggested that the addition of hydrocolloids reduces the gel strength since the hydrocolloids tend to hamper the amylose molecular gathering and rearrangement hence weakening the interaction of amylose

molecules (He *et al.*, 2014; Zheng *et al.*, 2020). Our findings also concur with those reported by da Silva Costa *et al.* (2020) where the addition of xanthan gum to arrow root starch gels produced the opposite effect on gel hardness, showing great hardness at very low levels, which gradually decreased as the hydrocolloid levels increased. Consequently, Hussain *et al.* (2020) observed that when compared to 6%, greater gum levels (i.e., 9% and 12%) reduced gel hardness. The researchers characterized this phenomenon as the starch dilution effect, which happens when the amount of amylose in the blends decreases as the gum level increases.

According to a previous study by Song *et al.* (2008), the starch-hydrocolloid combination affects the gel's hardness or firmness. The relative concentration of starch and gum is said to affect the hardness of the mixed gels by immobilization of water molecules and interaction between the hydroxyl group of the gum and starch molecules. The degree of polymerization and linearity of dispersed particles and interactions between molecules in the gel system have been shown to play a vital role in the textural properties including hardness/firmness of gel (Borries- Medrano *et al.*, 2018; Galkowska *et al.*, 2014).

The presence of GA in the cassava starch gels may have led to a modest increase in consistency, indicating a stronger gel structure as a result of the polymer interactions. The area of the positive region of the curve is used to assess the thickness of the sample during textural studies of starch gels using the back extrusion method; the larger the value, the thicker the sample (Haddad *et al.*, 2019). In the case of maize starch gels consistency of maize starch decreased with an increase in the levels of GA (Figure 3.2). The consistency of maize starch gels at higher gum concentration (8%) was significantly lower than the native maize starch and this may be attributed to the fact that the gum helps to weaken the amylose networking by hampering between the amylose molecules. Additionally, these findings suggest that a higher gum concentration weakens internal connections and decreases resistance to structural breakdown. This behavior has been attributed to reduced leaching of amylose molecules that are responsible for strengthening the internal bonds of starch gels as reported by several researchers (Chaisawang & Suphantharika, 2006; da Silva Costa *et al.*, 2020; Shahzad *et al.*, 2019). It is noteworthy that the strength of the cassava gel was found to be ten times lower than the strength of the maize starch gel when comparing the two gels without gelatin addition (GA). However, the presence of GA, especially at the lower

substitution levels with starch, reduced the differences in the strength values of the respective gels.

The maximum negative force is taken as an indication of cohesiveness of the sample therefore the more negative the value the more 'cohesive' is the sample (Shahzad *et al.*, 2019). These authors further explained that the strength of bonds which includes a mutual effect of cohesive and adhesive forces along with elasticity and viscosity dictates the sample cohesiveness. The results of this investigation indicate that gum Arabic did not have an impact on the cohesiveness of both starches however, maize starch gel was more cohesive than cassava starch gel and this could be due to high amylose content in maize starch as shown in Figure 3.2c. This behavior can be explained by the same interactions that influenced the firmness and consistency of the starches with added GA for instance coating the granules, restricting swelling and a reduction in leaching of amylose also as suggested by Ribotta *et al.* (2010) for xanthan gum, however this should be further investigated. Similarly, findings reported by Galkowska *et al.* (2014) on the influence of cassia gum on textural properties of native potato and maize starch gels showed that potato starch gel values in most cases occurred to be lower than those of respective maize starch gels for all the parameters determined. The area of the negative region of the curve may be referred to as the work of cohesion and various studies have reported that the higher the value the more resistant the sample to withdrawal which is an indication of the consistency or viscosity of the sample (Haddad *et al.*, 2019; Teng *et al.*, 2013). The results of the present study showed an increase in the work of cohesion for CaS gels as compared to MS gels (Figure 3.2d), an outlier was observed for MS at 4% (caused a sharp decrease in WOC). The MS gels also appear to require considerably more force to penetrate to the same depth as CaS gels and this may be linked to strong associative forces between MS granules. A recent study by Bae *et al.* (2019) demonstrated that the addition of 1.5% Arabic gum was the most effective in reducing the *in vitro* starch digestibility and improving the cooking properties of noodles therefore the current study recommends further studies incorporating the gum and the said starches on such properties.

3.4.3 Relationship between pasting and textural properties

The effect of gum Arabic on the functionality of cassava and maize starches has been examined by determining the pasting and textural properties is indicated in Table 3.1. Regression analysis showed a correlation between the textural parameters (firmness,

consistency, cohesiveness and work of cohesion) and viscosity parameters. However, the peak viscosity did not significantly correlate with any of the textural properties (Table 3.1). This may suggest that granule expansion is restricted and that forces associated with starch granules are weakened, making the granules more prone to breaking down in weak gel.

Firmness and consistency significantly correlated with setback and the final viscosity which indicates that the greater the ability of a starch to form a paste during cooling thus the greater the energy needed to penetrate or deform the gel. This is consistent with observations made by Galkowska *et al.* (2014), who discovered relationships between setback viscosity and hardness in cassia gum. The breakdown values significantly negatively correlated with firmness and consistency ($r = -0.866$ and $r = -0.875$) indicating retardation of starch swelling however onset pasting temperature significantly positively correlated with the mentioned texture parameters which may indicate more energy required to achieve stability of the pastes/gels. Values of the cohesiveness and work of cohesion were significantly negatively correlated with FV and SB values which may indicate a decrease in the sample's viscosity, flexibility, and internal starch gel linkages. These findings are consistent with previous reports (Chaisawang & Suphantharika, 2006; Chen *et al.*, 2015; Singh *et al.*, 2016).

3.5 Conclusion

The interactions of gum Arabic with native starch depended on the kind of starch, amylose content and gum Arabic level. We reject the null hypothesis that GA from *Acacia senegal* var. *kerensis* has no effect on the textural and pasting qualities in considering the study's findings. Substituting part of the starch, both cassava and maize, with GA resulted in modification of pasting characteristics of the starch. All the viscosity parameters decreased significantly with increasing levels of gum. However, the onset pasting temperature was not affected. Presence of gum Arabic in the starch systems analyzed also contributed to the changes observed in the textural properties of the gels.. Significant positive correlations were observed between firmness and consistency with pasting temperature, final and setback viscosities. Consequently, the substantial reduction in setback viscosity implies that GA is suitable for retarding retrogradation process, a common cause of undesirable textural characteristics in starch-rich foods. The results of this study indicate the possibility of use of mixtures of native starch with gum Arabic as an alternative modifier to enhance stability and functionality of starchy foods. Thus, we recommend further studies on inclusion of GA from *acacia senegal* var. *kerensis* in specific starch-based food products.

CHAPTER FOUR
EFFECTS OF GUM ARABIC FROM *ACACIA SENEGAL VAR KERENSIS*
ON THE SELECTED PHYSICAL PROPERTIES OF MAIZE AND CASSAVA
FLOURS AND STARCHES

Abstract

The limitations associated with the functionality of native flours and starches have led to the search for ingredients which could be useful in improving their properties for wider application. This study investigated the effect of incorporating gum Arabic (GA) on maize and cassava flours and starches on some selected physical properties *vis-à-vis* water holding capacity (WHC), oil holding capacity (OHC), foam capacity (FC), bulk density (BD), swelling capacity (SC), water solubility index (WSI) and water absorption index (WAI). Gum Arabic was substituted in cassava and maize starch and flour at five different levels of 0.0, 2.0, 4.0, 6.0 and 8.0 % on weight/weight basis. It was established that increasing gum Arabic substitution level in starches significantly decreased the BD but significantly increased WHC, FC, WSI, WAI, SC and OHC for both maize and cassava. Increasing the gum Arabic substitution level in flour did not have a significant effect on WHC of both maize and cassava, FC and WAI of maize and OHC of cassava. Increasing gum Arabic substitution level in cassava flour significantly increased FC, BD, WSI, WAI and SC while in maize flour only SC increased. Correlation of functional properties due to addition of gum Arabic in starches was different from correlation in flours. Findings of this study showed that adding gum Arabic from *Acacia senegal var. kerensis* optimized the selected functional qualities of maize and cassava flours and starches which could be used in the enhancement of the functionality of food products based on these starches and flours.

4.1 Introduction

In many foods, both as inherent ingredients and as additional components, carbohydrates predominate. Their molecular sizes, shapes, and structures vary widely. Moreover, their physiological effects on the human body differ based on their diverse chemical, physical, and functional features (Damodaran *et al.*, 2008). Functional properties of a food material have been defined as factors that dictate its use and application (Ohizua *et al.*, 2017). The inherent physical characteristics known as functional qualities are those that show the intricate relationship between the composition, structure, conformation, and other elements of food and the type of environment in which they are related and assessed (Chandra *et al.*, 2015).

The constituents of a certain flour or starch affect its physical characteristics, that is, the proximate components, sugar alcohols and the structures of these components. For example, functional roles of starch include the gelatinization, browning especially from caramelization, dextrinization and gelation. On the other hand, functional roles of protein include foaming, browning especially from Maillard reaction, emulsification, coagulation and denaturation whereas for fat/oils include emulsification, aeration and shortening (Awuchi *et al.*, 2019; Chisenga *et al.*, 2019).

Due to its practicality in diverse application of food products, the study of starch is becoming more popular than that of other polymers of carbohydrates (Santoso, 2018). Flours and starches are receptive to physical, chemically and biologically modifications. These Commercial adjustments are used to enhance their qualities, increase their utility and making it a very versatile source (Damodaran *et al.*, 2008). However, these modifications are faced with shortcomings including issues of food safety and high cost thus calling for use of clean label natural additives to improve these properties. Hydrocolloids such as gums are being utilized more and more in the food industries to modify various properties of starches owing to the expanding need in the market for affordable, secure and organic food ingredients (Hussain, 2015). Several studies on different gums have made it possible to find important natural sources of complex carbohydrate polymers that support the required level of quality, stability, texture as well as appearance (Salehi, 2019).

Functional characteristics include the ability to swell, absorb water or oil, absorb emulsion activity, maintain emulsion stability, produce foam, gelatinize, bulk density, dextrinize, preserve, denaturate, coagulate, form gluten, jell, shorten, be plastic, sense characteristics, retain moisture, aerate and flakiness (Awuchi *et al.*, 2019; Chandra *et al.*, 2015; Nkesiga *et al.*, 2021). Studies have demonstrated that gums offer substantial technological improvements in starches and flours (Sanchez *et al.*, 2002). Use of biopolymers for the improvement of various physical characteristics of starches includes water binding capacity, emulsion stability, ability to swell, foaming capacity, mass percentage and the capacity to hold oil has been considered as a cheap, readily available and safe option for food production (Bashir & Aggarwal, 2019). Additionally, there have been reports of gum added to food to boost dietary fiber and reduce caloric value by reducing moisture content (Rodge *et al.*, 2012). The foaming capacity of a food material has been shown to depend on the qualities of its protein that are surface-active (Hasmedi *et al.*, 2020).

Bulk density refers to a measure of the heaviness of a flour or starch sample. It has been used to ascertain the packaging needs for flour as dictated by the flours' moisture content and particle size (Oladele & Aina, 2007). For the majority of food applications, the ability to absorb oil is essential for maintaining flavor, enhancing palatability and extending product shelf life (Hasmadi *et al.*, 2020; Maha *et al.*, 2012). Various researchers have also shown that hydrocolloids can be applied to improve mouth-feel in reduced fat products. They are used as an alternative of gluten to prepare gluten free breads and other products owing to their viscoelastic behaviour particularly in the contemporary era where many people suffer from gluten intolerance (Lufti *et al.*, 2017; Varella *et al.*, 2016).

According to Olatidoye *et al.* (2020) research efforts are focused to partial substitution of wheat flour with cassava for use in making bread. The objective is to reduce the volume of wheat imported and make greater use of food crops that are readily available locally. Furthermore, blending of hydrocolloid with wheat and the functional and pasting qualities were significantly improved by using premium cassava flour. However, the bread's quality decreased throughout time when wheat was substituted with different flours. The loss of quality has been linked to a decrease in the strength of the flour and its ability to hold gas, a consequence of reduced gluten content. Incorporating gum could be beneficial due to its viscoelastic nature hence can imitate the viscoelastic properties of gluten (Devisetti *et al.*, 2015).

Many studies have not published findings about the effect of *Acacia senegal* var. *kerensis* gum on the physical behaviour of flours and starches for food production and industrial application. Thus, the objective of this study was to assess the actions of selected physical properties of maize and cassava flours and starches on adding varying concentrations of gum Arabic from *Acacia senegal* var. *kerensis*. Each flour and starch were substituted with five different levels of gum Arabic (0, 2, 4, 6 and 8%), and the physical properties of the resultant mixture determined. Native flours and starches of maize and cassava were used for the control experiment. It was hypothesized that gum Arabic will improve the examined physical characteristics the starches and flours made from maize and cassava, and consequently, enhance their range of application in food processing.

4.2 Materials and Methods

4.2.1 Materials

Maize flour and cassava flour were purchased from a local supermarket while the rest of materials used are discussed in Chapter Three, Section 3.2.1.

4.2.2 Sample preparation

Samples were prepared in accordance with Chapter Three, Section 3.2.2. Except that blends were prepared by inclusion of gum Arabic at five levels.

4.2.3 Determination of physical properties

1. Water Holding Capacity (WHC)

With minor adjustments, the technique described by Song *et al.* (2018) was utilized to calculate the water holding capacity. About 1g sample was weighed and placed into 15 ml plastic and distilled water (10 ml) was added to the centrifuge tube. The contents were shaken well to mix then kept at room temperature ($22 \pm 2^\circ\text{C}$) for a full day. Centrifugation was done 15 minutes at 4000 g, with the supernatant being collected, weighed, and dried at 105°C . The mean of each test replicated three times was reported. As a result, the WHC was expressed as grams of water per gram of dry material, as the following equation illustrates:

$$\text{WHC (g/g)} = \frac{\text{Wet residue weight} - \text{dry residue weight}}{\text{Dry residue weight}} \dots\dots\dots(i)$$

2. Foaming Capacity

The foaming capacity was determined with slight modification as stated by Chandra *et al.* (2015). After weighing one gram of sample, it was added to 20 ml distilled water at $25 \pm 0.5^\circ\text{C}$ in a graduated cylinder. To create foam, the suspension was thoroughly mixed and shaken for five minutes. The following formula was used to express the volume of foam after 30 seconds after whipping as foam capacity:

$$\text{FC (\%)} = \frac{\text{Vol. of foam following whipping} - \text{Vol. of foam prior to whipping}}{\text{Vol. of foam prior to whipping}} \times 100 \dots\dots\dots(ii)$$

3. Bulk Density

The method outlined by Maninder *et al.* (2007) with some alterations was employed. After carefully pouring the samples into graduated 10-milliliter cylinders, each cylinder's bottom was repeatedly tapped on a lab bench to determine the bulk density of the samples the sample level stopped dropping (constant volume obtained) after filling to the 10 ml mark. The initial

volume occupied by sample was noted and recorded. Next, bulk density was computed as sample weight per unit volume (g/cm³), as shown below:

$$\text{Bulk density (g/cm}^3\text{)} = \frac{\text{Mass of the flour sample}}{\text{Volume of the flour sample}} \dots\dots\dots \text{(iii)}$$

4. Water Solubility Index (WSI) and Water Absorption Index (WAI)

According to Makowska *et al.* (2018), the water solubility index (WSI) and absorption index (WAI) were calculated with slight modification. After weighing one gram of the sample, we put it in a test tube. Then 10 ml of distilled water was added to aid in suspension. The tubes containing the samples were shaken carefully then let them stand for 15 minutes. After that, the tubes were shaken and centrifuged for 10 minutes at 1000g. After carefully decanting the supernatant fraction onto an evaporating plate with a predetermined weight, the mixture was oven-dried for 12 hours at 105°C. The WAI was determined by weighing the gel that was still in the tube. As demonstrated below, the water solubility index was determined using the dried supernatant and the original sample weight, whereas the water absorption index was determined using the wet sediments.

$$\text{WAI (g/g)} = \frac{\text{Wet residue weight} - \text{dry residue weight}}{\text{Weight of the sample}} \dots\dots\dots \text{(iv)}$$

$$\text{WSI (g/g)} = \frac{\text{Weight of soluble}}{\text{Weight of sample}} \dots\dots\dots \text{(v)}$$

5. Swelling Capacity (SC)

The method outlined by Ge *et al.* (2017) after a few adjustments was utilized to ascertain the swelling capacity of the samples. One gram of the sample was precisely weighted into 20 ml graduated cylinder and gradually mixed with 10 ml of distilled water. The suspension was shaken and allowed to stand for 24 hours at room temperature. The absorbent treated sample's volume was measured, and it was oven-dried for 12 hours at 105 degrees Celsius. Three replicates of the tests were conducted, and the results were given as means for each treatment. The following equation was used to express swelling capacity (SC), which was measured in milliliters of water for every gram of the dried sample:

$$\text{SC (g/ml)} = \frac{\text{Amount of sample treated with absorbent} - \text{Amount of dry sample}}{\text{The dried sample's weight}} \dots\dots\dots \text{(vi)}$$

6. Oil Holding Capacity

With a few adjustments, the procedure outlined by Song *et al.* (2018) was used to assess the samples' oil retention capacity. In summary, 1g of the material was put into a weighted

centrifuge tube, and it was well mixed with 10 ml of sunflower oil. The mixture was allowed to stand at room temperature ($22 \pm 2^{\circ}\text{C}$) for a full day. The residue was centrifuged at 4000 g for 15 minutes before being collected, weighed, and dried at 105°C . Every test was done three times, and the results were presented as an average. The following equation was used to express the OHC as g of oil per mg of dry sample:

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

4.2.4 Data Analysis

All data obtained from the four samples was tested for normality before analysis. Version 17 of Minitab Software was used to analyze the data and *post-hoc* tests were done using Tukey’s honestly significant different method at $p < 0.05$.

4.3 Results

4.3.1 Physical properties of maize and cassava starch and flour

Analysis of Variance (ANOVA) showed that the type of the material (maize flour or starch and cassava flour or starch) the level of gum Arabic replacement in the materials and their relationship had significant impacts on the physical features (As shown in Appendix III part C). The chosen physical characteristics of the starch and flour made from maize and cassava are displayed in Figure 4.1. Cassava flour had significantly high WHC, FC, SC, WSI and WAI but significantly lowest BD and OHC as compared to starches and maize flour. Maize starch had significantly high OHC but significantly lowest WHC, FC and WAI. Both maize and cassava starches had lower FC and WAI compared to their corresponding flours.

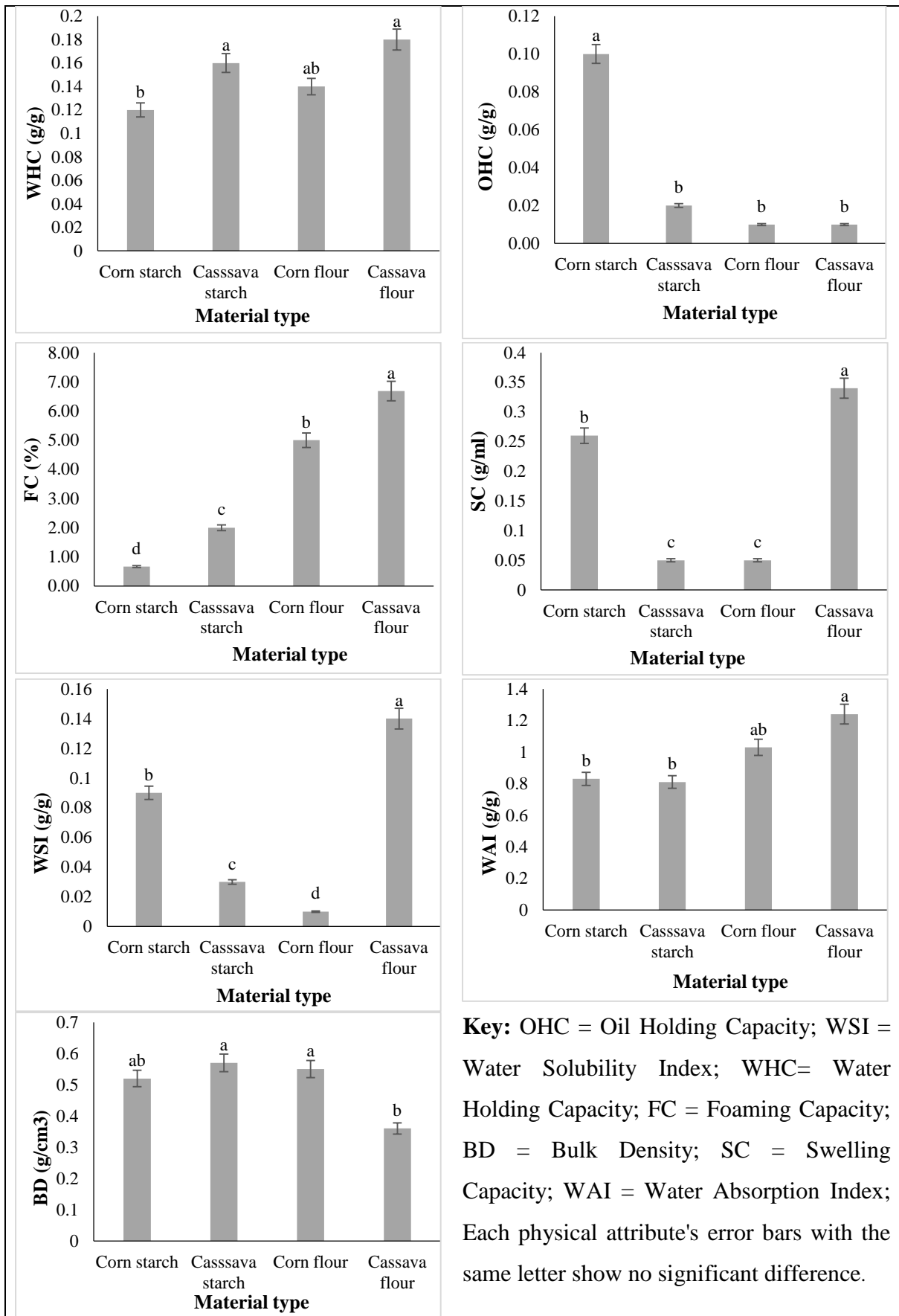


Figure 4.1: Physical properties of maize and cassava starch and flour

4.3.2 Effect of gum Arabic substitution in cassava and maize starches and flours on physical properties

Effect of gum Arabic substitution level in both starch and flour of maize and cassava on resultant physical properties is shown in Table 4.1. Increasing the gum Arabic substitution level in maize starch significantly decreased the bulk density but significantly increased WHC, FC, WSI, WAI and SC. However, increasing the gum Arabic substitution level in flour did not have a significant effect on WHC, FC, WAI and OHC. Two percent substitution level of gum Arabic in maize flour recorded highest values of BD (0.57g/cm^3), WSI (0.02g/g) and OHC (0.03 g/mg). On the other hand, for cassava starch, increasing the gum Arabic level significantly increased the WHC, WSI, WAI and SC but significantly decreased the bulk density with no observed effect on FC and OHC. But, in cassava flour, increasing the gum Arabic substitution level significantly increased the FC, BD, WSI, WAI and SC however, no significant effect was observed on WHC and OHC.

Table 4.1:Effect of gum Arabic substitution level in starch and flour of maize and cassava on physical properties

Material	Type	GA (%)	WHC	FC	BD	WSI	WAI	SC	OHC
Starch	Maize	0	0.12±0.01 ^b	0.67±0.09 ^c	0.52±0.01 ^a	0.09±0.00 ^b	0.83±0.05 ^c	0.26±0.05 ^b	0.10±0.01 ^a
		2	0.13±0.00 ^{ab}	0.87±0.09 ^{cb}	0.50±0.01 ^b	0.11±0.00 ^{ab}	0.91±0.03 ^{bc}	0.25±0.05 ^b	0.01±0.00 ^c
		4	0.14±0.00 ^a	1.25±0.09 ^b	0.48±0.00 ^{ab}	0.11±0.01 ^{ab}	0.97±0.02 ^{abc}	0.64±0.15 ^{ab}	0.07±0.00 ^b
		6	0.15±0.00 ^a	1.83±0.09 ^a	0.49±0.00 ^{ab}	0.12±0.00 ^a	1.01±0.01 ^{ab}	0.79±0.00 ^a	0.07±0.00 ^b
		8	0.15±0.01 ^a	2.21±0.09 ^a	0.51±0.00 ^{ab}	0.14±0.01 ^a	1.07±0.04 ^a	0.84±0.05 ^a	0.07±0.00 ^b
	Cassava	0	0.16±0.00 ^b	2.04±0.07 ^a	0.57±0.00 ^a	0.03±0.00 ^b	0.81±0.01 ^b	0.05±0.01 ^c	0.02±0.00 ^b
		2	0.16±0.00 ^b	1.92±0.00 ^a	0.56±0.00 ^a	0.07±0.00 ^{ab}	0.85±0.03 ^{ab}	0.10±0.01 ^{bc}	0.04±0.00 ^a
		4	0.18±0.00 ^a	1.92±0.00 ^a	0.53±0.00 ^b	0.08±0.00 ^{ab}	0.90±0.01 ^{ab}	0.39±0.10 ^{abc}	0.04±0.00 ^a
		6	0.18±0.00 ^a	1.92±0.00 ^a	0.51±0.00 ^c	0.09±0.00 ^{ab}	0.94±0.00 ^a	0.49±0.00 ^{ab}	0.02±0.00 ^b
		8	0.18±0.00 ^a	2.12±0.00 ^a	0.51±0.00 ^c	0.11±0.02 ^a	0.96±0.01 ^a	0.59±0.10 ^a	0.02±0.00 ^b
Flour	Maize	0	0.14±0.02 ^a	5.00±0.91 ^a	0.55±0.00 ^b	0.01±0.00 ^b	1.03±0.10 ^a	0.05±0.00 ^c	0.01±0.00 ^c
		2	0.19±0.05 ^a	4.86±0.93 ^a	0.57±0.00 ^a	0.02±0.00 ^a	0.91±0.10 ^a	0.25±0.05 ^b	0.03±0.00 ^a
		4	0.11±0.00 ^a	7.69±0.00 ^a	0.50±0.00 ^d	0.01±0.00 ^b	0.85±0.02 ^a	0.39±0.00 ^{ab}	0.02±0.00 ^b
		6	0.13±0.01 ^a	6.72±0.86 ^a	0.52±0.00 ^b	0.01±0.00 ^b	0.97±0.06 ^a	0.45±0.05 ^a	0.01±0.00 ^c
		8	0.14±0.01 ^a	5.41±0.04 ^a	0.52±0.00 ^b	0.01±0.00 ^b	1.02±0.04 ^a	0.50±0.00 ^a	0.01±0.00 ^c
	Cassava	0	0.18±0.00 ^a	6.68±0.89 ^b	0.36±0.00 ^b	0.14±0.00 ^b	1.24±0.01 ^b	0.34±0.05 ^c	0.01±0.00 ^a
		2	0.19±0.01 ^a	7.57±0.14 ^b	0.35±0.00 ^c	0.16±0.00 ^{ab}	1.32±0.05 ^{ab}	0.45±0.05 ^c	0.06±0.02 ^a

4	0.19±0.00 ^a	8.75±0.89 ^b	0.36±0.00 ^b	0.16±0.00 ^{ab}	1.30±0.01 ^{ab}	0.49±0.00 ^{bc}	0.05±0.00 ^a
6	0.21±0.00 ^a	11.52±0.01 ^{ab}	0.37±0.00 ^a	0.17±0.00 ^a	1.44±0.03 ^{ab}	0.75±0.05 ^{ab}	0.01±0.00 ^a
8	0.21±0.01 ^a	14.57±0.85 ^a	0.37±0.00 ^a	0.18±0.00 ^a	1.45±0.04 ^a	0.85±0.05 ^a	0.05±0.00 ^a

Key: BD stands for bulk density; WSI stands for water solubility index; WAI stands for water absorption index; SC stands for swelling capacity; OHC is for oil holding capacity. GA stands for gum Arabic. Means with the same letter with each material type are not significantly different at $P < 0.05$.

4.3.3 Effect of gum Arabic substitution in cassava and maize starches and flours on the correlation between physical properties

Coefficients of correlation relationship among the selected physical properties of starch and flour of maize and cassava substituted with gum Arabic are shown in Table 4.2. The correlation relationship among the physical properties on substitution with gum Arabic was different between starches and flours. In starches, WHC and FC did not have a significant correlation with BD, WSI and WAI in comparison with the flours where they showed significant relationship. However, for both starches and flour, BD showed a strong negative correlation with WSI, WAI and SC. Oil holding capacity showed a significant negative correlation with WHC ($r = -0.575$) only in starches but showed a positive correlation with WSI ($r = 0.512$) and a negative correlation with BD ($r = -0.469$) only in flours.

Table 4.2: Coefficients of correlation between physical properties of starch and flour of maize and cassava substituted with gum Arabic

Material type	Physical properties							
	WHC	FC	BD	WSI	WAI	SC	OHC	
Starch	WHC	1.000	0.731 ^{***}	0.229 ^{ns}	-0.215 ^{ns}	0.066 ^{ns}	0.034 ^{ns}	-0.575 ^{**}
	FC		1.000	0.314 ^{ns}	-0.040 ^{ns}	0.294 ^{ns}	0.262 ^{ns}	-0.326 ^{ns}
	BD			1.000	-0.804 ^{***}	-0.705 ^{***}	-0.702 ^{***}	-0.178 ^{ns}
	WSI				1.000	0.807 ^{***}	0.816 ^{***}	0.280 ^{ns}
	WAI					1.000	0.865 ^{***}	0.171 ^{ns}
	SC						1.000	0.329 ^{ns}
	OHC							1.000
Flour	WHC	1.000	0.539 [*]	-0.611 ^{***}	0.740 ^{***}	0.695 ^{***}	0.423 ^{ns}	0.433 ^{ns}
	FC		1.000	-0.642 ^{***}	0.719 ^{***}	0.666 ^{***}	0.829 ^{***}	0.335 ^{ns}
	BD			1.000	-0.965 ^{***}	-0.850 ^{***}	-0.590 ^{***}	-0.469 [*]
	WSI				1.000	0.915 ^{***}	0.629 ^{***}	0.512 [*]
	WAI					1.000	0.638 ^{***}	0.395 ^{ns}
	SC						1.000	0.209 ^{ns}
	OHC							1.000

Key: Key: BD stands for bulk density; WSI stands for water solubility index; WAI stands for water absorption index; SC stands for swelling capacity; OHC is for oil holding capacity. GA stands for gum Arabic; ns = Not Significant at $P < 0.05$; *= Significant at $P = 0.05$; **= Significant at $P = 0.01$; ***= Significant at $P = 0.001$.

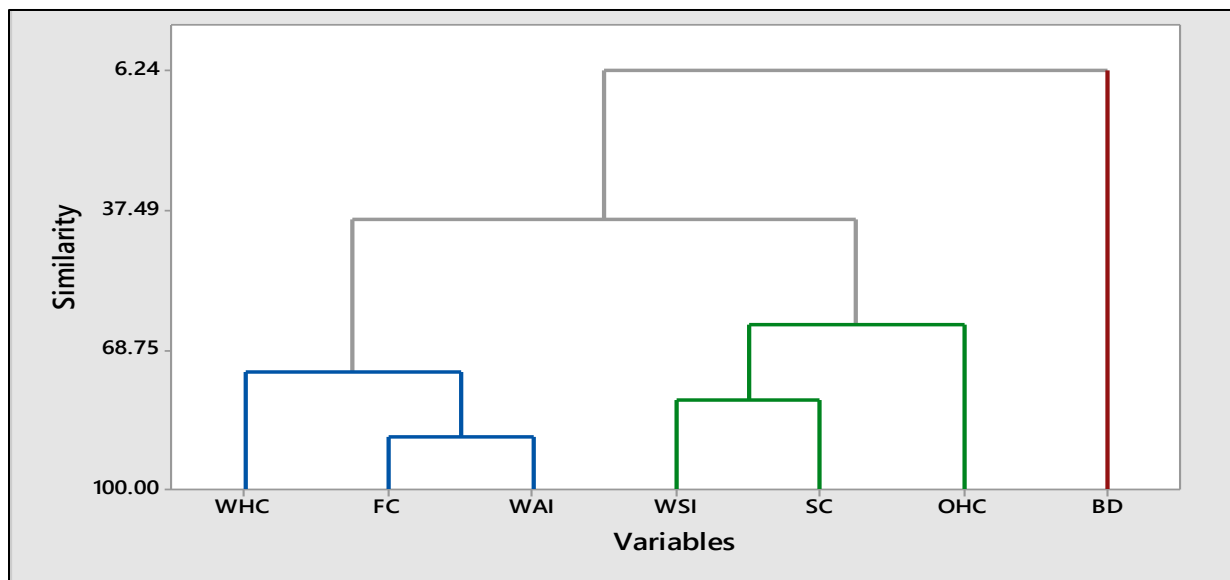


Figure 4.2: Dendrogram of clustering physical properties based on correlation coefficients due to addition of gum Arabic in maize and cassava starch and flour

Key: WHC = Water Holding Capacity; FC = Foaming Capacity; BD = Bulk Density; WSI = Water Solubility Index; WAI = Water Absorption Index; SC = Swelling Capacity; OHC = Oil Holding Capacity

Clustering of physical properties of starches and flours of maize and cassava based on correlation relations is presented as a Dendrogram in Figure 4.2. Based on similarity of correlation coefficients, the physical properties studied have been clustered in three classes: Class 1 contains WHC, FC and WAI, class 2 contains WSI, SC and OHC while class 3 has only BD.

4.4 Discussion

The differences in physical properties observed in maize and cassava starches and flours as shown in Figure 4.1 could be attributed to their different chemical composition, especially amylose, protein and lipid contents. According to Obadi and Xu (2021), cereal starches such as maize have relatively high fat (0.2%–0.8%) and protein (0.2%–0.5%) contents in comparison to

root crop starches such as cassava which have lower lipid (0.1%–0.2%) and protein (0.1%–0.2%) contents positively correlated with both their lipid contents and amylose content. The physical, chemical and technological properties of amylose are significantly influenced by the quantity and degree of polymerization (DP) that is present. Cassava flour, in contrast to maize flour and their corresponding starches exhibited substantial highest values for all characteristics of hydration: WHC, FC, SC, WSI and WAI but least significantly lowest values for BD and OHC. The results also indicate that GA did not affect the capacity of starch or flour to retain and absorb water, which is deduced from the results of the WHC and WAI for the flours, since this rate was not significantly different ($p < 0.05$) between control (0%) and samples added with the hydrocolloid. A study by Charoenkul *et al.* (2011) showed that cassava flour which consists of both starch and non-starch components exhibited broader variations in physical properties than the starches.

The swelling power of starches has been shown to be influenced by the ratio of amylose/amylopectin, molecular weight, the molecules' distribution, degree of branching, branch length and conformation (Ge *et al.*, 2017; Wang *et al.*, 2018). The lower swelling values obtained for the flours (Table 4.1), may be affected by the presence of lipid and protein which are also key factors in controlling the swelling capacity. According to Aditi and Arivuchudar (2018), water absorption index is an indicator of the capacity of flour to swell and absorb water to provide the proper consistency in the food system. This enhances yield and consistency as well as giving body to the food product developed. Compared to cassava starch, cassava flour had a higher WAI (Table 4.1) suggesting that the flour is more hydrophilic due to a higher protein and carbohydrate content however maize flour and starch depicted similar capacity in water absorption. The results of BD, WAI, SC and OHC discovered throughout this investigation for cassava flour were very low as compared to the findings of Olatidoye *et al.* (2020). This can be explained by the variation in the quality of cassava flour and the gum type.

Addition of gum Arabic to maize and cassava starches and flours showed a variation of effects to physical properties as shown in Table 4.1. Hydration properties of both maize and cassava starches improved significantly with increase in the levels of gum Arabic however, a decrease in BD and OHC were observed. This point out that GA not only increases components that are hydrophilic resulting in binding more water and repelling oil binding sites but also increases porosity. The current study depicted very low oil absorption capacity values for all the samples

as compared to the findings reported by Olatidoye *et al.* (2020) which can be attributed to the oil type and gum difference. The main chemical element influencing the oil absorption capacity is a protein made up of both hydrophilic and hydrophobic components (Hasmadi *et al.*, 2020).

Gum Arabic from *Acacia senegal* var. *kerensis* is a polysaccharide containing glycoproteins and arabinogalactan proteins totaling 3.42%. The gum provides both hydrophilic and hydrophobic sites (China *et al.*, 2020). Mugo *et al.* (2020) reported that *Acacia senegal* var. *kerensis* gum Arabic had 3.42 percent more protein than *Acacia senegal* var. *senegal* gum, which had 2.01% more protein. Thus, increasing the molecular weight associated to the arabinogalactan protein (AGP) content and the gelling property of this gum. According to Lelon *et al.* (2020) and Lelon *et al.* (2013) gum Arabic hydrophobic protein component in food additives acts as an emulsifier by adhering to the surface of oil droplets. The hydrophilic carbohydrate component prevents flocculation and molecular coalescence by steric and electrostatic repulsions. On the contrary, addition of gum Arabic in both maize and cassava flours resulted in a range of effects in the physical properties. This finding might be explained by the variations in the characteristics and composition of each flour.

The results (Table 4.1) obtained for native maize flour (0.55g/ml) bulk density is in accordance with those of Kaur *et al.* (2011) who reported a bulk density of 0.585g/ml. A larger number of particles that can pack together could be implied by a lower bulk density value and could result to higher energy content that can be obtained. The increase in foaming capacity of flours as opposed to starch with increase in gum level may be caused by a drop in the surface tension of the water-air interface, which, as described by China *et al.* (2020) can allow for the absorption of soluble protein molecules and therefore permit hydrophobic interactions. Foaming properties are vital to utilize in the production of diverse food products for the home market. Flours can create foams because of their surface-active proteins that create interfacial area (Hasmadi *et al.*, 2020). The results of the present research concur with those that have been reported by Soibe *et al.* (2015) where GA from *acacia senegal* var. *kerensis* improved the physicochemical characteristics of the wheat-plantain composite flour.

The correlation among the physical properties due to addition of gum Arabic in starches was different from the correlation in flours as indicated in Table 4.2. A unit decrease in BD due to addition of gum Arabic in starches significantly increased WSI by 80.4% ($r = -0.804$), WAI by

70.5% ($r = -0.705$) and SC by 70.2% ($r = -0.702$) and in flours increased WSI by 96.5% ($r = -0.965$), WAI by 85.0% ($r = -0.850$) and SC by 59.0% ($r = -0.590$). BD decrease did not significantly affect WHC and FC in starches but caused an increase of WHC by 61.1% ($r = -0.611$) and FC by 64.2% ($r = -0.642$) in flours. This could be attributed to the decrease in BD causing an increase in porosity that allows more absorption, solubility and swelling of particles in water. In starches, a unit increase in OHC caused a significant decrease in only WHC by 57.5% ($r = -0.575$) but in flours caused a significant decrease in BD by 46.9% ($r = -0.469$) and significant increase in WSI by 51.2% ($r = 0.512$). This point out that, the increase of gum Arabic addition in starches only increased hydrophilicity that favoured water holding but reduced hydrophobic sites that caused a reduction in OHC. In flours, increase in porosity due to decrease in BD caused an increase in solubility of components.

A dendrogram showing the three clusters of physical properties based on correlation coefficient similarities is shown in Figure 4.2. Increasing gum Arabic in maize and cassava flour and starches first of all affected properties under cluster 1: WHC, FC and WAI. As seen in Table 4.1, these attributes were significantly increased in both maize and cassava starches but no significant effect on maize flour. These attributes have been reported to be influenced by hydrophilic components contained such as polysaccharides and residues of polar amino acids which are highly attracted to molecules of water and amylose content (Awuchi, 2019). The second cluster had WSI, SC and OHC, which are parameters that are affected by proteins non-polar chains that form hydrophobic interactions and the amylose-amylopectin ratio (Ayaz, 2022; Chiranthika *et al.*, 2022). Lastly, the last cluster has only BD, which depends mostly on overall starch content, particle size, surface properties and solid density (Huang *et al.*, 2020). The bulk density has been described by these authors as a measurement of a flour or starch sample's weight that is frequently used to establish the amount of packaging needed for flour as dictated by the flour's moisture content and particle size. The decrease in this parameter in the current study shows that the flour and / starch particles were loosely packed. Analyzing these properties is critical in food product development as demonstrated by Islam *et al.* (2012) who reported that flour functional properties are extremely important in developing a product since they indicate the quantity of water or oil needed to develop optimum dough and also depicts the properties and behavior of flour with the addition of water.

4.5 Conclusion

We reject the null hypothesis that GA from *Acacia senegal* var. *kerensis* has no effect on the physical characteristics of flour and starch in relation to the results of this investigation. The result of the current study showed that incorporation of gum Arabic to cassava flour had significant higher FC, SC, WSI and WAI but least significant lower BD and OHC as compared to starches and maize flour no significant effect on WHC. Both maize and cassava starches had lowest FC and WAI compared to their corresponding flours. The differences in physical properties observed in maize and cassava starches and flours could be linked to their different chemical composition especially amylose, protein and lipid contents. The attributes impacted by gum Arabic are influenced by hydrophilic components and polar amino acid residues contained in the gum which have high affinity for water molecules and amylose content. Gum Arabic obtained from *acacia senegal* var. *kerensis* could be embraced as an appropriate candidate for enhancing the analyzed characteristics of natural starches and flours, especially those derived from maize and cassava. From the results, the optimal gum substitution level of 6% could be recommended and the incorporation of this gum could be used to modify food product functionality for desired attributes. This study also recommends further studies on specific starch-based foods incorporating this gum in order to obtain substantial technological properties of flours and starches.

CHAPTER FIVE

PASTING BEHAVIOUR AND TEXTURAL PROPERTIES OF CASSAVA AND MAIZE FLOURS CONTAINING GUM ARABIC FROM *ACACIA SENEGAL* VAR. *KERENSIS*

Abstract

The application of flour in food production and in the industry depends on various properties including texture and pasting. These properties are influenced by their interaction with food hydrocolloids especially gums. In this study, the effect of replacing gum Arabic at the levels of 0 %, 2%, 4%, 6% and 8% on the textural and pasting characteristics of maize and cassava flours was investigated. In Brabender Units (BU), resistance to stirring was expressed as viscosity. Substitution of cassava and maize flours by gum Arabic reduced significantly ($p < 0.05$) the peak viscosity, final viscosity, setback viscosity for both flour pastes. Even though the breakdown viscosity of cassava flour pastes reduced significantly with increasing levels of the gum, maize flour pastes recorded a zero breakdown as the substitution level increased from 2% to 8%. Pasting temperature (64.15-63.55°C) and (87.1-84.9°C) decreased with increasing gum content for cassava and maize flour pastes respectively though there was no discernible difference between the control sample and the lower level values. The textural characteristics of the mixed gels of maize flour, such as their firmness, consistency, cohesiveness and work of cohesion decreased with increasing level of gum Arabic however for cassava flour mixed gels the firmness and consistency increased. These results demonstrate that GA from *Acacia senegal* var. *kerensis* (Kenyan variety) could be taken into account when making different food items with cassava and maize flour to enhance binding potential, stability, softer texture as well as preventing retrogradation.

5.1 Introduction

Maize (*Zea mays*) is of paramount importance food commodity in Kenya. It accounts for about 40 percent of daily calories and is cultivated across extensive wide-ranging lands (SSEA, 2019). The common maize preparations in Kenya utilize either the grain or flour (the ground grain) whereas for cassava the root or flour is usually used. When the flours are heated in excess water, the starch-rich slurry transforms into porridge as a result of gelatinization of starch (Wanjala *et al.*, 2016). Cassava (*Manihot esculenta* Crantz) grows in varied zones characterized by similar climatic conditions. Githunguri *et al.* (2017) highlighted that cassava is the second most essential

crop after the Irish potato in Kenya and is cultivated broadly in Western and Coastal regions of the country. Being a climate smart crop cassava has attracted significant interest in Kenya due of its financial significance in resolving food shortages (Opondo *et al.*, 2020). Given its large yield, low cost of production, and the special functional qualities of its flour, cassava is one of the roots and tubers that can replace flour completely or partially (Gyedu-Akoto & Laryea, 2013). There have been reports that cassava flour is becoming increasingly popular and particularly has been used to substitute wheat flour in bread making and other baking processes because of its special quality attributes (Dudu *et al.*, 2019). However, these authors have highlighted technological challenges regarding the use of cassava flour in the preparation of food especially in bakery production. For decades hydrocolloids particularly gums have been employed for enhancement of the flour properties (Chhabra *et al.*, 2018).

Maize and cassava flour have potential to be used for various food formulations however they lack vital qualities *vis-à-vis* viscoelastic behaviour as well as structural stability hence limiting their application for this purpose. Reports have also indicated that cassava flour and starch in native form has limited application in refrigerated and frozen food systems as a result of high rate of retrogradation and syneresis (Seetapan *et al.*, 2015). Previous study also revealed that use of hydrocolloids was the best substitute to chemical methods of modification (Alam *et al.*, 2009). Consequently, increased interest in the use of gums to enhance native flour functionality is a result of the present consumer demand for natural ingredients.

For decades, flour's qualities have been enhanced through the application of hydrocolloids, mainly gums (Chhabra *et al.*, 2018). The viscometric and textural characteristics of food products are altered by hydrocolloids and these are the most paramount properties that eventually affect sensory characteristics and storage stability of the food product. They have found many applications in food systems as a result of their high molecular weight nature; an inherent property to hydrocolloids (Mahmood *et al.*, 2017). Because hydrocolloids are viscoelastic, they can also be used to formulate a variety of gluten-free products, where they act to mimic the way gluten functions to impart rheological features to the food system (Rojas *et al.*, 1999; Sahni *et al.*, 2020). Researchers have examined how hydrocolloids affect the rheological, gelling, syneresis, and textural characteristics of flours and starches. They have discovered that the addition of hydrocolloids affects viscosity, the retrogradation of starch dispersions, and the

syneresis of starch gels (Chhabra *et al.*, 2018; Hammed *et al.*, 2016; Mahmood *et al.*, 2017; Sahni *et al.*, 2020).

Gum Arabic (GA) is a commonly used food hydrocolloid and because of its strong binding abilities, low viscosity, low toxicity and high solubility; it has been shown to bring benefits to bakery products because of its ability to control moisture and produce films, which improves processing, texture, and shelf life (Patel & Goyal, 2015). A study by Alam *et al.* (2009) on the influence of different gums on wheat flour resulted to a lowered peak viscosity, reduced breakdown during heating and provided increased stability during cooking upon the addition of GA. These findings also showed that the inclusion of hydrocolloids could prevent starch retrogradation at an early stage of storage. According to Hammed *et al.* (2016) addition of hydrocolloids had an impact on the evaluation of the quality of the flour, dough, and bread using Microvisco-amylograph end of cooling, final viscosity, setback and breakdown values.

Application of maize and cassava flour in new product establishment and food preparations is directed by ultimate use properties such as the conformation, texture as well as pasting. Pasting behaviour of any flour is important for the detailed description of its starch for use in commerce due to the distinctive qualities that it adds to the food i.e the amylose and amylopectin contents (Sahni *et al.*, 2020). However, the addition of hydrocolloids may cause them to interact with the starch's hydroxyl bonds, changing the starch's pasting characteristics (Fu *et al.*, 2015). According to Chhabra *et al.* (2018), some gums for example xanthan and guar gum could be utilized for the establishment of products from maize flour to specifically improve the texture, adhesiveness as well as the viscosity of the paste. According to Olatidoye *et al.* (2020) the possibility for utilizing locally produced flours in bread baking was increased by the capacity to add premium cassava flour up to 18% and hydrocolloid at 2% levels without compromising the product's overall acceptability. Starch is produced in significant quantities by cereals and root crops, particularly cassava flours. The texture of starch gels plays a crucial role in food quality and sensory classification (Wang *et al.*, 2020).

Therefore, determining the impact of adding GA from *Acacia senegal* var. *kerensis* on the functioning of maize and cassava flours was the primary goal of this investigation. Data generated from this research provides enlightenment on the potential use of this gum in food production that could provide good functionality to the various food systems.

5.2 Materials and Methods

5.2.1 Materials

Cassava flour and maize flour were purchased from a local supermarket. *Acacia senegal* var. *kerensis* gum Arabic was obtained from the Kenya Forestry and Research Institute (KEFRI) located in Nairobi, Kenya.

5.2.2. Preparation of blends

Samples were prepared in accordance with Chapter 3, Section 3.2.2, with the exception that flour blends were made by adding gum Arabic at five different levels.

5.2.3 Pasting properties

Pasting behaviour of the flour were measured as described in section 3.2.3 of Chapter three. The viscosity, measured in Brabender Units, was used to indicate resistance to stirring (BU). The resultant pasting curves of both flours are shown in Figure 5.1.

5.2.4 Determination of textural properties

Back extrusion tests were used to determine the flour gels' textural characteristics. In short, 50mm diameter standard size A/BE back extrusion containers (Stable Micro Systems, Surrey, UK) were filled with 80g of the slurries that were extracted from the Brabender Viscograph - E. TA. XT - plus Texture Analyzer (Stable Micro Systems, Surrey, UK) was used to measure the back extrusion force at the following TA settings: method of measuring trigger force (10g), disc diameter 45mm, height calibration 80mm, pre-test speed 1mm/s, post-test speed 10mm/s, data acquisition rate 200pps. After reaching a 10g surface trigger, which is the point at which the disc's lower surface makes complete contact with the sample, the disc dug 30mm into the slurry before returning to its starting position. The EXPONENT Texture Analysis software version 6.1.5.0 (Stable Micro Systems, Surrey, UK) was used to determine the following: tensile strength (maximum positive force, g), cohesiveness (maximum negative force, g), work of cohesiveness or index of viscosity (area of the negative part of the curve), and consistency (area of the positive portion of the curve, g.s) (Onyango, 2014). Each determination was carried out three times.

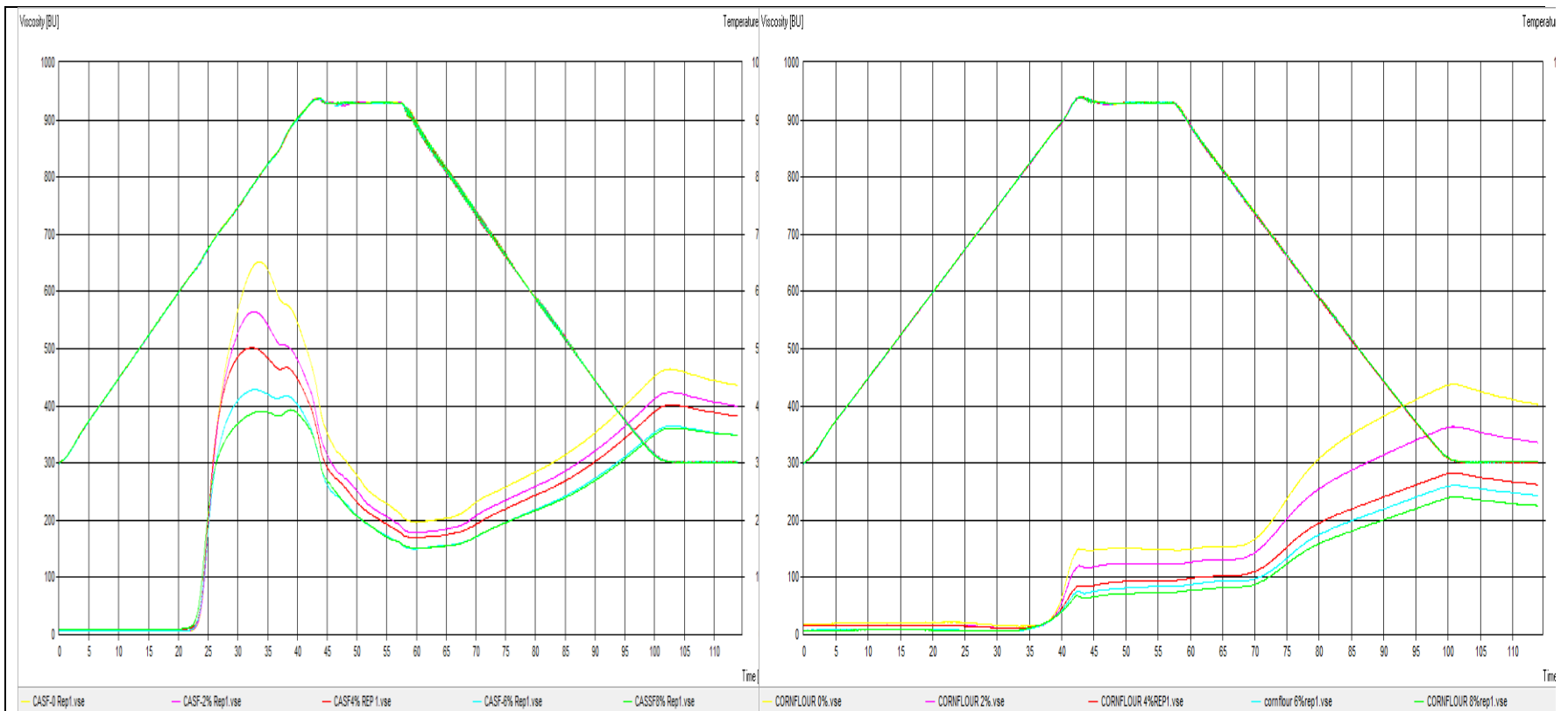


Figure 5.1a: Pasting curves of cassava flour- gum Arabic systems

Figure 5.1b: Pasting curves of maize flour-gum Arabic systems

Figure 5.1: Pasting curves

5.2.5 Statistical analysis

One-way analysis of variance (ANOVA) was used to assess the experimental data in order to ascertain whether the textural properties and pasting of mixtures of cassava and maize flour were significantly affected by varying gum Arabic concentrations. For post hoc multiple comparisons, Tukey's honestly significant difference (HSD) test was employed. *P* value < 0.05 was considered significant.

5.3. Results

5.3.1 Effect of gum Arabic (GA) on pasting behaviour of the maize and cassava flours

The overall impact of gum Arabic on the pasting characteristics of the various levels of GA in maize and cassava flour is shown in Table 5.1. It was found that cassava flour had significantly lower onset pasting temperature and setback viscosity than maize flour but significantly highest peak viscosity, final viscosity and breakdown viscosity. Effect of gum Arabic level of substitution in flour on pasting properties is shown in Table 5.2. It is shown that irrespective of the flour type, gum Arabic substitution level significantly reduced the onset pasting temperature, peak viscosity, final viscosity, breakdown and setback values as compared to the control.

5.3.2 Interaction effect between type of flour and level of gum Arabic substitution

The effect of gum Arabic substitution level in cassava and maize flour on pasting properties of cassava and maize flours is presented are presented in Table 5.3 and Appendix V. For both types of flours, all pasting properties decreased with increasing level of gum Arabic substitution. However, including gum Arabic in maize flour reduced the breakdown value from 7.5 BU at 0% to 0 BU at 4 % - 8% substitution levels.

Table 5.1: Overall effect of gum Arabic on the pasting properties of cassava and maize flour

Material	OPT (°C)	PV (BU)	FV (BU)	Bd (BU)	Setback (BU)
CaF	63.92±0.07 ^b	502.70±1.63 ^a	383.10±2.77 ^a	320.90±4.15 ^a	201.10±6.51 ^b
CF	86.10±0.28 ^a	106.60±0.14 ^b	293.60±2.95 ^b	1.60±0.12 ^b	207.70±5.49 ^a

Key: OPT= Onset Temperature; PV= Peak Viscosity; FV= Final Viscosity; Bd= Breakdown; CaF= cassava flour; CF= Maize flour. The means that share the same letter down the column do not differ substantially.

Table 5.2: Effect of gum Arabic of substitution level in flours on pasting properties

GA(%)	OPT	Peak viscosity	Final viscosity	Breakdown	Setback
0	75.63±0.63 ^a	401.00±1.92 ^a	426.50±2.15 ^a	216.75±0.92 ^a	259.00±5.42 ^a
2	75.43±0.54 ^{ab}	345.00±1.89 ^b	367.75±8.92 ^b	186.25±7.24 ^b	221.75±7.09 ^b
4	75.10±0.44 ^b	295.25±1.37 ^c	321.00±1.37 ^c	159.00±1.81 ^c	193.00±3.63 ^c
6	74.68±0.25 ^{bc}	253.75±8.31 ^c	296.00±4.27 ^d	131.00±5.65 ^d	180.50±5.87 ^d
8	74.23±0.16 ^c	228.25±8.74 ^e	280.50±4.00 ^d	113.25±5.42 ^e	167.75±5.02 ^e

Key: GA= Gum Arabic; OPT= Onset Pasting Temperature; Means with the same along the column are not significantly different at $p < 0.05$

5.3.3 Effect of GA on gel textural properties of cassava and maize flours

The texture characteristics of maize and cassava flours are displayed in Figure 5.2. Cassava flour had significantly higher firmness and consistency at 79.22±4.59 and 1963.6±7.42 respectively as compared to maize flour which had 58.41±5.83 and 1515.20±6.52 respectively.

Table 5.3: Pasting profile of cassava and maize flour containing different levels of gum Arabic

Flour	Gum level	OPT	PV	FV	BD	SB
		%	(BU)	(BU)	(BU)	(BU)
Cassava	0.0%	64.15±0.05 ^a	645.00±7.00 ^a	446.00±1.00 ^a	426.00±2.00 ^a	232.00±4.50 ^a
	2.0%	64.10±0.00 ^a	566.50±1.50 ^b	400.50±1.50 ^{ab}	372.00±0.00 ^b	209.50±0.50 ^{ab}
	4.0%	63.95±0.05 ^a	494.50±7.50 ^c	375.00±7.00 ^b	318.00±3.00 ^c	198.00±2.00 ^b
	6.0%	63.95±0.05 ^{ab}	424.00±4.00 ^d	355.00±7.00 ^{bc}	262.00±4.00 ^d	189.50±6.50 ^{bc}
	8.0%	63.55±0.05 ^b	383.50±1.50 ^e	339.00±9.00 ^c	262.00±5.50 ^e	189.50±3.00 ^c
Maize	0.0%	87.10±0.20 ^a	157.00±5.00 ^a	407.00±5.00 ^a	7.50±3.50 ^a	285.50±1.50 ^a
	2.0%	86.75±0.25 ^a	123.50±1.50 ^b	335.00±1.00 ^b	0.50±0.50 ^b	234.00±1.00 ^b
	4.0%	86.25±0.15 ^{ab}	96.00±1.00 ^c	267.00±5.00 ^c	0.00±0.00 ^b	188.00±5.00 ^c
	6.0%	85.50±0.20 ^b	83.50±0.50 ^{cd}	237.00±6.00 ^{cd}	0.00±0.00 ^b	171.50±1.50 ^{cd}
	8.0%	84.90±0.10 ^b	73.00±1.00 ^d	222.00±3.00 ^d	0.00±0.00 ^b	159.50±2.50 ^d

Key: OPT= onset pasting temperature; PV= peak viscosity; FV= final viscosity; BD= breakdown; SB= setback; BU=Brabender units. Means with the same letter along the column within each flour type are not significantly different at $p < 0.05$.

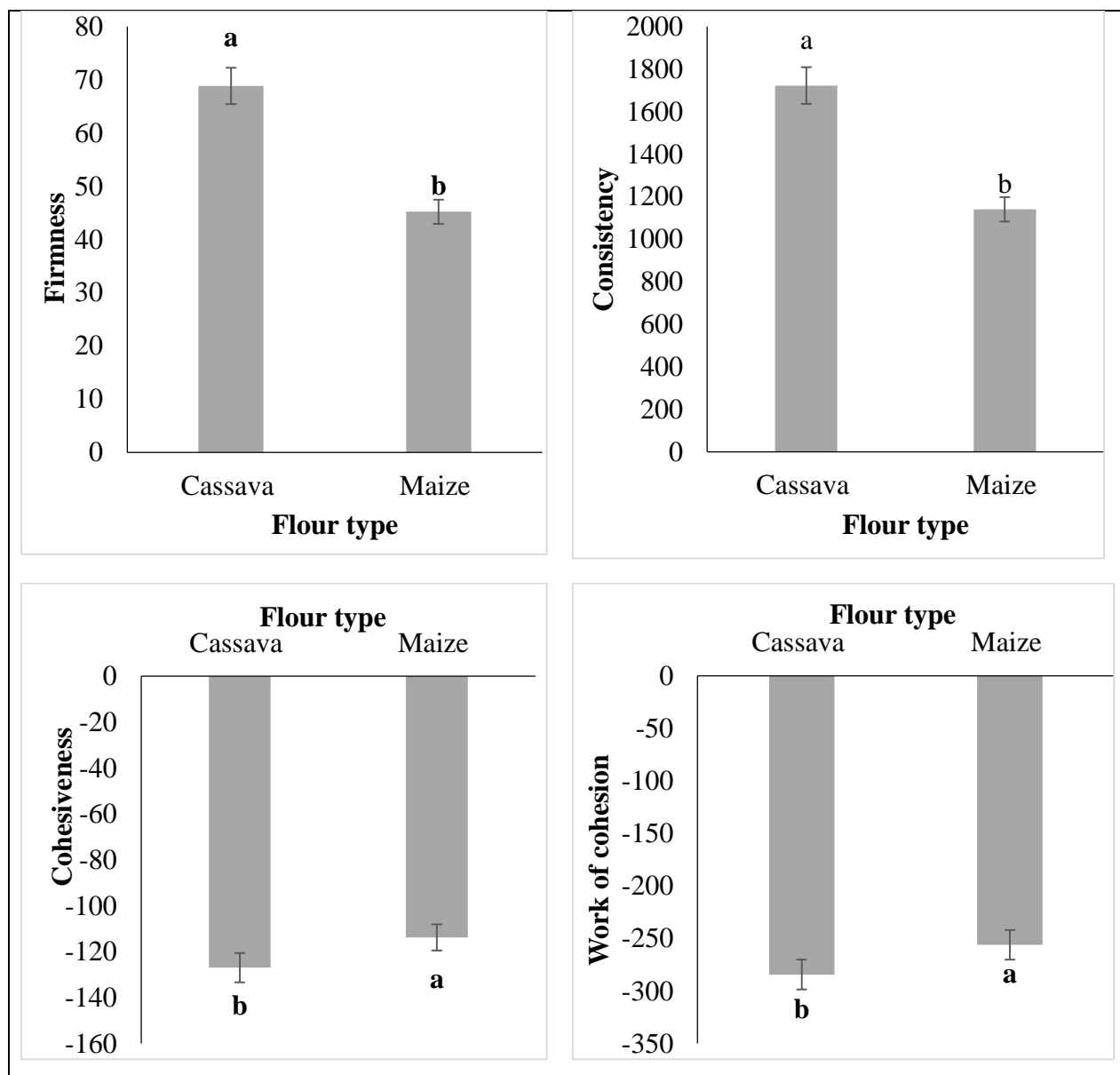


Figure 5.2: The textural characteristics of maize and cassava flours

Key: Mean errors bars with the same letter not significantly different at $p < 0.05$

Maize flour depicted a significantly higher cohesiveness and work of cohesion at -89.65 ± 3.30 and -61.98 ± 2.87 respectively than that of cassava flour at -119.50 ± 6.84 and -204.30 ± 8.00 respectively. The addition of hydrocolloid had different effects on the texture parameters of cassava and maize flours as shown in Table 5.4. Increase of gum Arabic substitution level caused a significant increase in firmness and consistency of cassava flour but a significant decrease of these parameters in maize flour.

Table 5.4: Effect of gum Arabic substitution levels on textural properties of cassava and maize flour

Flour type	GA (%)	Firmness	Consistency	Cohesiveness	Work of cohesion
Cassava	0	64.52±5.39 ^b	1639.78±49.04 ^{bc}	-116.78±9.34 ^a	-256.74±17.19 ^{ab}
	2	63.26±1.55 ^b	1587.74±37.16 ^c	-106.58±2.24 ^a	-235.38±07.39 ^a
	4	86.39±4.65 ^a	2136.49±14.56 ^a	-121.40±4.57 ^a	-269.51±18.06 ^{ab}
	6	96.89±4.54 ^a	2387.73±17.70 ^a	-133.12±0.22 ^a	-299.43±02.97 ^b
	8	85.05±2.07 ^a	2066.47±07.52 ^{ab}	-119.81±3.81 ^a	-270.44±05.14 ^{ab}
Maize	0	86.65±4.93 ^a	2320.20±15.03 ^a	-142.31±6.94 ^c	-316.09±10.72 ^c
	2	69.77±1.09 ^b	1830.40±03.56 ^b	-109.33±1.23 ^b	-248.21±1.21 ^b
	4	50.58±2.75 ^c	1287.51±07.80 ^c	-74.92±4.24 ^a	-173.15±11.77 ^a
	6	44.06±0.35 ^c	1112.50±12.55 ^c	-63.86±0.91 ^a	-150.32±1.83 ^a
	8	40.98±0.40 ^c	1025.24±17.90 ^c	-57.82±1.68 ^a	-133.84±3.43 ^a

Key: GA= Gum Arabic; Means with the same letter along the column within each flour are not significantly different

Increasing the level of gum Arabic substitution in maize flour caused a significant increase in work of cohesion but started to decrease when the level was at 4% and above.

5.3.4 Correlation between pasting properties and textural parameters of the flours

Coefficients of correlation of the association between texture and pasting attributes are shown in Table 5.5. The onset pasting temperature, cohesiveness and the work of cohesion (WOC) were negatively correlated with almost all other parameters. The Peak viscosity was significantly positively correlated with breakdown viscosity ($r = 0.995$) and final viscosity ($r = 0.778$), but not with consistency or setback viscosity. Similarly, the final viscosity showed a significant positive correlation with firmness ($r = 0.645$) and consistency ($r = 0.669$) but had strong negative correlation with work of cohesion ($r = -0.847$). Setback viscosity showed a significant positive correlation with consistency ($r = 0.510$) but had a significant negative correlation with cohesiveness ($r = -0.657$) and work of cohesion ($r = -0.647$). Firmness had very strong positive correlation with consistency ($r = 0.992$) but a very strong negative correlation with cohesiveness ($r = -0.934$) and WOC ($r = -0.944$).

Table 5.5: Correlation coefficients of pasting and textural properties of maize and cassava flours

	OPT	PV	FV	BV	SV	Firmness	Consistency	Cohesiveness	WOC
OPT	1.000	-0.932 ^{**}	-0.589 [*]	-0.946 ^{**}	0.140 ^{ns}	-0.524 [*]	-0.441 [*]	0.496 [*]	0.479 [*]
PV		1.000	0.778 ^{**}	0.995 ^{**}	0.125 ^{ns}	0.452 [*]	0.402 ^{ns}	-0.544 [*]	-0.516 ^{***}
FV			1.000	0.714 ^{**}	0.712 ^{**}	0.645 ^{**}	0.669 ^{**}	-0.847 ^{**}	-0.822 ^{***}
BV				1.000	0.034 ^{ns}	0.404 ^{ns}	0.345 ^{ns}	-0.477 [*]	-0.449 [*]
SV					1.000	0.409 ^{ns}	0.510 [*]	-0.657 ^{**}	-0.647 ^{**}
Firmness						1.000	0.992 ^{***}	-0.934 ^{**}	-0.944 ^{**}
Consistency							1.000	-0.956 ^{**}	-0.964
Cohesiveness								1.000	0.997
WOC									1.000

Key: OPT = onset pasting temperature; WOC = work of cohesion; PV=Peak viscosity; PV= Final viscosity; BV= Breakdown viscosity; SV= Setback viscosity

5.4 Discussion

5.4.1 Effect of gum Arabic substitution in cassava and maize flours on pasting properties

Findings derived from the flour's pasting profile, as shown in Table 5.1 stated that starch granules are insoluble in water below a temperature that causes gelatinization (a disturbance of molecular order), which results in a low aqueous suspension's viscosity. It is anticipated that viscosity will rise when starch granules are heated above the gelatinization temperature in the presence of water because the granules absorb a lot of water and swell resulting in high viscosity (Phimolsiripol *et al.*, 2011). Cassava flour displayed high pasting viscosities and a lower pasting temperature as compared to maize /maize flour, and this can be ascribed to low amylose starch content of the former thus less restriction to swelling of the granules upon heating. Monthe *et al.* (2019) reported similar findings where cassava flour depicted high pasting characteristics possibly due to high starch and low amylose contents and this resulted to addition of cereal flour in composite bread preparation by these authors.

From the results as shown in Table 5.2, it can be observed that the level of gum Arabic addition profoundly affected the pasting parameters of maize and cassava flours. This observation is similar to the report by Hammed *et al.* (2016). According to these researchers, the type and concentration of hydrocolloids added to wheat flour had a significant ($p < 0.05$) impact on the pasting capabilities. The interaction of the gum and flour affects the pasting characteristics of flour and hydrocolloid systems. According to various researchers, this interaction is determined by the hydrocolloid gel matrix's morphological characteristics, the flour's swelling characteristic, and based on their thermodynamic compatibility determined by molecular weight and heterogeneity, the starch and protein molecules of the flour and gum matrix ultimately interacted. (Sahni *et al.*, 2020; Zhu, 2015). Increasing the level of gum Arabic addition caused far lower viscosities than the control sample. The temperature at the onset that results to an increase in viscosity is referred to as the pasting temperature and is thought to represent the beginning of gelatinization (Phimolsiripol *et al.*, 2011).

The addition of GA decreased marginally the onset pasting temperature in both maize and cassava flours. This suggests that the gum might have caused a delay in granule swelling. The slight decrease in pasting temperature could also be as a result of the increasing concentration of

starch granules in the continuous phase as well as the boosted association among the granules as explained by Gałkowska *et al.* (2014). Lu *et al.* (2020) earlier reported a decrease in OPT, observing that the onset pasting temperature of cassava flour was lowered by the addition of xanthan gum. Though their value for the cassava flour alone (59 °C) was slightly lower than our results (64 °C) and this may be due to difference in the source of the flour and the gum type. Similarly, Alam *et al.* (2009) found no discernible impact on addition of gum Arabic on the onset pasting temperature (gelatinization temperature) of wheat flour. According to recent studies pasting temperature reveals the least temperature needed to cook the flour and also indicates resistance against swelling therefore the addition of GA in the present study at the concentrations used resulted in the reduction of energy used. These results indicate that cassava flour (17% starch amylose content) depicted low pasting temperatures (64 °C) but high peak viscosity as compared with maize flour (25% starch amylose content) that depicted high pasting temperature (87 °C). This observation is very well supported by earlier research by Ai *et al.* (2013) and BeMiller and Whistler (2009), which found that flours with starch that had a higher amylose content, especially when lipids were present, showed a higher pasting temperature and a lower peak viscosity because amylose prevents starch granules from swelling during heating and shearing. The crystalline size and association within the granules of maize flour appear to be of a larger order of magnitude than those of cassava flour, based on the higher pasting temperature. Shahzad *et al.* (2021) on the other hand, found contrary results, showing that whereas other hydrocolloids greatly reduced the pasting temperature, adding gum Arabic to gluten-free flour significantly raised it relative to the control.

The results in Table 5.3 and Appendix V showed that the peak viscosity (PV), final viscosity (FV), breakdown viscosity (BV) and setback viscosity (SB) decreased with increasing concentrations of the gum. Maize flour depicted low peak viscosity values (157 BU at 0% GA to 73 BU at 8% GA) as compared to cassava flour (645 BU at 0% GA to 384 BU at 8% GA). These results are in consistent with findings reported by Alam *et al.* (2009) who found that gum Arabic significantly reduced the PV of wheat flour up to 890 BU. Similarly, Shahzad *et al.* (2021) reported that addition of gum Arabic reduced the PV (441cP) value of gluten-free flour though it was statistically to that of the control (464cp). The reduction in PV values might be attributed to the fact that GA is characterized by low viscosity hence lacking thickening effect. However,

contrary results were reported by other authors (Chhabra *et al.*, 2018; Lu *et al.*, 2020) where the addition of xanthan gum (0% to 1%) caused a significant increase in the viscosities (peak, hot paste and final) of maize flour as compared to control. The addition of increasing quantities of xanthan gum, the peak viscosity and final viscosity of the cassava flour significantly ($p < 0.05$) increased respectively. The water binding capabilities of gum Arabic may have prevented the starch granules from swelling because of insufficient water, which would have decreased the amylose leaching from the granules due to their poor swelling and, ultimately, the paste's peak viscosity.

Cassava flour exhibited a higher peak viscosity than maize flour and this can be attributed to the lipid content in latter. The ability of starch to create a viscous paste is indicated by the final viscosity. Both flours showed a notable reduction in ultimate viscosity after adding GA. Alam *et al.* (2009) and Shahzad *et al.* (2021) observed a similar trend where addition of GA decreased significantly the final viscosity (FV) of wheat flour batter and gluten-free flour respectively though other gums caused an increase in the FV. The starch dilution effect of the flour may have contributed to the ultimate viscosity's drop because the gum was substituted for the flour. The peak, final, set back and break down viscosity decreased gradually as the gum concentration increased (0% to 8%) as shown by the pasting correlation curves (Figure 5.1 and Appendix V). This could be explained by the increased concentration of GA in the paste matrix, which may have led to poorer gelation by competing with the starch granules for water and poorer interaction of the starch molecules as a result of high electrostatic repulsion (Sahni *et al.*, 2020). The tendency of gum molecules to form hydrogen bonds with amylose molecules that cover the surface of starch granules with resultant hindrance in the swelling of starch granules and consecutive leaching of amylose that thickens the paste often results in low peak viscosity (Gałkowska *et al.*, 2013; Ma *et al.*, 2019).

In accordance with Phimolsiripol *et al.* (2011), granule swelling and amylose leaching raise viscosity; however, since granules may burst during additional heating, viscosity may decrease, as is the case with the current results. The amylose molecules that are leached out are frequently oriented in the direction of flow, this contributes to a decrease in viscosity (Ribotta *et al.*, 2010). With increasing amount of GA, maize flour did not exhibit significant difference in the break down viscosity values as compared with cassava flour were the breakdown reduced significantly

with increasing amount of gum up to 226 BU. The latter finding agrees with Alam *et al.* (2009) who reported that GA greatly reduced the breakdown up to 189 BU which the authors attributed to the tightening of the cassava starch granules which made it more heat resistant thus requiring more cooking time. Gum Arabic led to a significant reduction of breakdown value of maize flour from 7.5 BU to 0 BU. This agrees with another study by Chhabra *et al.* (2018) who observed a significant reduction in the breakdown values of maize flour from three varieties; JL3459 (66cP to 4cP), PMH1 (94cP to 11cP) and Buland (10cP to 0cP) by xanthan gum. Lu *et al.* (2020) reported the same result, wherein adding more xanthan gum to cassava flour reduced the breakdown by forming a solid, three-dimensional network structure with the starch molecular chain segments of the flour.

Poor starch granule swelling is another reason for the low BV values and the viscosity of the paste could be ascribed to the hydrated gum Arabic molecules, which have a tendency to withstand shear pressures during the pasting cycle and produce a low breakdown viscosity value. However, it is supposedly that the interaction between flour and the hydrocolloids affect the swollen granules by making them more fragile. Accordingly, the breakdown viscosity may have dropped as a result of the reduced shear pressures applied to the enlarged grains due to the decreased viscosity (Chhabra *et al.*, 2018). The ability of a flour paste to tolerate heat and shear stress during cooking decreased with increasing BV as explained by Chhabra *et al.* (2018). Furthermore, Park *et al.* (2007) reported that low breakdown viscosity of flour might be utilized to create meals that are firm but do not have to adhere to one another.

Setback viscosity, which is frequently employed as a marker of starch retrogradation, is caused by the reorganization of starch granules into a condition that is somewhat organized. With addition of gum Arabic, the setback values significantly decreased. The bonding between the molecules of gum Arabic and amylose is responsible for the decrease in setback viscosity. This decreases the potential of starch paste to retrograde by preventing amylose chains from interacting with one another. Shahzad *et al.* (2021) reported a similar finding where gum Arabic significantly decreased the setback viscosity of gluten free flour compared to that of the control sample. Sidhu and Bawa (2004) reported a similar trend where they established lower setback values of wheat flour pasted with Arabic gum and this observation could be linked to lower PV and FV caused by this hydrocolloid. The current results also concur with Brenna *et al.* (2008)

who reported that use of gum Arabic yielded pastes with lowest viscosities for all treatments. The highly branched structure of the GA molecule results in the formation of a relatively compact tiny hydrodynamic volume, which only at high concentrations turns into a viscous solution (Montenegro *et al.*, 2012). These effects may be explained by the trapping of the gum in the starch granules and the electrostatic contact between the proteins in the flour and GA. This could have resulted in change in the surface characteristics of starch granule hence restricting its swelling and therefore the decrease in the aforementioned pasting viscosities. It has been observed that gum Arabic exhibit inherent low viscosity with Newtonian flow behavior in an aqueous system. This has been linked to the spherical molecular configuration which may also contribute to the system lubrication without generating adhesiveness or viscosity (Funami *et al.*, 2008).

5.4.2 Effect of gum Arabic substitution in cassava and maize flour on textural properties

From the results shown in Table 5.4, it was evident that all texture characteristics were significantly different ($p < 0.05$) from each other for both flours. Substitution of flour by GA gave significant different textural parameters for maize flour including firmness, consistency, cohesiveness and work of cohesion but had no significant effect on the latter two parameters for cassava flour. The force needed to compress a material by a specific quantity is also known as the peak force and is often used to describe a product's firmness or hardness (Olatidoye *et al.*, 2020). With increasing levels of gum Arabic, the firmness ranged from 64.52 to 85.05g and 86.65 to 40.98g for cassava flour and maize flour respectively. The addition of higher levels of GA resulted to a significant increase on the firmness (64g to 85g) and consistency (1639g.s to 2066g.s) of cassava flour gels on the other hand these parameters decreased significantly for maize flour gels.

The firmness of maize flour gels decreased upon addition of gum implying that GA weakened the associative forces between starch molecules of the flours. Jarnsuwan and Thongngam (2012) reported similar findings whereby at higher hydrocolloid concentration caused a decrease in the hardness and elasticity of noodles and this was ascribed to the high molecular weight of the hydrocolloid that might have interfered with the gluten network formation. Similar outcome was noted by Brenna *et al.* (2008) on wheat flour gel where the hardness decreased with increasing substitution levels of gum Arabic though galactomannans gave opposite effect on hardness.

Therefore, it is suggested that when soft gel texture is desired high concentration of GA could be used since it becomes viscous.

The maximum force is shown by consistency, and the thicker the consistency of the sample, the higher the value. According to the current findings, cassava flour gels were thicker than maize flour gels because they had greater consistency values. Increasing the gum Arabic replacement levels resulted in a considerable reduction of the maize flour gels, which may have been caused by amylose molecules leaching and weakening of the internal bonds (da Silva Costa *et al.*, 2020). From the present study cohesiveness and work of cohesion increased significantly ($p < 0.05$) for maize flour gels with increasing levels of GA but for cassava flour addition of the gum did not affect the cohesiveness and work of cohesion of the gels. Cohesiveness of paste is connected to the degree of breakdown of flour molecules during heating and agitation. According to Phimolsiripol *et al.* (2011) cohesiveness can be seen more as an internal characteristic involving the interaction of cohesive and adhesive forces, as well as viscosity and elasticity. Greater cohesiveness values signify a more cohesive starch gel, resulting in a more robust texture. Cassava flour-gum blend gels exhibited low work of cohesion values with no significant difference between the control and higher gum levels. This often results to lower resistance to withdrawal thus lowering the viscosity as compared to maize flour gels that showed slightly higher values hence higher index of viscosity.

Jarnsuwan and Thongngam (2012), suggested that hydrocolloids might affect the textural properties of cooked noodles and also the variations in the flours' structures may have an impact on the final product's textural qualities. Hammed *et al.* (2016) reported contrary results where texture parameters of flour/ dough increased with increase in hydrocolloid concentration. Significant reduction ($p < 0.05$) of the measured textural parameters resulted in more viscous gels. The gum may have possibly reduced the gel formation by acting as a physical barrier in H-bond formation between the dispersed amylose molecules or by interacting with the amylose molecules thus decreasing the interaction between them (Charoenkul *et al.*, 2011). Among the various textural properties of flour for making various products hardness level is one of the important quality parameters. Studies have reported that hardness relates to crispness as in bread and snacks. This is one of the main consumer considerations in purchasing snacks. Moreover, crispness may be connected with some characteristics of products such as firmness, brittleness as

well as a specific sound when it is broken. It should be noted that a decrease of crispness in snacks or other products based on flour can become the primary reason of product rejection (Ambarsari *et al.*, 2018).

5.4.3 The relationship between pasting and textural properties of cassava and maize flour substituted with gum Arabic

The results in Table 5.5 show strong positive correlation behaviour between peak viscosity with final viscosity and breakdown. This may be explained by a stronger barrier to granule enlargement, which makes them more fragile. Additionally, there was a significant negative correlation between the final viscosity and the work of cohesion, which suggested that the forces holding the granules together had weakened, producing a rather weak gel.

Hammed *et al.* (2016) found a comparable finding for blends of guar, xanthan, and alginate hydrocolloid-flour. The current research indicates a close association between the viscosity of flour paste at 50°C as determined by the Brabender viscograph and the texture cohesiveness, stability, and work cohesiveness of gum gels. Arabic flour mixtures. Gum Arabic may behave differently in slurry and gel systems, as indicated by the correlation values, which showed a discrepancy in the measurement of paste slurry and gel stabilities. By adding GA, the system's texture became more consistent and the pasting qualities of the maize and cassava flour were enhanced. Several authors' reports have also shown comparable results using various starch-hydrocolloid systems (Lu *et al.*, 2020; Phimolsiripol *et al.*, 2011; Singh *et al.*, 2016).

5.5 Conclusion

The current research findings indicates that GA from *Acacia senegal* var. *kerensis* has no effect on the textural and pasting qualities of flour. Therefore, we reject the null hypothesis. The pasting and textural qualities of maize and cassava flours were dramatically altered by the addition of gum Arabic. These findings highlight a decrease in onset pasting temperature and viscosities of the flours with increasing levels of gum Arabic incorporation. The nature of the flour, variations in flour particle size, variations in varieties, and the production of amylose-lipid complexes are the reasons for the differences between the flours. The paste became more stable as a consequence of the setback values, which are thought of as a measure of gelling ability or retrogradation tendency. This indicates that the gum could be an appropriate candidate for

preventing retrogradation and staling in flour-based products. The gum increased the firmness and consistency of cassava flour gels hence was thicker as compared to maize flour gels. For maize flour gels, cohesiveness and work of cohesion greatly enhanced as GA levels increased. There was no influence on these parameters for cassava flour gels. Cohesiveness of paste is connected to the degree of breakdown of flour molecules during heating and agitation. Significant reduction of the measured textural parameters resulted in more viscous gels. This study suggests that gum Arabic from *Acacia senegal* var. *kerensis* can be used to inhibit retrogradation and improve binding and stability process while making a variety of food products using cassava and maize flours. We therefore recommend further research that incorporates the gum in specific food products made from the aforementioned flours to enhance their application.

CHAPTER SIX
COMPARISON OF HYDROCOLLOID MAGNITUDE OF EFFECT OF GUM ARABIC FROM ACACIA SENEGAL VAR KERENSIS ON THE FUNCTIONAL PROPERTIES OF FLOURS AND STARCHES OF CASSAVA AND MAIZE USING MULTINOMIAL LOGISTIC REGRESSION

Abstract

Modification of starches and flours from underutilized food crops to obtain some specific desired functional properties is increasingly becoming necessary practice in food processing. The objective of this study was to compare the magnitude of effect of gum Arabic hydrocolloid substitution level on textural, physical and pasting properties between cassava and maize flours and starches. Pasting properties were determined using a Brabender viscograph, textural characteristics of the gels were analyzed using a texture analyzer while various methods were used to measure the physical properties of the pastes. Multinomial Logistic Regression (MRL) model was used to compare the effect of magnitude of gum Arabic functional properties on cassava versus maize. Maize starch had significantly highest level of firmness and consistency and also significantly lowest cohesiveness after gelling as compared to other materials. Maize flour and cassava starch did not differ significantly for all the textural properties. Each of the substitution levels did not differ significantly on onset pasting temperature in flours and starches for both cassava and maize. Cassava flour showed significant higher values of the selected physical properties as compared to other materials under study. From the results gum Arabic could be used to modify the various properties of flours and starches to achieve desirable qualities. The study recommends incorporation of this hydrocolloid into specific food products based on the aforementioned flours and starches.

6.1 Introduction

Globally, there is a growing interest by the food industry in research of underutilized plant species as a contribution to consumers' diet diversification and the incorporation of ingredients with particular textural and technological properties (Colgrave *et al.*, 2021; Dini *et al.*, 2014). Studies have shown that flour and starch from tubers and roots can be used to replace wheat flour in specific food application, though current world policies and demographic claims have been key drivers to the application of starchy materials. A growing number of consumers are looking

for certain starch qualities, even though the market offers a wide range of native starches with different functions. This has called for exploration of new strategies or alternative novel sources (Adewale *et al.*, 2022; Aprianita *et al.*, 2012; Charles *et al.*, 2007). This is crucial because unmodified starches are commonly chemically treated to boost their characteristics because they lack the desirable properties for use in manufactured food items (Kim *et al.*, 2013; Obadi & Xu, 2021). The range of functional properties that can be obtained by converting a chemical compound into a derivative has expanded, however, due to consumer preference, starches derived from different plant sources, particularly tropical sources, are now being examined for the requisite usefulness, avoiding the need for chemical substance modifications (Aprianita *et al.*, 2012).

Some of the desired features of starch, according to Kim *et al.* (2013), include controlling water mobility, enhancing paste and gel textures, providing cold storage and/or freeze-thaw stability, and increasing their tolerance to processing conditions. It has been proposed that in order to address perceptible and technical concerns, the food industry would embrace new methods that could improve the quality of flours and starches rich in nutrients (Culetu *et al.*, 2021). Studies, therefore, have shown that certain hydrocolloids in combination with certain starches provide some improvement of properties without chemical modification (Alam *et al.*, 2009; Kim *et al.*, 2013).

Numerous tests has been done on gums to enhance the useful qualities of flour and starch obtained from various locations (Cappelli *et al.*, 2020; Salehi, 2019; Yamul & Navarro, 2020). Though some have recorded successes, some still have not. For instance, research conducted by Dini *et al.* (2014) examined the effects of xanthan gum, high methoxy hydroxypropyl methylcellulose (HM HPMC), carrageenan, alginate, and carboxymethylcellulose on formulations made using rice flour and cassava starch. They stated that adding these hydrocolloids alone did not appear to be sufficient to replicate the qualities of wheat bread and gluten dough. According to a different study, adding gum Arabic improved the physical characteristics of potato flour-based batters (Yamul & Navarro, 2020). However, there exist a gap on use of research on the application of GA from *Acacia senegal var kerensis* to improve other carbohydrates ingredients, including making a waxy corn starch alternative for industrial use. Gum Arabic, a highly branched polymer found in *Acacia senegal*, is composed of a core of -

1,3-linked D-galactose that branches into 3- and 6-linked galactose and 3-linked arabinose. Here, glucuronic acid and rhamnose terminate some of the branches of the molecules at their periphery (Williams & Phillips, 2009).). This unique structural orientation could be explored in flours and starches in developing products with desired functional properties. Flour and starch from tubers, roots, and other cereals can be substituted for wheat flour in some food applications, in addition to having potential wider uses in the food or non-food industries. Moreover, biodegradable packaging materials, thermoplastic thin films, medications, textiles and fuels are possible applications (Egharevba, 2019; Santos *et al.*, 2021).

The food industry is very interested in creating commercial cassava starch with little to no amylose as an alternative to commercial waxy maize starch, according to Hsieh *et al.* (2019) and Santos *et al.* (2021). These researchers attributed to the sticky starchy material from tapioca that offers the industry advantages over other cereal starches, such as unique gel textures and increased resistance to freezing and thawing.

Models using Multinomial Logistic Regression (MLR) have a greater possibility of comparing the impact of gum Arabic's functional characteristics on cassava as opposed to maize. A mathematical modeling technique called the MLR is mostly used to forecast nominal response variables with greater than two distinct levels (Bayaga, 2010; Vilaça *et al.*, 2019). The relationship between the predictor variable(s) and response variable(s) cannot be examined using linear regression when the response is merely a designation of one of two or more possible outcomes. When there are more than two notional or unorganized categories in the dependent variable, linear regression is frequently used. The fact that each one indicates how the risk predictors affect the likelihood of success in that category relative to the reference category is the most important factor to take into account in this situation. Neither linearity nor normalcy nor even homoscedasticity are assumed in this multinomial analysis.

Therefore, MLR analysis was used to determine the extent of Acacia gum variety *kerensis* replacement level of cassava and maize flour and starch on their physical, textural and pasting capabilities. The hypothesis postulated that the hydrocolloid substitution levels in the starches of cassava and maize did not differ in terms of the extent of an impact they had on functional characteristics when compared to their respective flours.

6.2 Materials and method

6.2.1 Materials

Materials used in this study are described in section 4.2.1 of chapter four.

6.2.2 Sample preparation

Samples were prepared as described in section 3.2.1 of Chapter three.

6.2.3 Determination of pasting properties

Pasting properties were determined as described in Chapter three.

6.2.4 Determination of physical properties

Physical properties were determined as described in Chapter four.

6.2.5 Determination of textural properties

Textural properties were determined as described in Chapter five.

6.2.6 Data analysis

Data obtained was analyzed with SAS® software version 9.4 at 95% confidence level. PROC GLM was used to do analysis of variance (ANOVA) on effect of material type on functional properties while post-hoc analysis employed Tukey's honestly significant difference (HSD). Multinomial logistic regression (MLR) analysis used PROC LOGISTICS with a glogit link in the command. For both cassava and maize, the binary response variable was type of material (starch and flour) while predictor variables were the functional properties analyzed.

6.3 Results

6.3.1 Textural properties

Figure 6.1. shows the textural properties of cassava and maize starches and flours. Maize starch had significantly highest level of firmness and consistency as well as significant lowest cohesiveness after gelling as compared to other materials. On the contrary, gels from cassava flour had significantly lowest firmness and consistency but significant highest work of cohesion. Maize flour and cassava starch gels did not differ significantly for all the textural properties.

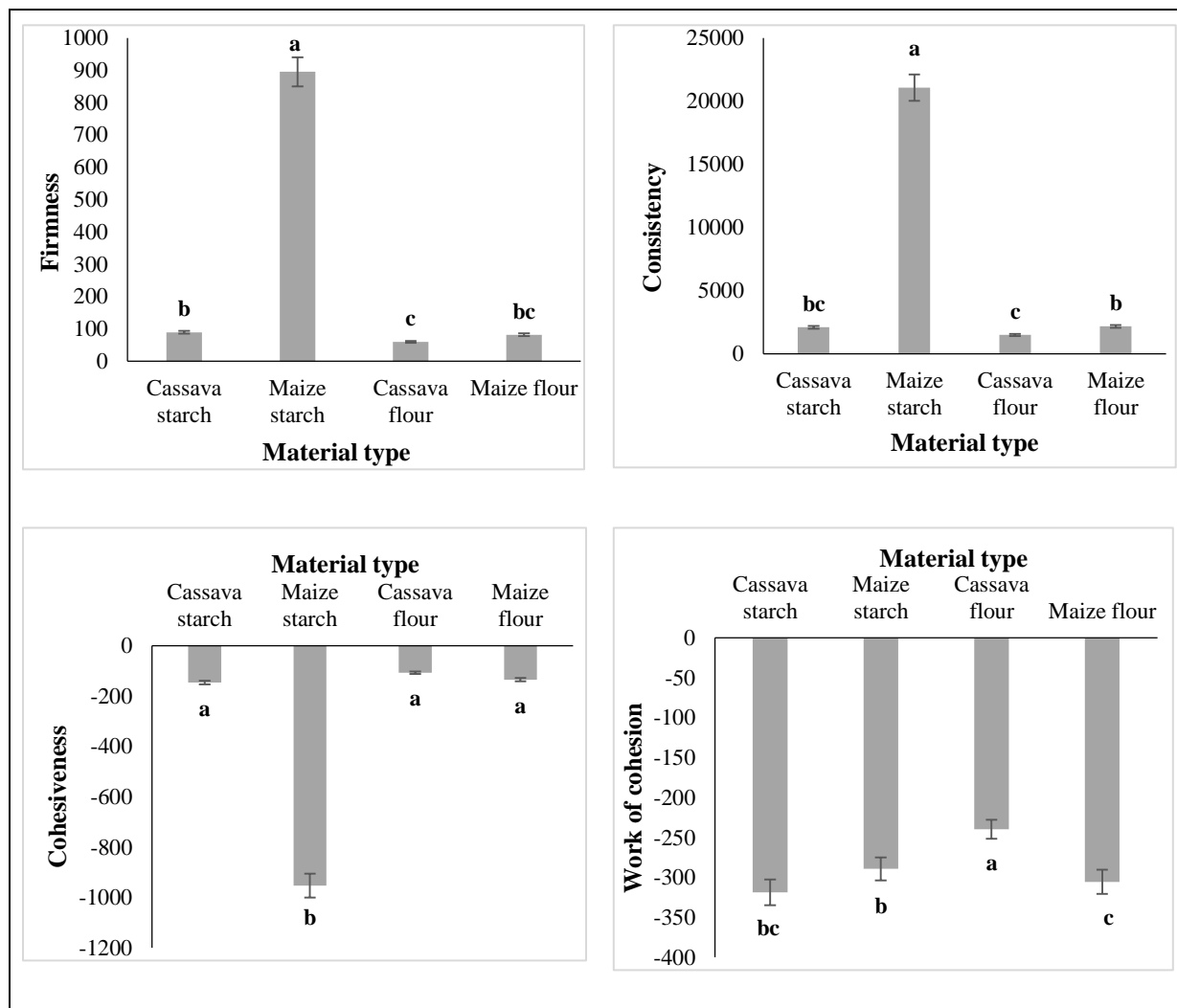


Figure 6.1: Textural properties of cassava and maize flours and starches

Key: Error bars with the same letter are not significantly different at $p \leq 0.05$

Table 6.1. displays odds ratio point estimates of each gum Arabic level of substitution on textural properties of cassava flour and starch compared to maize flour and starch in reference to the control. Effect of a 2.0% gum Arabic substitution level in cassava flour compared to maize flour on firmness, cohesiveness and work of cohesion was higher but not significantly different though for consistency there was a significant difference. Effect of 4.0, 6.0 and 8.0% levels of substitution in cassava flour compared to maize flour were significantly higher on all textural properties except for consistency at 8.0% level which showed no significance difference.

The only starch substitution levels that demonstrated a notably greater impact on firmness when compared to their maize starch counterparts were those of gum Arabic replacement at 6.0 and

8.0% in cassava starch though a non-significant reduced effect was seen at the 0.5 and 2.0% levels, whereas a non-significant larger effect was seen at the 4.0% level. The only textural attribute in cassava starch where all degrees of gum Arabic substitution had a noticeably smaller impact than in maize starch is work of cohesion. However, consistency was shown to be considerably lower in cassava starch at the 2.0% level compared to maize starch, greater but not statistically different at the 4.0% level, and significantly higher at the 6.0 and 8.0% levels. In terms of cohesiveness, cassava starch showed a greater but non-significant impact at the 4.0 and 6.0% levels when compared to maize starch; conversely, a stronger and significant effect was seen at the 2.0 and 8.0% levels.

6.3.2 Pasting properties

Figure 6.2 displays the initial pasting characteristics of maize and cassava flour and starch. Maize starch had significantly the highest final viscosity and setback but the lowest breakdown compared to other materials. Similarly, maize flour had highest onset pasting temperature but the lowest peak viscosity as compared to other materials. But cassava starch exhibited significantly highest peak viscosity and breakdown.

6.3.3 Physical properties

Table 6.3 displays the physical characteristics of the starch and flour made from cassava and maize. When compared to other materials under investigation, cassava flour had significantly higher WHC, FC, WSI, WAI, and SC values but significantly lower OHC values.

Table 6.1: Odds ratio point estimates of gum Arabic level of substitution on textural properties of cassava compared to maize for both flours and starches

Material	Effect	GA (%)		Firmness	Consistency	Cohesiveness	WOC
Flours	Cassava vs. Maize	2.0	PE	1.217 ^{ns}	1.228 ^{***}	1.185 ^{ns}	1.165 ^{ns}
			CL	(0.872- 1.698)	(1.150- 1.310)	(0.917- 1.532)	(0.981- 1.384)
	Cassava vs. Maize	4.0	PE	2.310 ^{***}	2.348 ^{***}	1.971 ^{***}	1.922 ^{***}
			CL	(1.651- 3.234)	(2.198- 2.509)	(1.508- 2.577)	(1.607- 2.297)
	Cassava vs. Maize	6.0	PE	2.980 ^{***}	3.038 ^{***}	2.563 ^{***}	2.456 ^{***}
			CL	(2.119- 4.192)	(2.841- 3.250)	(1.949- 3.371)	(2.049- 2.944)
Cassava vs. Maize	8.0	PE	2.803 ^{***}	2.852 ^{ns}	2.533 ^{***}	2.492 ^{***}	
		CL	(1.975- 3.978)	(0.583-1.065)	(1.911- 3.358)	(2.067- 3.006)	
Starches	Cassava vs. Maize	2.0	PE	0.938 ^{ns}	0.917 ^{***}	1.208 [*]	0.458 ^{***}
			CL	(0.749- 1.175)	(0.875- 0.960)	(1.012- 1.443)	(0.395- 0.532)
	Cassava vs. Maize	4.0	PE	1.106 ^{ns}	1.022 ^{ns}	1.031 ^{ns}	0.255 ^{***}
			CL	(0.884- 1.385)	(0.976- 1.070)	(0.861- 1.233)	(0.221- 0.296)
	Cassava vs. Maize	6.0	PE	1.315 [*]	1.252 ^{***}	1.194 ^{ns}	0.417 ^{***}
			CL	(1.054- 1.641)	(1.197- 1.311)	(0.996- 1.431)	(0.358- 0.484)
Cassava vs. Maize	8.0	PE	1.529 ^{***}	1.383 ^{***}	1.312 ^{***}	0.425 ^{***}	

Key: Gum Arabic substitution level of 0% is the reference category; GA= Gum Arabic; PE= Point Estimate; CL= 95% Wald confidence Limits; WOC= Work of Cohesion; ***= significant at p<0.001; *=significant at p<0.05; ns= Not Significant

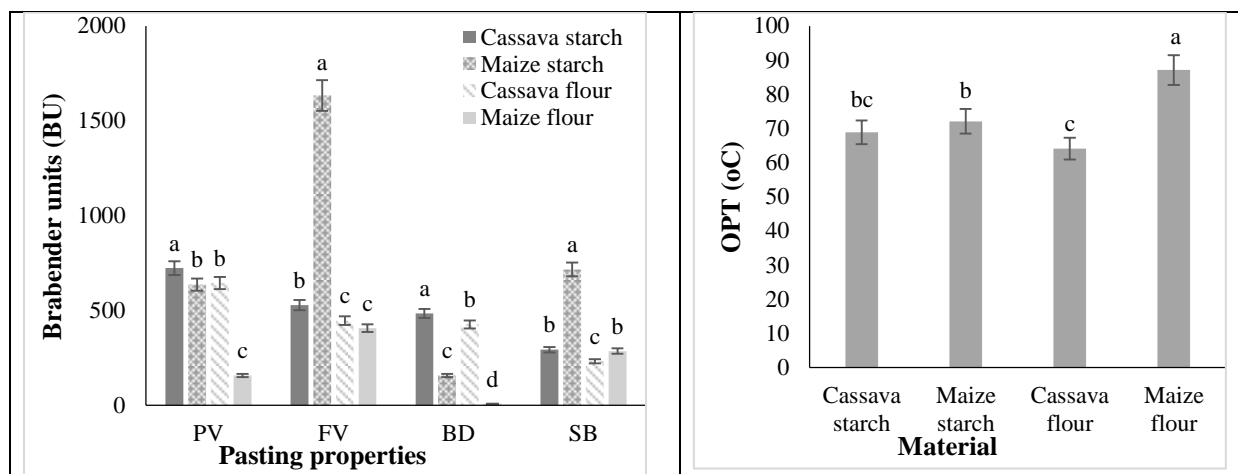


Figure 6.2: Initial pasting properties of starch and flour from cassava and maize

Key: OPT= Onset Pasting Temperature; PV= Peak Viscosity; FV= Final Viscosity; BD= Breakdown; SB= Setback. Error bars with same letter for each pasting property are not significantly different

Table 6.2 displays the odds ratio point estimates of each gum Arabic level of substitution on pasting properties of cassava flour and starch compared to maize flour and starch in reference to the control. Each of the substitution levels did not have any significant difference on onset pasting temperature in cassava flour as compared to maize flour. As compared to other levels, 2.0% level had a higher but not significant effect in cassava flour compared to maize flour for peak viscosity, final viscosity and setback but for 4.0, 6.0 and 8.0% levels a significant higher effect was observed. However, a higher but not significant effect was observed in 8.0% level in cassava flour as compared to maize flour while levels 2.0, 4.0 and 6.0% showed significantly very high effect. For starches, each level of gum Arabic substitution in cassava starch did not have a significantly different effect on onset pasting temperature, breakdown and setback as compared to maize starch. However, for peak viscosity only 8.0% level showed a significantly lower effect in cassava starch as compared to maize starch.

Table 6.2: Odds ratio point estimates of gum Arabic level of substitution on pasting properties of cassava compared to maize for both flours and starches

	Effect	GA (%)		OPT	PV	FV	Breakdown	Setback
Flours	Ca vs. Ma	2.0	PE	1.000 ^{ns}	1.117 ^{ns}	1.091 ^{ns}	6.549 ^{***}	1.099 ^{ns}
			CL	(0.724- 1.381)	(0.928- 1.528)	(0.949- 1.255)	(1.493- 28.735)	(0.918- 1.316)
	Ca vs. Ma	4.0	PE	0.998 ^{ns}	1.254 [*]	1.282 ^{***}	5.599 [*]	1.293 [*]
			CL	(0.722- 1.379)	(1.029- 1.528)	(1.107- 1.483)	(1.276- 24.574)	(1.073- 1.559)
	Ca vs. Ma	6.0	PE	1.002 ^{ns}	1.236 [*]	1.367 ^{***}	4.611 [*]	1.357 ^{***}
			CL	(0.724- 1.386)	(1.005- 1.520)	(1.176- 1.588)	(1.050- 20.241)	(1.121- 1.642)
	Ca vs. Ma	8.0	PE	1.008 ^{ns}	1.279 [*]	1.393 ^{***}	3.983 ^{ns}	1.355 ^{***}
			CL	(0.728- 1.394)	(1.031- 1.587)	(1.196- 1.624)	(0.907- 17.480)	(1.115- 1.646)
Starches	Ca vs. Ma	2.0	PE	1.007 ^{ns}	1.034 ^{ns}	1.076 ^{ns}	1.046 ^{ns}	1.026 ^{ns}
			CL	(0.723- 1.403)	(0.927- 1.154)	(0.974- 1.188)	(0.867- 1.263)	(0.894- 1.177)
	Ca vs. Ma	4.0	PE	1.007 ^{ns}	1.022 ^{ns}	1.173 ^{***}	1.062 ^{ns}	1.120 ^{ns}
			CL	(0.723- 1.403)	(0.912- 1.145)	(1.059- 1.299)	(0.871- 1.293)	(0.972- 1.291)
	Ca vs. Ma	6.0	PE	1.000 ^{ns}	0.953 ^{ns}	1.129 [*]	1.069 ^{ns}	1.035 ^{ns}
			CL	(0.718- 1.393)	(0.848- 1.071)	(1.017- 1.253)	(0.868- 1.317)	(0.894- 1.197)
	Ca vs. Ma	8.0	PE	1.014 ^{ns}	0.851 [*]	1.009 ^{ns}	1.013 ^{ns}	0.891 ^{ns}
			CL	(0.728- 1.413)	(0.756- 0.959)	(0.908- 1.121)	(0.818- 1.256)	(0.769- 1.032)

Gum Arabic substitution level of 0% is the reference category; Ca= cassava; Ma= maize; GA= Gum Arabic; OPT= Onset Pasting Temperature; PV= Peak Viscosity; FV= Final Viscosity PE= Point Estimate; CL= 95% Wald confidence Limits; WOC= Work of Cohesion; ***= significant at p<0.001; *=significant at p<0.05; ns= Not Significant

The results revealed that whilst maize starch displayed much higher OHC, cassava starch displayed significantly higher BD. Odds ratio point estimates of each gum Arabic level of substitution on the physical properties of cassava flour and starch compared to maize flour and starch respectively in reference to the control is shown in Table 6.4. For both starch and flour, each level of gum Arabic substitution did not have a significantly different effect on bulk density of cassava as compared to their respective counterparts in maize. Each level of substitution showed a significant difference in effect on WSI and FC in cassava starch compared to maize starch but no significant difference in cassava and maize flours. On the contrary, each level of substitution showed a significant difference in effect on WAI and WHC in cassava flour compared to maize flour but no significant difference in cassava and maize starches. Although each level of substitution showed a significant difference in effect on SC for both cassava and maize starches and flours, the effect in cassava starch was higher than in maize starch while the effect was lower in cassava flour than in maize flour. Only 2.0% and 4.0% substitution levels that a significant difference in effect was observed on OHC in cassava starch as compared to maize starch while only 4.0 and 8.0% levels caused a significant difference in effect of cassava and maize flours.

Table 6.3: Physical properties of cassava and maize starch and flour

Material type	WHC	FC	BD	WSI	WAI	SC	OHC
CS	0.16±0.00 ^a	2.04±0.08 ^c	0.57±0.00 ^a	0.03±0.00 ^c	0.81±0.01 ^b	0.05±0.00 ^c	0.02±0.00 ^b
MS	0.12±0.01 ^b	0.67±0.10 ^d	0.52±0.01 ^a	0.09±0.00 ^b	0.83±0.05 ^b	0.26±0.05 ^b	0.10±0.01 ^a
CF	0.18±0.00 ^a	6.68±1.02 ^a	0.36±0.00 ^b	0.14±0.00 ^a	1.24±0.01 ^a	0.34±0.05 ^a	0.01±0.00 ^b
MF	0.14±0.02 ^b	5.00±1.00 ^b	0.55±0.00 ^a	0.01±0.00 ^d	1.03±0.12 ^{ab}	0.05±0.00 ^c	0.02±0.00 ^b

Key: Means with the same letter along the column are not significantly different. WHC= Water Holding Capacity; FC= Foaming Capacity; BD= Bulk Density; WSI= Water Solubility Index; WAI= Water Absorption Index; SC= Swelling Capacity; OHC= Oil Holding capacity; CS= Cassava starch; CF= Cassava flour; MS= Maize starch; MF= Maize flour

Table 6.4: Odds ratio point estimates of gum Arabic level of substitution on physical properties of cassava compared to maize for both flours and starches

	Effect	GA (%)		WHC	FC	BD	WSI	WAI	SC	OHC
Flours	Cas.vs. Ma.	2.0	PE	0.793*	1.458 ^{ns}	0.949 ^{ns}	0.510*	1.203***	0.260***	1.719 ^{ns}
			CL	(0.642- 0.980)	(0.436- 4.879)	(0.830- 1.084)	(0.271- 0.958)	(1.107- 1.308)	(0.206- 0.330)	(0.901- 3.281)
	Cas.vs. Ma.	4.0	PE	1.307*	0.952 ^{ns}	1.111 ^{ns}	0.591 ^{ns}	1.286***	0.182***	1.980*
			CL	(1.041- 1.640)	(0.316- 2.873)	(0.971- 1.271)	(0.311- 1.124)	(1.181- 1.399)	(0.145- 0.229)	(1.017- 3.855)
	Cas.vs. Ma.	6.0	PE	1.255*	1.527 ^{ns}	1.092 ^{ns}	0.755 ^{ns}	1.242***	0.243***	0.733 ^{ns}
			CL	(1.007- 1.563)	(0.511- 4.566)	(0.955- 1.247)	(0.389- 1.466)	(1.144- 1.348)	(0.194- 0.304)	(0.321- 1.673)
	Cas.vs. Ma.	8.0	PE	1.183 ^{ns}	2.332 ^{ns}	1.102 ^{ns}	1.109 ^{ns}	1.184***	0.247***	5.021***
			CL	(0.952- 1.471)	(0.771- 7.056)	(0.964- 1.259)	(0.544- 2.258)	(1.092- 1.284)	(0.198- 0.309)	(2.323- 9.851)
Starches	Cas.vs. Ma.	2.0	PE	0.924 ^{ns}	0.734***	1.046 ^{ns}	1.672***	0.947 ^{ns}	2.161***	2.063***
			CL	(0.732- 1.167)	(0.675- 0.798)	(0.927- 1.179)	(1.165- 2.398)	(0.861- 1.042)	(1.648- 2.835)	(1.205- 5.563)
	Cas.vs. Ma.	4.0	PE	0.950 ^{ns}	0.508***	1.021 ^{ns}	2.016***	0.945 ^{ns}	3.296***	3.144***
			CL	(0.756- 1.195)	(0.469- 0.550)	(0.904- 1.152)	(1.419- 2.864)	(0.860- 1.038)	(2.610- 4.161)	(2.046- 4.833)
	Cas.vs. Ma.	6.0	PE	0.941 ^{ns}	0.348***	0.958 ^{ns}	2.120***	0.942 ^{ns}	3.329***	1.289 ^{ns}
			CL	(0.750- 1.182)	(0.322- 0.375)	(0.848- 1.081)	(1.501- 2.994)	(0.858- 1.033)	(2.646- 4.189)	(0.790- 2.103)
	Cas.vs. Ma.	8.0	PE	0.947 ^{ns}	0.316***	0.915 ^{ns}	2.212***	0.916 ^{ns}	3.784***	1.220 ^{ns}
			CL	(0.754- 1.189)	(0.293-0.340)	(0.811- 1.033)	(1.580- 3.098)	(0.835- 1.004)	(3.012- 4.754)	(0.737- 2.018)

Key: Gum Arabic substitution level of 0% is the reference category; Cas= cassava; Ma= maize; GA= Gum Arabic; WHC= Water Holding Capacity; FC= Foaming Capacity; BD= Bulk Density; WSI= Water Solubility Index; WAI= Water Absorption Index; SC= Swelling Capacity; OHC= Oil Holding capacity; ***= significant at p<0.001; *=significant at p<0.05; ns= Not Significant

6.3.4 Relationship between textural, pasting and physical properties due to gum Arabic addition

Table 6.5 and Figure 6.3 compares the principal component loading matrix of functional characteristics between flours and starches. For starches, there were only two principal components each contributing 61.4% and 24.8% respectively, where all properties loaded on principal one except WAI (0.823), SC (0.796), and FC (0.608) and PV (-0.874). On the contrary, for the flours there were three principal components each contributing 57.5%, 23.1% and 9.84 % respectively. Majority of the properties loaded on component one except setback (-0.953) and SC (0.763) while component three had only OHC (0.825).

Table 6.5: Comparison of loading matrix coefficients of functional properties on principal components between starch and flours

Property	Starches		Property	Flours		
	Prin. 1	Prin. 2		Prin. 1	Prin. 2	Prin. 3
OPT	0.979732	-	WSI	0.946817	-	-
Consistency	0.972972	-	WAI	0.898294	-	-
Firmness	0.965333	-	Peak viscosity	0.878812	-	-
Final viscosity	0.937861	-	Breakdown	0.862455	-	-
Setback	0.922755	-	WHC	0.793175	-	-
WSI	0.682118	-	Firmness	0.783661	-	-
WAI	-	0.823171	Final viscosity	0.751833	-	-
SC	-	0.795691	Consistency	0.730376	-	-
FC	-	0.607682	FC	0.630150	-	-
WHC	-	-	Setback	-	-	-
	0.804839				0.953464	
Cohesiveness	-	-	SC	-	0.763101	-
	0.945629					
OHC	0.600718	-	Cohesiveness	-	-	-
				0.773939		
BD	-	-	Work of	-	-	-
	0.727243		cohesion	0.763419		

Work of cohesion	-	-	BD	-	-	-
	0.674277			0.868309		
Peak viscosity	-	-	OPT	-	-	-
		0.874238		0.927315		
Breakdown	-	-	OHC	-	-	0.825451
	0.949662					

Key: Prin. = Principal Component; WHC= Water Holding Capacity; FC= Foaming Capacity; BD= Bulk Density; WSI= Water Solubility Index; WAI= Water Absorption Index; SC= Swelling Capacity; OHC= Oil Holding capacity; OPT= Onset Pasting Temperature

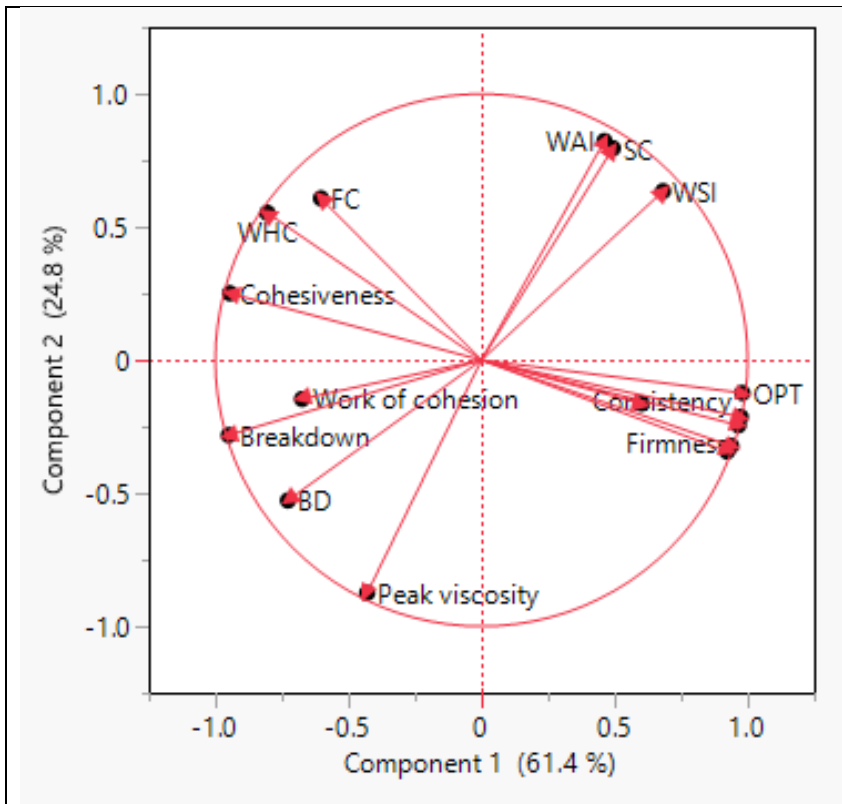


Figure 3a: Loading of properties of starch

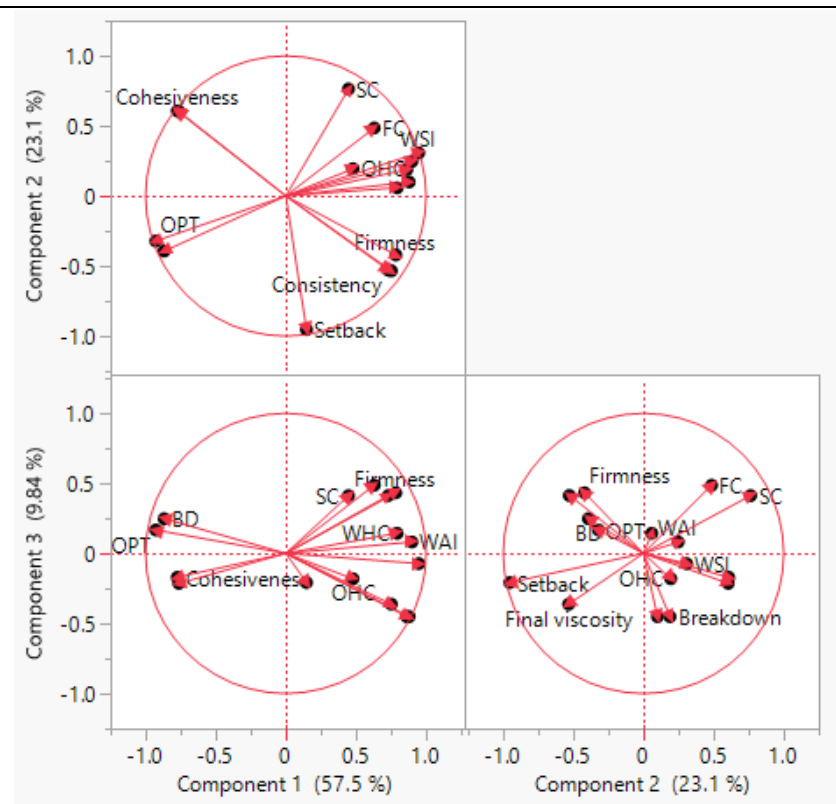


Figure 3b: Loading of properties of flours

Figure 6.3: Functional properties loading matrix on principal components

6.4 Discussion

Several factors, including the size of the starch granule, the molecular structure of the amylopectin (branch, length, and weight), the content of starch, protein, and dietary fiber, as well as the presence of other compounds, influence the variation in textural, pasting, and physical properties among the different flours (Culetu *et al.*, 2021).

6.4.1 Textural properties

Figure 6.1 shows that the textural features of the gels generated by the materials utilized in this study varied greatly. An interesting finding revealed an antagonistic relationship between cassava flour and maize starch for every textural property. In addition to its proximate composition, maize starch can be responsible for this discrepancy since it has a relatively high amylose percentage (over 27%), whereas cassava flour's amylose content ranges from 13–17% and is primarily resistant starch (He *et al.*, 2020; Zhang *et al.*, 2014). Because amylopectin can bind and hold water better than amylose, the gel is stiffer because amylopectin is packed into crystallites more tightly (Kim *et al.*, 2013). Another notable observation was that cassava starch and maize flour did not differ significantly, and this could be attributed to both being categorized as having waxy starch structure (Santos *et al.*, 2021).

In general, the degree to which gum Arabic replacement affected the textural qualities of flour varied significantly between maize and cassava, as seen in Table 6.1. Since the odds ratio estimates for cassava flour were higher than 1.0, the effect of gum replacement amount on textural qualities was greater than for maize flour. Nevertheless, the only difference between the two types of flour at the 2.0% substitution level was consistency with regard to textural qualities. Another factor that's important to note is that the difference in effect between the two types of flours increased along with the substitution amount. As with flours, the degree of substitution in starches increased along with the difference in magnitude of influence between the two types of starches on the textural qualities of gels. In contrast to flours, the degree of gum Arabic substitution's impact on the textural characteristics of starches revealed inconsistent results. Gum Arabic's effect on cassava starch was more pronounced than that on maize starch in terms of gel firmness, consistency, and cohesiveness, although maize starch surpassed cassava starch with regards to work of cohesion. According

to related research, the amylose content rather than the additional gum may have a greater impact on this finding (Kim *et al.*, 2013).

Gum substitution level of 2.0% gave a gel that was 22.8% more consistent in cassava flour than in maize flour but 8.3% less consistent and 20.8% more cohesive in cassava starch than in maize starch. A 4.0% substitution level gave a gel that was 2.3 times firmer and more consistent and 1.9 times more cohesive and work of cohesion in cassava flour than in maize flour. The same level gave a gel that was 74.5% less work of cohesion in cassava starch than in maize starch while other properties remained not significantly different. Among the flours, addition of gum at 6.0 and 8.0% gave a gel that was 2.8 to 2.9 times firmer, 2.5 times more cohesive and 2.4 times more work of cohesion in cassava than in maize. However, for starches, the same level of substitution gave 31.5 - 52.9% more firm, 25.2 - 38.8% more consistent and 57.5 - 58.3% less work of cohesion in cassava than in maize.

We hypothesise that these findings, which were more pronounced in the flours than in the starches, may be the result of net chemical, ionic, and thermodynamic reactions. Numerous investigations have demonstrated that variations in the interactions between cations may be the cause of the ionic processes. While some cations are found in the flours, others are found in the gum Arabic powder. It is significant to remember that many hydrocolloids require cations in order to gel (Edwards-Stuart & Barbar, 2021; Laaman, 2011; Williams & Phillips, 2021). The hydrocolloids that have charges include gum Arabic (Sabet *et al.*, 2021). Consequently, because maize flour has a higher content of different ingredients than cassava flour, a few of these ingredients may also have a beneficial effect on and consequently restricting gum Arabic's action. However, soluble polymers, like gum Arabic, typically promote the gelling of starch material's transition to its compacted structured state in order to reduce thermodynamically unfavorable segmented contacts, or segregative connections, between the two polymeric materials (Hoey *et al.*, 2016). This implies that the ionic process had a greater effect on cassava flour and starch than on maize, possibly because they contain fewer components that can produce cations.

6.4.2 Pasting properties

As seen in Figure 6.2, pasting qualities differed greatly among the gels made from the materials utilized in this investigation, just like the textural features did. When compared to

other materials, maize flour showed the highest OPT but the lowest PV, FV, and Bd. Conversely, maize starch was found to have the highest FV and SB but the lowest Bd. With the exception of OPT, cassava flour and starch differed greatly in all pasting characteristics. These intrinsic variations between the materials under investigation may result from variations in the amount of amylose, the size of the starch granules, the degree of branching, and the arrangement of amylopectin linkages (Jin & Xu, 2020; Zhang & Xu, 2019). According to Zhang and Xu (2019), breakdown and PV have a positive correlation with starch content and a negative correlation with starch granule size, the proportion of long chain to protein type, and its concentration. The current findings revealed a reduction in viscosity with the inclusion of GA. Gum Arabic, a polyelectrolyte, has the propensity to reduce a solution's viscosity when electrolytes are present because of lower pH levels and charged assessment, when groups of carboxyl undissociate as reported by Williams and Phillips (2009).

For various food applications, such as confectionery, weaning foods, and other liquid foods, the low viscosity of the flour and starches has been proven useful (Aprianita *et al.*, 2012; Hoover, 2001). Table 6.2 shows that the impact of gum Arabic addition on the pasting capabilities of cassava differed in magnitude when in relation to maize in terms of starches and flours. Gum Arabic added to flour and starch had no appreciable effect on OPT in cassava compared to maize. A gum replacement level of 2.0% in flours produced a gel with 6.5 times more breakdown in cassava compared to maize, but other characteristics remained primarily identical. To compare cassava flour to maize flour, increasing the percentages to 4.0, 6.0, and 8.0 resulted in a gel that had higher breakdown rates (3.9 - 5.6 times higher), higher PV (23.6 - 27.9%), higher FV (28.1- 39.3%), and greater setback (29.3 - 35.7%).

This could suggest that the amount of gum Arabic added has no effect on how well starches in cassava and maize swell and rupture (Kumar & Khatkar, 2017). Culetu *et al.* (2021) noted that the presence of non-starch components, such as fat, disrupts the swelling and rupture of the starch granule and raises the temperature of gelatinization. The effect was more pronounced in cassava flour than in maize flour, rising noticeably for PV, FV, and SB but sharply declining for breakdown as gum Arabic addition the quantity increased. The disparity in composition between both flours which even affects the way starch molecules aggregate

could account for these differences. Studies show a link between lower PV and a higher protein content (Guo *et al.*, 2022; Uthayakumaran *et al.*, 2000) while aggregation of the solubilized amylose molecules was associated with an increase in FV, SB and breakdown (Blazek & Copeland, 2008; Pourmohammadi & Abedi, 2020). However, comparing cassava and maize starches, GA was added, but the quantity of Bd and SB did not significantly change. In contrast, PV was much reduced at the 8.0% level and FV was significantly greater at the 4.0 and 6.0% levels. This observation in starch indicates that gum Arabic has relatively low impact on pasting qualities, while other elements that exist in starches, such as flour, have a higher impact on pasting. Research has indicated that part of the pasting characteristics of starch may be influenced by swelling power and amylose content, as the pasting process itself entails granular swelling, amylose leaching, and granule disintegration during heating (Aprianita *et al.*, 2012; Thitipraphunkul *et al.*, 2003).

Low breakdown viscosity of starches and flours indicates these materials' stability under mechanical processing and heat, according to Aprianita *et al.* (2012). This characteristic is essential for the manufacturing of food that includes mechanical processing and heat, especially for foods that are canned. The same study also revealed that these samples' low setback values, which are indicative of their low retrogradation potential, are significant for frozen or cold-stored foods.

6.4.3 Physical properties

The materials under investigation revealed, as shown in Table 6.3, that their physical characteristics were fundamentally distinct. Dhillon *et al.* (2022) suggest that the flour's bulk density indicates how compact the matrices are, which indicates that cassava flour is the most porous while maize starch, cassava starch, and maize flour were the most compact. Additionally, it may be inferred that cassava flour's high porosity revealed more hydrophilic sites for water molecules to adhere to, resulting in the lowest OHC in comparison to other substances but greater WHC, FC, WSI, WAI, and SC (Sharma & Kotari, 2017). There may be more hydrophobic and lipophilic sites in maize starch than in other materials, as evidenced by its lowest WHC and highest OHC values. According to a study by Culetu *et al.* (2021) the kind of protein, amino acid content, protein polarity, and hydrophobicity all affect how well a food absorbs water and oil. Conversely, Table 6.4 shows that the amount of gum Arabic

added had varying effects on cassava's physical characteristics in contrast with maize for both starches and flours. With the exception of FC, BD, WAI, and OHC in starches, the degree of variation between cassava and maize's physical qualities for both starch and flour increased as the gum percentage increased. Compared to maize, Gum Arabic added to cassava did not significantly alter the compactness of the starch and flour matrices. Nonetheless, on WHC, WSI and OHC, gum addition in cassava flour demonstrated a greater significant magnitude than maize flour, while on SC, it demonstrated a greatly smaller magnitude. In contrast, there was no discernible difference in the impact of gum Arabic addition on WHC and WAI between cassava and maize starches. On WSI, SC, and OHC, however, cassava outperformed maize in terms of significant magnitude, although on FC, it was less significant.

Gum substitutions of 2.0, 4.0, 6.0, and 8.0% resulted in flours with 18.4 to 28.6% greater WAI and 74.0 to 81.8% less SC in cassava than maize. Furthermore, a 2.0% level resulted in a combination that contained 20.7% less WHC and 49% less WSI in cassava flour than maize flour. At the 8.0% substitution level, OHC was 5 times higher in cassava flour than in maize flour, but other levels of substitution were not substantially different. But for starches, gum substitution of 2.0, 4.0, 6.0 and 8.0% gave starch that had 26.6 to 68.4% less FC, 1.6 to 2.2 times higher WSI, and 2.1 to 3.7 times higher SC in cassava compared to maize. Also, substitution levels of 2.0 and 4.0% gave starch that had 2.0 to 3.1 times higher OHC in cassava than in maize while other levels had no significant differences.

6.4.4 The correlation between the physical, textural and pasting characteristics of GA

The loading matrix on primary components, as indicated in Table 6.5 and Figure 6.3, further illustrates that the hydrocolloid addition in flours was different in amount than that of starches. Breakdown and cohesiveness were the most adversely affected qualities in starches, but OPT, consistency, hardness, FV, and setback were the parameters that improved with the addition of the hydrocolloid. Conversely, WSI was the flour's most enhanced attribute by the addition of hydrocolloid, whereas OPT and setback were the most adversely affected. Notably, OHC was modestly enhanced in starches but as a first priority, whereas it was significantly improved in flours but as a last priority. Among all the characteristics investigated, SC was enhanced, although as a secondary priority in both starches and flours.

This observation indicates that gum Arabic has an opposite effect on starch characteristics compared to flour. Gum Arabic decreases textural quality (lower cohesiveness and work of cohesion) while increasing hydration (increased WSI, WHC, and WAI) and pasting (reduced OPT, peak viscosity, final viscosity, setback, and breakdown) in flours. Conversely, GA decreased gelatinization in starches (reduced PV and Bd but increased OPT and FV) but enhanced gel stability (increased consistency and hardness but decreased cohesiveness and work of cohesion). Starches often have lower levels of fiber, proteins, and other substances known as contaminants than flours do (Ren *et al.*, 2021). Starches typically have more than 98–99% starch and less than 0.5% fiber, but their flours have about 75% starch and 1%–3% fiber (Asare *et al.*, 2021; Majzoobi & Farahnaky, 2021). In comparison to their respective flours, this increases the hygroscopicity, hydrolyzability, and gelatinizability of starches (Mitrus *et al.*, 2009). Consequently, this leads to flours having usually limited functional qualities, which reduce their applicability in food systems. Examples of these properties include low shear stress resistance, sensitivity to heat decomposition, significant retrogradation and syneresis.

6.5 Conclusion

The impact of adding GA on the characteristics of cassava and maize showed distinct magnitudes for both starches and flours. Compared to other materials, maize starch exhibited a notably greater degree of stiffness and consistency, along with a notably reduced cohesion upon gelling. When comparing the onset pasting temperature of cassava flour to maize flour, there was no discernible change between any of the substitution levels. The compactness of the flour and starch matrices in cassava was not significantly changed by the addition of GA in comparison to maize. There are several possible reasons for the variations in the flours and starches, including their composition, granule size, varietal variation, level of branching, distribution of amylopectin chain length, amylose content, protein and lipid contents, and creation of amylose-lipid complexes. In order to improve the binding ability, texture, and prevent retrogradation of starchy foods, as well as their stability and functionality, this study suggests using gum Arabic from *acacia senegal* var. *kerensis* in the preparation of various food products made from cassava and maize flours and starches.

CHAPTER SEVEN

GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

7.1 Rationale for the Study

Cassava and maize are very important crops especially in developing world where they make a substantial contribution to the security of food and nutrition. However, apart from being used as human food and animal feed, these two crops have not been embraced for production of starches and flours to be used for industrial applications. One of the primary obstacles to the industrial use of flours and starches from cassava and maize is their lack of versatility in functionality. This problem could be attributed to the nature of their chemical components, morphology and arrangement. Several attempts have been put in place via chemical modification of the morphology and arrangements to improve on the functionality of these flours and starches (Fan & Picchioni, 2020; Nawaz *et al.*, 2020). However, there has been very little success from the use of chemical modification methods especially in cassava and maize flours and starches. Use of alternative methods of flour and starch modification has recently captured the attention of food processors (Alam *et al.*, 2009; Yamul and Navarro, 2020).

One of such alternative methods that studies are now focusing on; is the process of altering starches' structural makeup with hydrocolloids to enhance their potential uses in the food sector. There are so many types of hydrocolloids that have been tested but very few, if not none, has focused on incorporating these hydrocolloids in cassava and maize flour and starch to improve their functionality. However, when it comes to cost-effectiveness and clean label, natural hydrocolloids have been praised as the best choice when faced with synthetic counterparts (Alam *et al.*, 2009; da Silva Costa *et al.*, 2020; Kim *et al.*, 2013). Therefore, gum Arabic, which is naturally harvested from *Acacia Senegal* varieties has got the eye of food processors due to its abilities of being a stabilizer, emulsifier and a binder in foods. Gum Arabic particularly from the variety *kerensis* has been used successfully in stabilizing yoghurt, extending meat, stabilizing low sugar jams, stabilizing mozzarella cheese and improving the bread's textural qualities among many more applications (Mugo *et al.*, 2020; Mwove *et al.*, 2016; Soibe *et al.*, 2015).

This study therefore focused on investigating the modification and enhancement of the techno-functional qualities of starch and flour made from maize and cassava using gum

Arabic from *acacia senegal* var *kerensis*. Physical and rheological properties are the key techno-functional properties that were considered. The main three hypotheses that were addressed include: (i) Gum Arabic has no effect on the pasting properties of maize and cassava flour and starch (ii) Gum Arabic has no effect on the textural properties of maize and cassava flour and starch (iii) Gum Arabic has no effect on the physical properties of maize and cassava flour and starch. Results that examined these hypotheses are provided in Chapters 3, 4, and 5, in that order.

7.2 Design and Implementation of the Study

This study utilized a completely randomized design (CRD) which was set up in a factorial arrangement. The main factor was the material type, two sources of starch or flour (maize and cassava) and the other factor was the six levels of gum Arabic substitution (0.0 %, 0.5 %, 2.0 %, 4.0 %, 6.0 % and 8.0 % g/g dry weight basis). The levels of gum Arabic that was added in flour or starch of maize and cassava were determined in pre-trial experiments. Statistical analysis involved testing the main factor effect, sub-factor effect and the interaction effect between the two factors. Chapter 3 tested these effects on pasting and textural properties of starches only, Chapter 4 tested them on physical properties of both starches and flours whereas Chapter 5 tested them on pasting and textural properties on flours only.

Analysis of variance (ANOVA) was employed to test the research hypotheses. after establishing the test for assumption of normality and equal variances (homoscedasticity). According to Mishra *et al.* (2019) the test of normality is an important step for deciding the measures of central tendency and the statistical methods to be used for data analysis. When data follows normal distribution, parametric tests statistical methods are used to compare the groups. Homoscedasticity assumes that different sample treatments have same variance (Bonnett, 2020) and Levenes' method was used for this test because of its robustness in checking the equality of variances (Gastwirth *et al.*, 2009). To perform *post-hoc* analysis, Tukey's honestly significant difference (HSD) test was used. This test has the ability to manage multiple comparisons in ANOVA that still keeps the experiment a wide error at or below set significance level without maintaining as much power as possible (Kang *et al.*, 2020). Statistical relationships between various variables under study were established using logistics regression, correlation and principal component analysis (PCA) methods. Chapter 6 adopted the use of logistics regression to establish the extent to which each level of

replacement on textural, pasting and physical properties as compared to the control treatment. The purpose of using logistics regression was to quantify the impact of gum arabic level using odds ratio value of the level of substitution to the control. According to Sperandei (2014) logistic regression is often preferred in quantifying the impact of each variable because the response variable is binomial which gives odds ratio of the observed event of interest in the presence of more than one explanatory variable without confounding effects by analyzing the association of all variables together.

7.3 Summary of the Results

In Chapter 3, besides cassava and maize starches having significantly different pasting properties, substitution level of gum Arabic also significantly affected all pasting properties except onset pasting temperature. This might be linked to the interference of the intermolecular forces by the gum Arabic in pastes causing decrease in viscosities. On other hand, increasing the level of gum Arabic substitution in both maize and cassava starches led to a notable decrease in the firmness, consistency and work of cohesion up to 4% level and started to increase afterwards. These changes could be due to the limitation of interaction forces that hold molecules at gum Arabic levels below 4%. This demonstrates that pasting and textural properties of starches of cassava and maize are affected differently.

In Chapter 4, cassava flour exhibited significantly highest WHC, FC, SC, WSI and WAI but lowest OHC as compared to maize flour. However, maize starch exhibited significantly highest OHC but lowest WHC, FC, and WAI as compared to cassava starch. This difference is due to their differences in the ratio of amylose to amylopectin, conformation of molecules and presence of proteins, lipids and minerals among other components. Nevertheless, the WHC of both flours, FC of cassava starch and maize flour, and WAI of maize flour were not impacted by increasing the gum Arabic level.

Similar to Chapter 4, in Chapter 5 cassava and maize flours differed significantly in their pasting and textural properties. This is also as a result of their difference in amylose-amylopectin ratio as well as compositions. Increasing the level of gum Arabic substitutions caused a significant decrease in all pasting properties for both cassava and maize flours due to the increasing weakening of intermolecular forces. Also increasing the level of gum Arabic substitutions caused a significant increase in all studied textural properties of cassava flour

except cohesiveness. But for maize flour, there was a significant decrease of firmness and consistency as well as significant increase in cohesiveness and work of cohesion due to the interference of the molecular bonds. It was established that cohesiveness and work of cohesion had strong negative correlation with pasting properties except onset pasting temperature. The pasting and textural properties of cassava and maize flour are affected differently.

Chapter 6 is a culmination of chapters 3, 4 and 5, where the actual effect of each substitution level of gum Arabic in cassava was compared to maize, where the controls were the reference point. With the exception of the cohesion work in starches, the impact of each gum Arabic substitution level on textural qualities was greater in cassava than in maize for both flours and starches. The magnitude of each substitution level on pasting properties was significantly higher in cassava flour than maize flour except for onset pasting temperature. However, for starches, there was no significant difference between cassava and maize on pasting properties except that it was higher at 4.0 and 6.0% for final viscosity and lower at 8.0% for peak viscosity.

When comparing starches to flours, the degree to which each gum Arabic substitution level affected their physical characteristics varied. The magnitude was significantly higher in cassava flour than maize flour for WHC, WAI and OHC and higher in maize than cassava for SC. On other hand, magnitude was higher in cassava starch than maize starch for WSI, SC and OHC and was higher in maize than cassava for FC. Principal component analysis revealed that onset pasting temperature, consistency and firmness were the properties that increased the most on addition of gum Arabic in starches while breakdown and peak viscosity reduced the most. However, WSI, WAI and peak viscosity were the most increased properties in flours on addition of gum Arabic while onset-pasting temperature was the most reduced property. The high content of non-starch components majorly protein and fat present in the maize flour could have resulted to the main difference between the technological and functional characteristics of maize starch and flour.

7.4 Conclusions

Generally, the findings in this study provide a vital insight into how gum Arabic, a hydrocolloid, affects the different techno-functional characteristics of flours and starches from maize and cassava.

- i. For objective one, the substitution of part of the starch and flour from maize and cassava with gum Arabic from *Acacia senegal* var. *kerensis* resulted in the modification of pasting characteristics. The current findings demonstrate the reduction of setback values by the addition of the gum, which is an important feature with regards to the retardation of retrogradation. This could improve the storage properties of flavors, confectionery, beverages, special diets, bakery and dairy products.
- ii. For objective two, the findings shows the potential application of GA from *Acacia senegal* var. *kerensis* in modifying texture hence could improve the stability of products.
- iii. For objective three, the findings showed that incorporating gum Arabic from *Acacia senegal* var. *kerensis* depicted variations on the studied physical properties of maize and cassava flours and starches. The analyzed properties are extremely important in developing a product since they indicate the quantity of water or oil needed to develop optimum dough and also depict the properties and behavior of flour/starch upon water addition.

Notably, the current information can be used to develop custom-made flour or starches from maize and cassava for specific uses for food industry applications. It has been shown that native starches or flours of both maize and cassava are affected differently by gum Arabic compared to their processed starch counterparts. Incorporation of GA to maize and cassava native flours and starches would therefore be an effective method of modification.

7.6 Recommendations

In general, the various formulations created in this investigation are suggested for further trials in specific food materials. These formulations are of particular interest because of their modified pasting, textural and physical properties which could have possible applications in confectionery, beverages, special diets, bakery, dairy, hydrogels as well as other food sectors.

- i. Objective one: The addition of gum Arabic from *Acacia senegal* var. *kerensis* caused a decrease in viscosity parameters. This is suitable for incorporating only in less

viscous foods. Further trials of the various levels in particular food items incorporating such flours and starches are recommended.

- ii. Objective two: The current findings suggest that gum Arabic acts differently in slurry and gel systems. We therefore recommend further studies that incorporate gum Arabic from *Acacia senegal* var. *kerensis* in specific food products made from maize and cassava flours and starches, particularly as a gluten substitute to enhance their application.
- iii. Objective three: Addition of GA to corn and cassava starches and flours showed a variation of effects to the studied physical properties hence we recommend further trials of the various levels on specific food application.

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APPENDICES

Appendix I: General Properties of Some Starch Granules and Their Pastes

	Common Maize Starch	Waxy Maize Starch	High-Amylose Maize Starch	Potato Starch	Tapioca Starch	
Wheat						
Granule size (major axis, μm)	2–30	2–30	2–24	5–100	4–35	2–55
% Amylose	28	<2	50–70	21	17	28
Gelatinization/pasting temp. ($^{\circ}\text{C}$) ^a	62–80	63–72	66–170 ^b	58–65	52–65	52–85
Relative viscosity	Medium	Medium high	Very low ^b	Very high	High	Low
Paste rheology ^c	Short	Long	Short	Very long	Long	Short
Paste clarity	Opaque	Very slightly cloudy	Opaque	Clear	Clear	Opaque
Tendency to gel / retrograde	High	Very low	Very high	Medium to low	Medium	High
Lipid (% DS)	0.8	0.2	—	0.1	0.1	0.9
Protein (% DS)	0.35	0.25	0.5	0.1	0.1	0.4
Phosphorus (% DS)	0.00	0.00	0.00	0.08	0.00	0.00
Flavor	Cereal (slight)	“Clean”	Slight		Bland	Cereal(slight)

^a From the initial temperature of gelatinization to complete pasting.

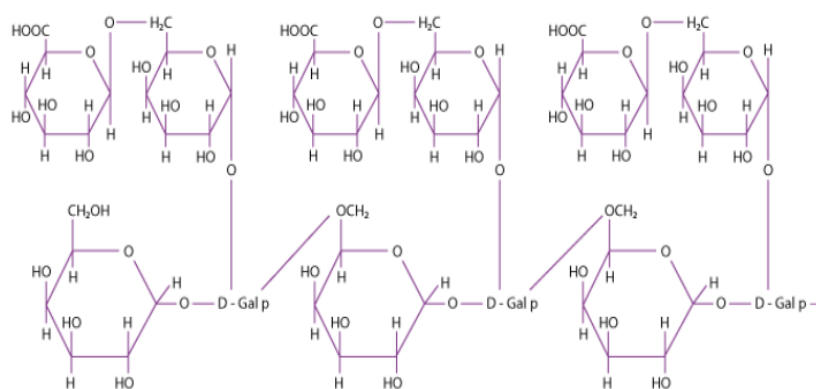
^b Under ordinary cooking conditions, where the slurry is heated to 95–100 $^{\circ}\text{C}$, high-amylose maize starch produces essentially

no viscosity. Pasting does not occur until the temperature reaches 160–170 $^{\circ}\text{C}$ (320–340 F).

^c For a description of long and short flow

Source: Damodaran *et al.* (2008)

Appendix II: Structure of the Arabic gum & granules



Source: <https://byjus.com/chemistry/gum-arabic/>

Appendix III: Analysis of variance (ANOVA) mean squares

A. Pasting properties

S.O.V	DF	Onset temperature	Peak viscosity	Final viscosity	Breakdown	Setback
Material	3	918.6*	527,396.4*	3,178,290.8*	338,890.1*	519,982.8*
Gum Arabic	5	0.6*	49,726.6*	86,687.1*	18,313.9*	22,698.4*
Rep	1	0.1	141.8	236.5	63.8	114.6
Material*GA	13	0.3*	2,642.1*	16,775.6*	3,546.7*	3,007.6*
Error	21	0.1	55.9	832.9	41.7	303.4
R ²		0.9998	0.9994	0.9983	0.9992	0.9963
C.V.		0.19	1.66	4.28	3.08	5.12

Key: S.O.V= Source of Variation; DF= Degree of Freedom; R²= Coefficient of determination; C.V= Coefficient of Variation

B. Textural properties

S.O.V	DF	Firmness	Consistency	Cohesiveness	Work of cohesion
Material	3	1,405,944.8*	87,089,3697.0*	1473065.4*	345,983.9*
Gum Arabic	5	7,930.3*	4,192,461.0*	25157.6*	19,912.4*
Rep	1	529.8	895,097	11272.0	26,962.2
Material*GA	13	7,522.6*	3,484,664.0*	11719.8*	37,859.9*
Error	21	129.5	113,021.0	4698.9	6,922.4
R ²		0.9994	0.9991	0.9795	0.9192
C.V.		4.30	5.13	-2.21	-2.39

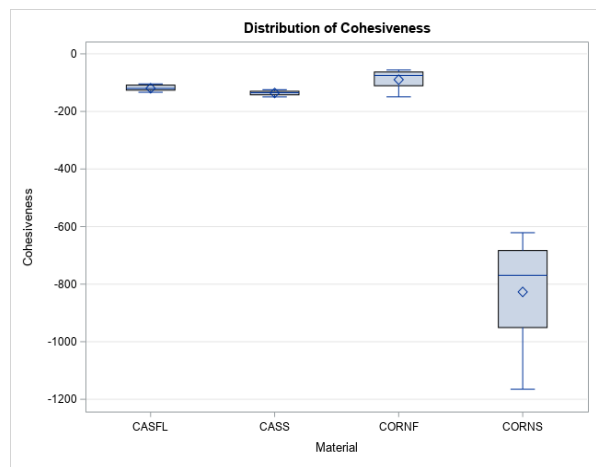
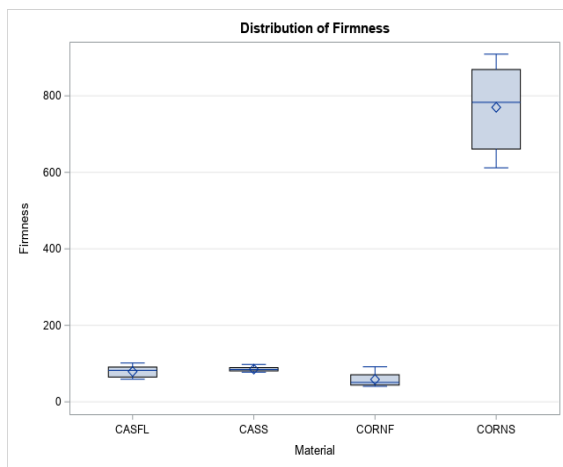
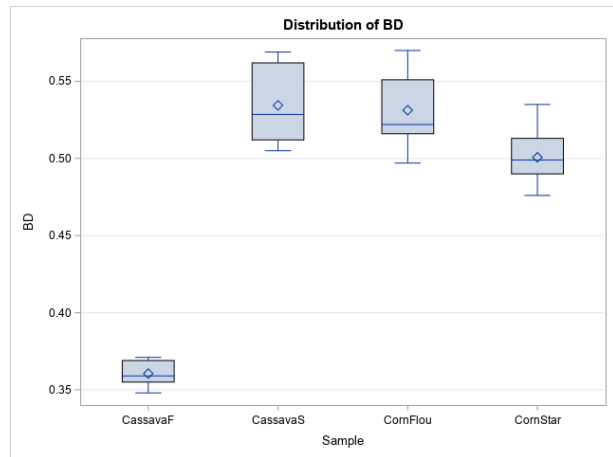
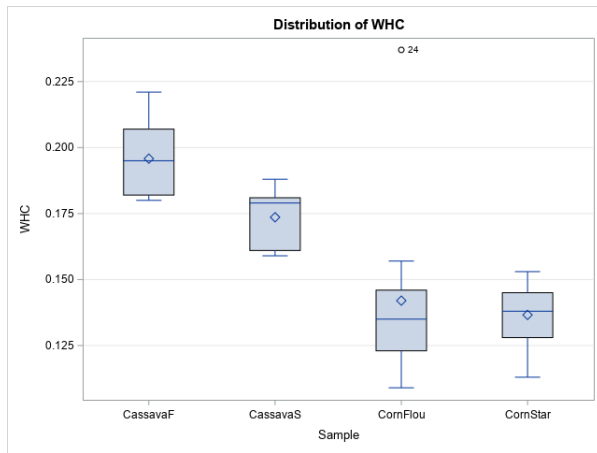
Key: S.O.V= Source of Variation; DF= Degree of Freedom; GA= Gum Arabic; R²= Coefficient of determination; C.V= Coefficient of Variation

C. Physical properties

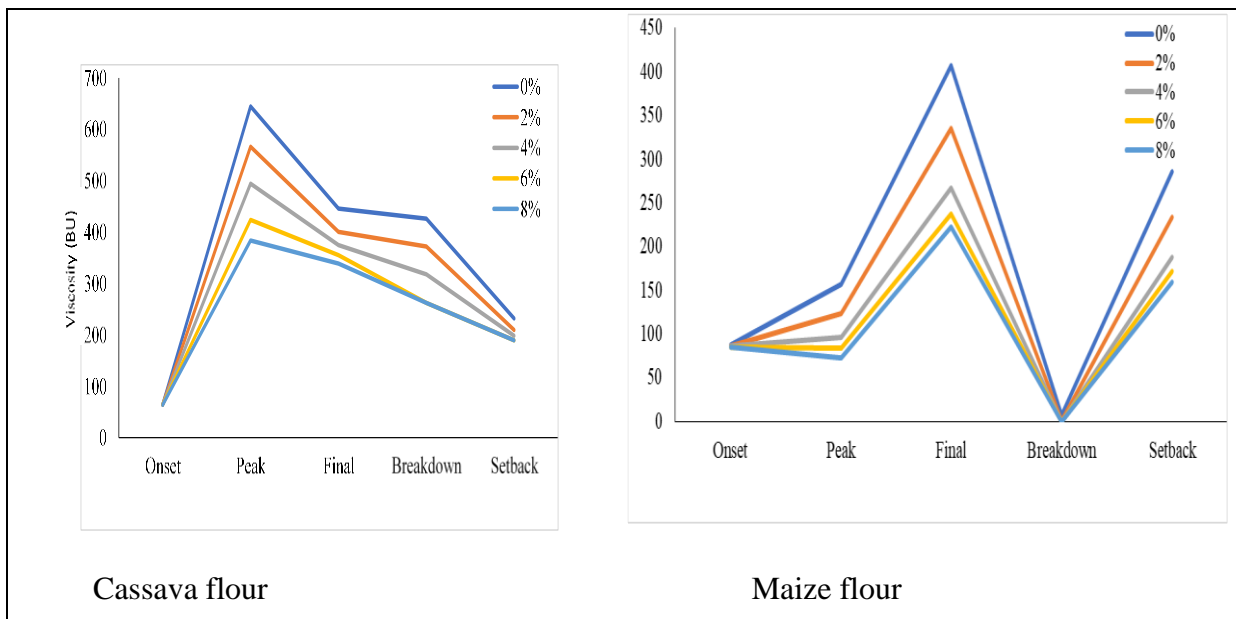
S.O.V	DF	WHC	FC	BD	WSI	WAI	SC	OHC
Material	3	0.0077***	154.007***	0.0676***	0.0417***	0.4394***	0.1918***	0.0039***
GA	4	0.0007 ^{ns}	9.120***	0.0015***	0.0021***	0.3210***	0.3990**8	0.0004***
Rep	1	0.0002	0.684	0.0001	0.0001	0.0011	0.0009	0.0000
Material*GA	12	0.0006 ^{ns}	5.175***	0.0008***	0.0003***	0.0071 ^{ns}	0.0111 ^{ns}	0.0013***
Error	19	0.0059	12.232	0.00002	0.0001	0.0042	0.0080	0.0001
R ²		0.8487	0.9787	0.9981	0.9879	0.9506	0.9380	0.9596
C.V.		10.94	1.680	0.96	10.22	6.23	2.09	2.15

Key: S.O.V= Source of Variation; DF= Degree of Freedom; GA= Gum Arabic; R²= Coefficient of determination; C.V= Coefficient of Variation

Appendix IV: Example of box plots



Appendix V: Effect of gum Arabic substitution level on pasting properties



Appendix VI: Example of SAS output for ANOVA

Dependent Variable: WSI

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	20	0.13768400	0.00688420	77.62	<.0001
Error	19	0.00168510	0.00008869		
Corrected Total	39	0.13936910			

R-Square	Coeff Var	Root MSE	WSI Mean
0.987909	10.2197	0.009418	0.092150

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Sample	3	0.12498250	0.04166083	469.74	<.0001
GA	4	0.00849585	0.00212396	23.95	<.0001
Rep	1	0.00007290	0.00007290	0.82	0.3760
Sample*GA	12	0.00413275	0.00034440	3.88	0.0042

Dependent Variable: WorkCohesion

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	22	1653145.090	75142.959	10.86	<.0001
Error	21	145370.709	6922.415		
Corrected Total	43	1798515.800			

R-Square	Coeff Var	Root MSE	Work Cohesion Mean
0.919172	-2.3902	83.20105	-348.0930

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Material	3	1037951.534	345983.845	49.98	<.0001
GA	5	99562.201	19912.440	2.88	0.0394
Rep	1	26962.156	26962.156	3.89	0.0617
Material*GA	13	488669.200	37589.938	5.43	0.0003

Dependent Variable: Onsetpastemp

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	22	2762.764091	125.580186	6471.62	<.0001
Error	21	0.407500	0.019405		
Corrected Total	43	2763.171591			

R-Square	Coeff Var	Root MSE	Onsetpastemp Mean
0.999853	0.192194	0.139301	72.47955

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Material	3	2755.666424	918.555475	47336.6	<.0001
GA	5	3.171583	0.634317	32.69	<.0001
Rep	1	0.027500	0.027500	1.42	0.2472
Material*GA	13	3.898583	0.299891	15.45	<.0001

Appendix VII: T-test for starch and flour

The TTEST Procedure										
Statistics										
Variable	Type	N	Lower CL Mean	Upper CL Mean	Lower CL Mean	Upper CL Mean	Std Dev	Std Dev	Std Dev	Std Err
Firmness	Flour	20	59.755	68.815	77.875	14.722	19.358	28.274	4.3286	
Firmness	Starch	24	276.52	427.66	578.8	278.19	357.93	502.09	73.063	
Firmness	Diff (1-2)		-520.9	-358.8	-196.8	218.66	265.19	337.07	80.292	
Consistency	Flour	20	1511.8	1739.4	1967	369.8	486.27	710.23	108.73	
Consistency	Starch	24	6816.5	10578	14340	6924	8908.8	12497	1818.5	
Consistency	Diff (1-2)		-12872	-8839	-4806	5442.6	6600.7	8389.6	1998.5	
Cohesiveness	Flour	20	-118	-104.6	-91.14	21.863	28.748	41.988	6.4282	
Cohesiveness	Starch	24	-640	-481.4	-322.9	291.82	375.47	526.7	76.643	
Cohesiveness	Diff (1-2)		206.64	376.82	547	229.66	278.53	354.01	84.328	
WorkCohesion	Flour	20	-264.1	-235.3	-206.5	46.834	61.584	89.948	13.771	
WorkCohesion	Starch	24	-540.9	-442.1	-343.2	181.92	234.06	328.33	47.778	
WorkCohesion	Diff (1-2)		97.951	206.77	315.58	146.85	178.09	226.36	53.92	

T-Tests						
Variable	Method	Variances	DF	t Value	Pr > t	
Firmness	Pooled	Equal	42	-4.47	<.0001	
Firmness	Satterthwaite	Unequal	23.2	-4.90	<.0001	
Consistency	Pooled	Equal	42	-4.42	<.0001	
Consistency	Satterthwaite	Unequal	23.2	-4.85	<.0001	
Cohesiveness	Pooled	Equal	42	4.47	<.0001	
Cohesiveness	Satterthwaite	Unequal	23.3	4.90	<.0001	
WorkCohesion	Pooled	Equal	42	3.83	0.0004	
WorkCohesion	Satterthwaite	Unequal	26.8	4.16	0.0003	

Equality of Variances						
Variable	Method	Num DF	Den DF	F Value	Pr > F	
Firmness	Folded F	23	19	341.88	<.0001	
Consistency	Folded F	23	19	335.65	<.0001	
Cohesiveness	Folded F	23	19	170.59	<.0001	
WorkCohesion	Folded F	23	19	14.45	<.0001	

Appendix VIII: T-test for comparison between maize and cassava starch and flour

The TTEST Procedure										
Statistics										
Variable	Material	N	Lower CL Mean	Upper CL Mean	Lower CL Mean	Upper CL Mean	Std Dev	Std Dev	Std Dev	Std Err
Firm_flour	CASS	10	68.849	79.223	89.597	9.9745	14.501	26.474	4.5857	
Firm_flour	MAIZES	10	45.215	58.407	71.599	12.685	18.442	33.667	5.8318	
Firm_flour	Diff (1-2)		5.2297	20.816	36.402	12.535	16.589	24.532	7.4188	
Cons_flour	CASS	10	1722.7	1963.6	2204.6	231.7	336.85	614.96	106.52	
Cons_flour	MAIZES	10	1140.7	1515.2	1889.6	360.04	523.43	955.59	165.52	
Cons_flour	Diff (1-2)		34.931	448.47	862.01	332.58	440.14	650.89	196.84	
Cohe_flour	CASS	10	-127	-119.5	-112.1	7.1798	10.438	19.056	3.3009	
Cohe_flour	MAIZES	10	-113.8	-89.65	-65.5	23.218	33.755	61.623	10.674	
Cohe_flour	Diff (1-2)		-53.36	-29.89	-6.418	18.878	24.983	36.946	11.173	
WCohe_flour	CASS	10	-284.4	-266.3	-248.2	17.413	25.315	46.215	8.0053	
WCohe_flour	MAIZES	10	-256.1	-204.3	-152.6	49.752	72.332	132.05	22.873	
WCohe_flour	Diff (1-2)		-112.9	-61.98	-11.06	40.945	54.188	80.135	24.234	
Firm_starch	CASS	12	81.041	84.936	88.832	4.0518	5.799	10.177	1.7485	
Firm_starch	MAIZES	12	699.4	769.89	840.37	78.586	110.94	188.36	32.024	
Firm_starch	Diff (1-2)		-754.7	-685	-615.2	61.847	80.389	114.88	33.556	
Cons_starch	CASS	12	1923.6	2004.9	2086.3	84.616	121.1	212.53	36.514	
Cons_starch	MAIZES	12	17585	19140	20695	1733.6	2447.3	4155.2	706.47	
Cons_starch	Diff (1-2)		-18675	-17135	-15596	1364.2	1773.2	2534	740.17	
Cohe_starch	CASSA	12	-141.6	-136.7	-131.7	5.1647	7.3917	12.972	2.2287	
Cohe_starch	MAIZES	12	-944.5	-827	-709.5	131.01	184.94	314	53.387	

Cohe_starch Diff (1-2)	574.02	690.3	806.57	103.05	133.95	191.42	55.912
WCohe_starch CASSA	12	-309.8	-290.7	-271.5	19.902	28.483	49.986 8.5879
WCohe_starch MAIZES	12	-754	-593.8	-433.6	178.65	252.19	428.18 72.8
WCohe_starch Diff (1-2)	143.77	303.13	462.48	141.23	183.58	262.34	76.629

T-Tests

Variable	Method	Variances	DF	t Value	Pr > t
Firm_flour	Pooled	Equal	18	2.81	0.0117
Firm_flour	Satterthwaite	Unequal	17.1	2.81	0.0121
Cons_flour	Pooled	Equal	18	2.28	0.0351
Cons_flour	Satterthwaite	Unequal	15.4	2.28	0.0374
Cohe_flour	Pooled	Equal	18	-2.68	0.0154
Cohe_flour	Satterthwaite	Unequal	10.7	-2.68	0.0220
WCohe_flour	Pooled	Equal	18	-2.56	0.0198
WCohe_flour	Satterthwaite	Unequal	11.2	-2.56	0.0264
Firm_starch	Pooled	Equal	21	-20.41	<.0001
Firm_starch	Satterthwaite	Unequal	11.1	-21.36	<.0001
Cons_starch	Pooled	Equal	21	-23.15	<.0001
Cons_starch	Satterthwaite	Unequal	11.1	-24.22	<.0001
Cohe_starch	Pooled	Equal	21	12.35	<.0001
Cohe_starch	Satterthwaite	Unequal	11	12.92	<.0001
WCohe_starch	Pooled	Equal	21	3.96	0.0007
WCohe_starch	Satterthwaite	Unequal	11.3	4.14	0.0016

Equality of Variances

Variable	Method	Num DF	Den DF	F Value	Pr > F
Firm_flour	Folded F	9	9	1.62	0.4851
Cons_flour	Folded F	9	9	2.41	0.2052
Cohe_flour	Folded F	9	9	10.46	0.0018
WCohe_flour	Folded F	9	9	8.16	0.0045
Firm_starch	Folded F	11	10	365.97	<.0001
Cons_starch	Folded F	11	10	408.38	<.0001
Cohe_starch	Folded F	11	10	626.00	<.0001
WCohe_starch	Folded F	11	10	78.39	<.0001

Appendix IIX: Example of multinomial regression analysis output

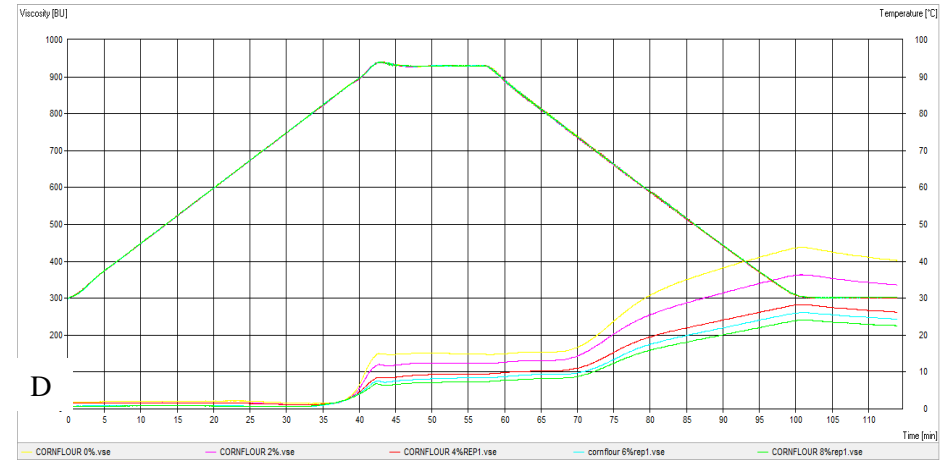
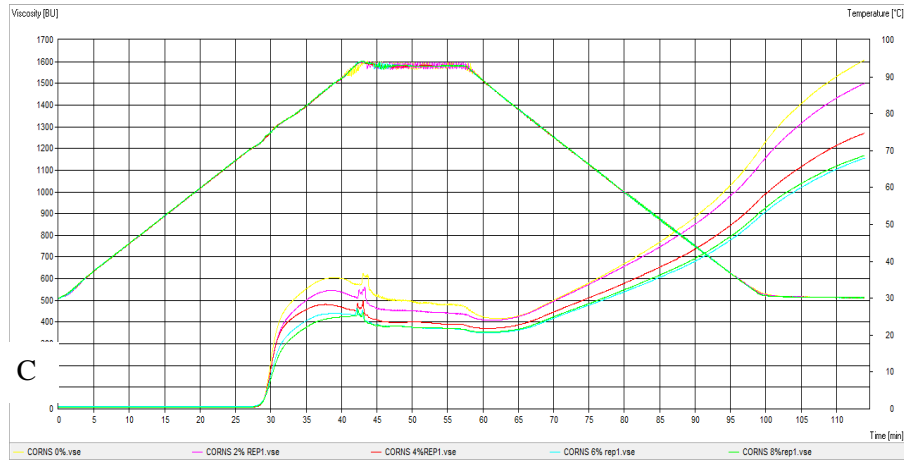
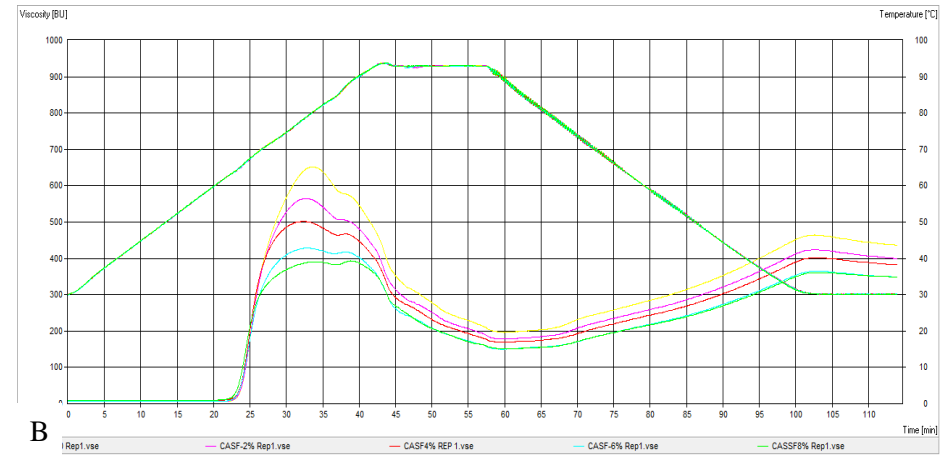
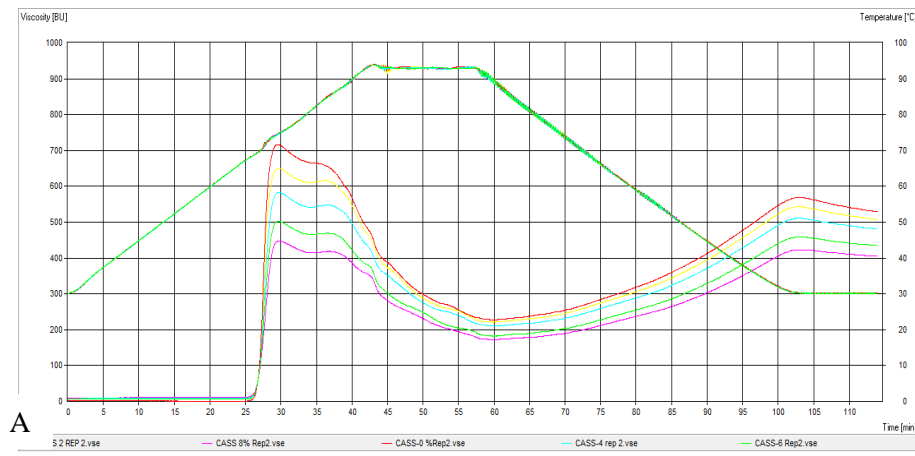
Model Fit Statistics		
Criterion	Intercept Only	Intercept and Covariates
AIC	4396.632	4337.555
SC	4417.508	4379.307
-2 Log L	4388.632	4321.555

Testing Global Null Hypothesis: BETA=0			
Test	Chi-Square	DF	Pr > ChiSq
Likelihood Ratio	67.0768	4	<.0001
Score	66.8252	4	<.0001
Wald	65.3360	4	<.0001

Analysis of Maximum Likelihood Estimates						
Parameter	level	DF	Estimate	Standard Error	Wald Chi-Square	Pr > ChiSq
Intercept	2	1	-0.1222	0.0850	2.0677	0.1504
Intercept	4	1	-0.1234	0.0858	2.0708	0.1501
Intercept	6	1	-0.1357	0.0870	2.4291	0.1191
Intercept	8	1	-0.2378	0.0893	7.0928	0.0077
Material Cassava	2	1	0.0982	0.0850	1.3353	0.2479
Material Cassava	4	1	0.4187	0.0858	23.8244	<.0001
Material Cassava	6	1	0.5460	0.0870	39.3586	<.0001
Material Cassava	8	1	0.5154	0.0893	33.3194	<.0001

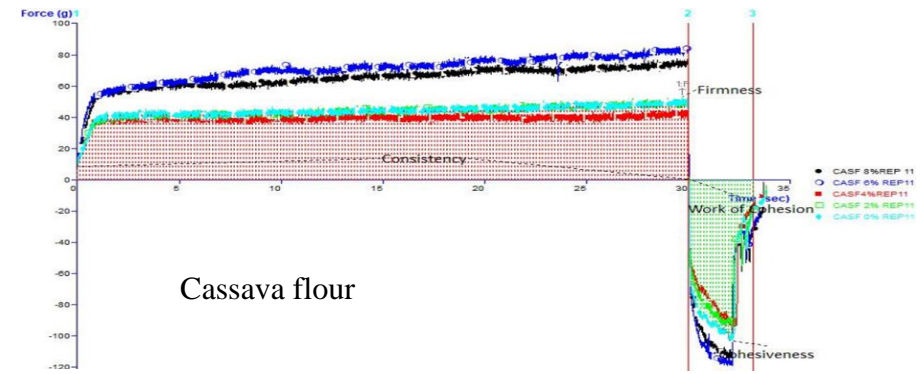
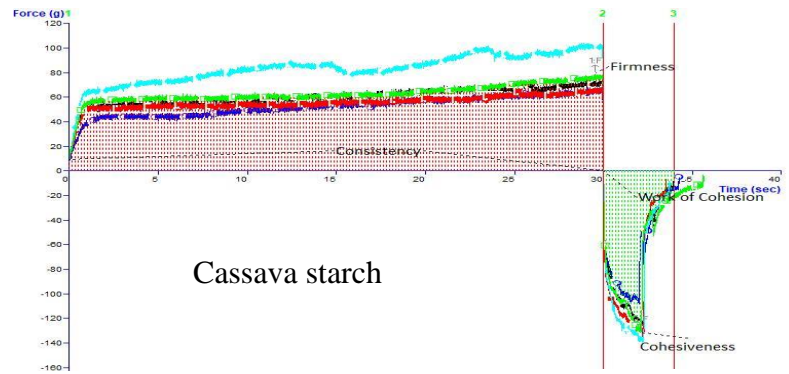
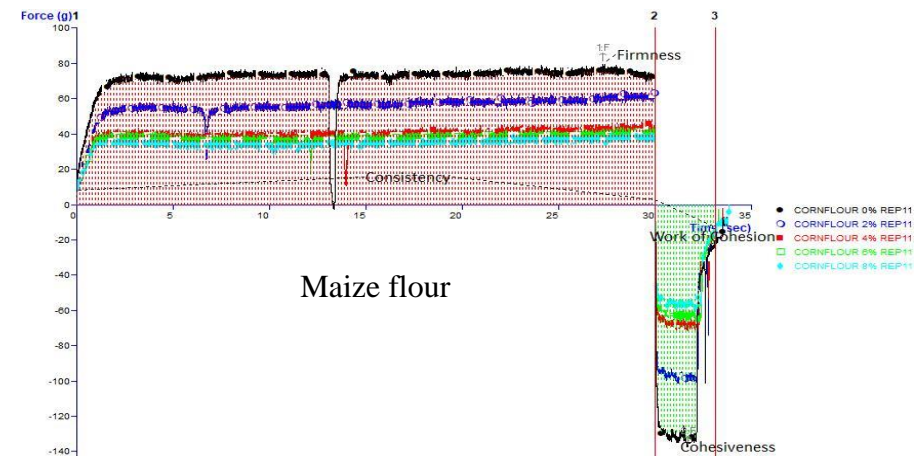
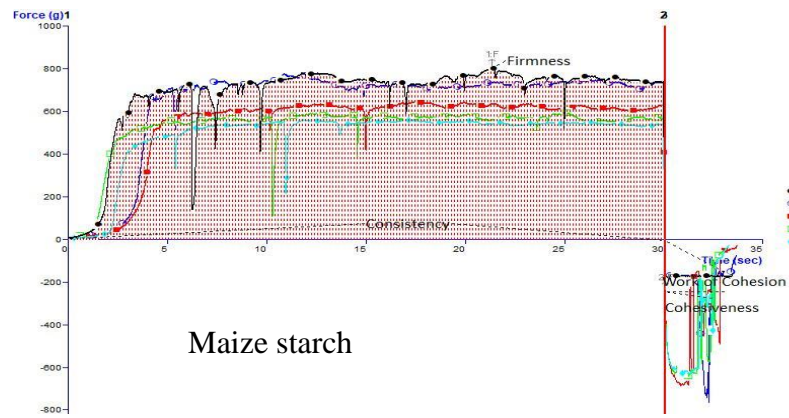
Odds Ratio Estimates				
Effect	level	Point Estimate	95% Wald Confidence Limits	
Material Cassava vs Maize	2	1.217	0.872	1.698
Material Cassava vs Maize	4	2.310	1.651	3.234
Material Cassava vs Maize	6	2.980	2.119	4.192
Material Cassava vs Maize	8	2.803	1.975	3.978

Appendix X :Examples of Correlation Curves



KEY: A = cassava starch; B = cassava flour; C = Maize starch; D = Maize flour

Appendix XI: Examples of back extrusion graphs



KEY: MS = cassava starch; CF = cassava flour; MS = Maize starch; MF = Maize flour

Appendix XII: Nacosti Licence


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Appendix XIII: Certificate of Paper Presentation





Influence of Gum Arabic from *Acacia senegal* var. *kerensis* on the Modifications of Pasting and Textural Properties of Cassava and Corn Starches

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Abstract

The use of hydrocolloids to modify the properties of native starches has been on the rise in the recent times due to the market demand for natural, safe and economical food ingredients. The objective of this study was to investigate the effect of gum Arabic from *Acacia senegal* var. *kerensis* to modify pasting and textural properties of corn and cassava starches, as an alternative to chemical and enzymatic modification. Blends were prepared by substituting the starches with gum at different levels (0%, 0.5%, 2.0%, 4.0%, 6.0% and 8.0%), whereas native corn and cassava starches were used as control. The pasting properties of the starch-gum mixed systems were determined using the Brabender viscograph while the textural properties (firmness, consistency, cohesiveness and work of cohesion) were determined using Texture Analyzer. Results showed that the gum Arabic significantly decreased all the viscosity parameters (peak viscosity, final viscosity, break down and setback values) of both starches at all levels of substitution. However, there was no significant effect of gum Arabic on the pasting temperature (72.05°C - 71.85°C) for corn starch and (68.90°C - 68.65°C) for cassava starch. The degree of gel firmness and consistency was higher in corn starch than in cassava starch and the effect of gum addition differed with each starch. The findings from this study indicate that gum Arabic significantly modified the pasting and textural properties of corn and cassava starches due to strong interaction between the gum and the starches. Hence, this property of gum Arabic could be useful in controlling starch retrogradation and determining starch end use functionality.

Keywords

Starch, Gum Arabic, Pasting Properties, Textural Properties, Retrogradation

Comparison of Magnitude of Effect of Hydrocolloid on Functional Properties of Flours and Starches of Cassava And Maize Using Multinomial Logistic Regression

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Abstract:- Modification of starches and flours from underutilized food crops to obtain some specific desired functional properties is increasingly becoming necessary practice in food processing. The objective of this study was to compare the magnitude of effect of gum Arabic hydrocolloid substitution level on textural, physical and pasting properties between cassava and maize flours and starches. Pasting properties were determined using a Brabender viscograph, textural characteristics of the gels were analyzed using a texture analyzer while various methods were used to measure the physical characteristics of the pastes. Multinomial Logistic Regression (MRL) model was used to compare the effect of magnitude of gum Arabic functional properties on cassava versus maize. Maize starch had significantly highest level of firmness and consistency and also significantly lowest cohesiveness after gelling as compared to other materials. Maize flour and cassava starch did not differ significantly for all the textural properties. Each of the substitution levels did not have a significant difference on the onset pasting temperature in flours and starches for both cassava and maize. Cassava flour showed significant higher values of the selected physical properties as compared to other materials under study. From the results gum Arabic could be used to modify the various properties of flours and starches to achieve desirable qualities. The study recommends incorporation of this hydrocolloid into specific food products based on the aforementioned flours and starches.

Keywords:- Functional properties, cassava flour and starch, maize flour and starch, gum Arabic, Multinomial Logistic Regression.

I. INTRODUCTION

Globally, there is a growing interest by the food industry in research of underutilized plant species as a contribution to consumers' diet diversification and the incorporation of ingredients with particular textural and technological properties (Colgrave *et al.*, 2021; Dini *et al.*, 2014). Studies have shown that flour and starch from tubers and roots can be used to replace wheat flour in specific food application, though current world policies and demographic claims have been key drivers to the application of starchy materials. Although a variety of native starches with diverse functionalities are available in

the market, there is also an increasing demand for specific starch properties. This has called for exploration of new strategies or alternatively novel sources (Adewale *et al.*, 2022; Apriamita *et al.*, 2012; Charles *et al.*, 2007). This is crucial because native starches in general lack the desired properties for use in processed foods hence they are often chemically modified to improve their properties (Obadi and Xu, 2021; Kim *et al.*, 2013). The conversion of a chemical compound into a derivative has extended the range of functional properties nonetheless owing to consumers demand, starches from other botanical sources including tropical sources are now being assessed for required functional properties thus evading the need for chemical modifications (Apriamita *et al.*, 2012).

According to Kim *et al.* (2013) some of the desired properties of starch include increasing their tolerance to processing conditions, improving paste and gel textures, providing cold storage and/or freeze-thaw stability as well as to control water mobility. It has been suggested that other methods that can improve the quality of nutrient flours and starches as solutions for sensory and technological challenges are welcomed in the food industry (Culetu *et al.*, 2021). Therefore, studies have shown that certain hydrocolloids in combination with certain starches provide some improvement of properties without chemical modification (Kim *et al.*, 2013).

Several hydrocolloids have been tested in improving functional properties of both flours and starches from different sources (Cappelli *et al.*, 2020; Yamul and Navarro, 2020; Salehi, 2019). Though some have recorded successes, some still have not. For example, a study by Dini *et al.* (2014) which tested the addition of xanthan gum, carboxymethylcellulose, carrageenan, alginate and high methoxy hydroxypropyl methylcellulose (HM HPMC) on formulations based on rice flour and cassava starch, reported that the addition of these hydrocolloids solely seemed not to be enough to effectively simulate gluten dough and wheat bread properties. Some studies have shown that Arabic gum improved mechanical properties of doughs from potato flour (Yamul and Navarro, 2020), but there is a gap on use of gum Arabic from *Acacia senegal* var *kenensis* in improving other flours and starches such as development of alternative to commercial waxy maize starch. Gum Arabic a hydrocolloid from *Acacia senegal* is a highly branched structure consisting of a -1, 3-linked D-galactose core with extensive branching through 3- and 6-

Abstract 3

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Pasting Behaviour of Cassava and Maize Flour Containing Gum Arabic from *Acacia senegal* var. *kerensis*

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Abstract

The application of flour in food production and in the industry depends on various properties including texture and pasting. These properties of flour are influenced by their interaction with food hydrocolloids, especially gums. In the current study, the influence of replacing gum Arabic (GA) from *Acacia senegal* var. *kerensis* (Kenyan variety) at the levels of 0 %, 2%, 4%, 6% and 8% on the pasting behaviour of maize and cassava flour was investigated. Resistance to stirring was recorded as viscosity in Brabender Units (BU). Substitution of cassava and maize flour by GA reduced significantly ($p < 0.05$) the peak viscosity, final viscosity and setback viscosity for both flour pastes. Even though the breakdown viscosity of cassava flour pastes reduced significantly with increasing levels of the gum, maize flour pastes recorded a zero breakdown as the substitution level increased from 2 % to 8%. Pasting temperature (64.15-63.55°C) and (87.1-84.9°C) decreased with increasing gum content for cassava and maize flour pastes respectively though no significant difference was observed at lower levels and the control sample. Maize flour depicted low peak viscosity values (157 BU at 0% GA to 73 BU at 8% GA) as compared to cassava flour (645 BU at 0% GA to 384 BU at 8% GA). A significant decrease in final and setback viscosities were observed in both flour with the addition of GA. Maize flour did not however display significant difference in breakdown viscosity values as opposed to cassava flour which exhibited significant reduction in breakdown viscosity with increasing amount of gum. These results demonstrate that GA from *A. senegal* var. *kerensis* (Kenyan variety) could be considered in the preparation of various food products from cassava and maize flour to enhance binding potential, stability as well as preventing retrogradation.

Key words: Cassava flour, maize flour, gum Arabic, pasting behaviour, viscosity

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