EVALUATION OF QUALITY PROPERTIES OF EGGLESS MAYONNAISE ANALOGUE PREPARED FROM CHIA MUCILAGE *(Salvia hispanica ˆ L.)* WITH ADDED GUM ARABIC FROM *Acacia senegal* var. *kerensis*

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DECLARATION AND RECOMMENDATION

Declaration

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

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Recommendation

This thesis is the candidate's original work and has been prepared with our guidance and assistance. It has been submitted with our approval as the official University supervisors.

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DEDICATION

This thesis is devoted to my mother, siblings, husband and children for their endless love, a great source of inspiration, emotional and spiritual support and encouragement throughout my pursuit for education and for having always stood by me and dealt with all of my absence from many family occasions with a smile. I hope this accomplishment will fulfill the dream they envisioned for me.

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ABSTRACT

Eggless low fat mayonnaise was prepared by substituting portion of the oil with gum Arabic and chia mucilage and the result of their inclusion on the physico-chemical, sensory and shelf life properties was evaluated and equated to control with 75% oil and egg yolk. Physico-chemical properties were analyzes using AOAC methods, both consumer acceptability test and quantitative descriptive analysis were done for sensory evaluation. Peroxide value was used as a spoilage indicator for shelf-life evaluation. Gum Arabic (GA) from *Acacia Senegal* var *kerensis* has been approved as an emulsifier and stabilizer in food processing industry associated with higher lipoprotein content and high-water solubility. Chia mucilage on the other hand has been approved to be incorporated as an egg yolk and fat mimetics as it is dense in polysaccharides. In this study, eggless fat reduced mayonnaise analogue was innovatively prepared using chia seeds mucilage and gum Arabic from *Acacia senegal* var. *kerensis*. Chia mucilage was used at 15, 30, 45, and 60% levels to partially replace sunflower oil and substitute the egg yolk in the mayonnaise. The findings showed that all fat-reduced eggless mayonnaises had a greater water content of 0.74 but a much lower calorie content of 493 kcal/100g and 20% fat content. The control had 0.39 moisture, 77% fat, and 784 kcal/100g of calories. These variations grew as the amount of chia mucilage substituted increased, affecting protein, pH, and carbohydrates. The amount of ash in RFM and the control did not differ significantly. The results of the sensory evaluation showed that using gum Arabic and chia seed mucilage in place of mayonnaise was acceptable. Overall acceptability showed a positive link with all the measures, with flavor showing the largest correlation (r=0.78). Principal component analysis (PCA) loadings of 16 mayonnaise sensory qualities revealed that the first six principal components accounted for almost 66% of the variances in sensory characteristics. With regards to texture, RFM had desirable texture in terms of firmness, adhesiveness and viscosity. The microbial counts of all samples tested were in the acceptable limits for example the total viable count<50, yeast and molds <15 while salmonella and coliforms were not detected thus rendered safe before organoleptic evaluation. The shelf life (SL) of the samples reduced with increasing temperatures and time ranging 45 to 52 days. The formulated mayonnaise analogue had lower peroxide value (PV) ranging 0.2-11.8 than control with PV 0.5-12.6 thus longer SL. This is the first time an eggless fat-reduced mayonnaise analogue prepared using chia seed and gum Arabic from *Acacia senegal* var. *kerensis* has been informed.

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ACRONYMS AND ABBREVIATIONS

AOAC	Association of Official Analytical Chemists
CAC	Codex Alimentarius Commission
CRD	Completely Randomized Design
CVD	Cardio Vascular Diseases
DMRT	Duncan's Multiple Range Test
FAO	Food and Agriculture Organization
FDA	Food and Drug Administration
HDL	High Density Lipoprotein
LDL	Low Density Lipoprotein
MBS	Malawi Bureau of Standard
O/W	Oil in Water
PCA	Plate Count Agar
PDA	Potato Dextrose Agar
PUFAS	Poly Unsaturated Fatty Acids
PV	Peroxide Value
RF	Reduced Fat
SAS	Statistical Analysis Software
SFA	Saturated Fatty Acids
SL	Shelf Life
SS	Salmonella Shigella Agar
TA	Titratable Acidity
TCC	Total Coliform Counts
TVC	Total Viable Counts
W/O	Water in Oil
WHO	World Health Organization

CHAPTER ONE

INTRODUCTION

1.1 Background information

Mayonnaise is a thick oil-in-water emulsion that is used as a dip and as a condiment sauce on salads and burgers (McClements, 2005). It is composed of scattered droplets of oil in a continuous phase of water that is stabilized by stabilizers, homogenizers, and emulsifiers (Aruyama *et al*., 2006; Depree & Savage, (2001). In order to uphold a densely packed oil droplet foam, the emulsion is created by gradually mixing oil combined with a pre-mix of mustard, vinegar, water, and egg yolk. An emulsion that readily transitions from oil in water to water in oil is created when oil and aqueous phase are mixed simultaneously (Liu *et al*., 2007). Using non-fat functional components such proteins, gums, and starches to create a reduced-fat mayonnaise that mimics the quality attributes of regular mayonnaise results in a loss of quality attributes (Mun *et al*., 2009).

Globally, North America is foremost in the manufacture and marketing of mayonnaise due to the popularity of the product in fast foods and snacks. The popularity is significant in the Middle East, Asia Pacific, Europe, and South Africa (GMMS, 2022). Fast food chains and the rise in convenient food consumption are driving mayonnaise production, consumption, and market expansion. However, because of its high oil content (65–80%) and high cholesterol from egg yolks, most people avoid eating mayonnaise (Raikos *et al*., 2016; Zanjani *et al*., 2019). Due to the consumers' health concerns, food industries are obliged to develop low-fat products for the growing niche market due to consumers' demand.

Egg yolk stabilizes emulsion by inhibiting flocculation, thus forming the desired texture of mayonnaise (Laca *et al*., 2010). Chia mucilage can be applied in place of egg yolks to boost microbiological stability and lower fat and cholesterol levels (Nikzade *et al*., 2012). Egg yolk replacement with chia mucilage and gum Arabic as fat mimetics enhances dietary fiber, emulsification stabilization, and processing functions (Siu *et al*., 2010). Generally, Chia seed mucilage is a clear gel formed when the chia seeds (Salvia hispanica ˆ L.) are sodden in water (Iserliyska *et al*., 2021). It is abundant in proteins, dietary fiber, and vital fatty acids, therefore important in human well-being and nutrition (Coorey *et al*., 2014; Fernandes & Mellado, 2017). The chia seed mucilage is utilized as a thickening, gelling agent, chelator, stabilizer, emulsifier, bulking agent, encapsulant, inhibitor of syneresis, and film/coating agent

(Capitani *et al*., 2012; Souza *et al.*, 2021). Furthermore, chia seed mucilage is suitable for usage in most culinary products in place of fat and eggs. Applying chia seed mucilage to salads, mayonnaise sauce, and baked goods improves their capacity to hydrate, increase viscosity, and preserve freshness (Fernandes & Mellado, 2017).

The dried exudate known as gum Arabic is extracted from the stem and branches of *Acacia Senegal* (Mugo *et al*., 2020). The food industry uses gum Arabic for stability, coating formation, thickening, emulsifying, gelling, and retaining water. Gums are biopolymers made of hydrophilic polymers with polar or charged functional groups of high molecular weight. These groups have the capacity to stabilize the texture of the emulsion and give mayonnaise its desired sensory qualities (Bratu & Pupescus, 2016).

Most studies have focused on the physio-chemical and sensory attributes of low-fat mayonnaise produced with watermelon rind and soy milk as fat substitutes. Nevertheless, there aren't many published research on the creation of low-fat, eggless mayonnaise substitutes that have the same qualities as full-fat mayonnaise made from egg yolks. Thus, the objective of this study was to evaluate the quality characteristics of a newly developed low-fat eggless mayonnaise substitute made with gum Arabic from *Acacia senegal* var *Kerensis* and chia mucilage (*Salvia hispanica* ˆ *L*).

1.2 Statement of the problem

Commercial mayonnaise contains high oil content of above 75% and high cholesterol due to the inclusion of egg yolk as an emulsifier. Therefore, there is need to develop an eggless low-fat mayonnaise. Chia seed mucilage has the ability to mimic fat and egg yolk while gum Arabic exhibits water-binding properties that stabilizes the emulsion. This was anticipated to produce a nutritious eggless low fat mayonnaise analogue.

1.3 Objectives

1.3.1 General objective

To contribute to nutrition security by innovatively producing an eggless fat-reduced mayonnaise analogue utilizing chia seed mucilage and gum Arabic from *Acacia senegal* var. *kerensis*.

1.3.2 Specific objectives

i. To prepare and determine the physico-chemical properties of an eggless reduced fat mayonnaise analogue.
ii. To evaluate the microbial and sensory properties of an eggless reduced fat mayonnaise analogue
iii. To determine the shelf life of an eggless reduced fat mayonnaise analogue.

1.4 Hypotheses

i. There is no significant effects on the physicochemical properties of the eggless reduced fat mayonnaise analogue.
ii. There is no significant effects on the microbial and sensory properties of the eggless reduced fat mayonnaise analogue.
iii. There is no significant effects on the shelf life of the eggless fat reduced mayonnaise analogue.

1.5 Justification of the study

Mayonnaise contains a high-fat content of about 65-80% and cholesterol from egg lecithin thus imposing health issues on consumers. The formulated eggless reduced fat mayonnaise substitute product is composed of dietary fiber which is linked to a decrease in the risk of cardiovascular disease, diabetes, and different types of cancers. It contains increased PUFAs, increased oxidation resistance and thermal stability as a result of chia seeds' polyphenolic content (Masood, 2022). By aligning with Goals 1 (no poverty), 2 (no hunger), 3 (good health and well-being), and 9 (industry, innovation, and infrastructure) of the Sustainable Development Goals this initiative seeks to foster sustained economic growth, better health, and greater technological innovation. Chia seed mucilage possess excellent water holding capacity, high emulsion and good viscosities. Chia mucilage has potential application as fat mimetic in several foods because of its capacity to enhance stability and rheological characteristics of the products whereas reducing fats. Gum

Arabic has better emulsification property associated with higher lipoprotein content. It is used as gelling agent even at lower concentration due higher intrinsic viscosity thus imparts desirable texture and sensory quality to foods. Gum Arabic is richly packed with dietary soluble fiber. It's highly soluble in water and a good oil in water emulsion stabilizer" Emulsion sauces' value chain can be enhanced and new products can be developed with the help of the information this research project has provided. This would also improve the use of gum and chia mucilage. Growing more acacia trees will encourage gum Arabic agronomists and industries in Kenya since it would enhance their socioeconomic well-being.

CHAPTER TWO
LITERATURE REVIEW

2.1 Mayonnaise

2.1.1 History and source of mayonnaise

The genesis of mayonnaise is said to have occurred in 1756 in Port Mahon, France. In honor of Duc's triumph over the British at Port Mahon, the French chef of Duc de Richelieu created it. The cook invented a feast of victory which involved the sauce prepared from eggs and cream but unfortunately, he realized that the cream was not available thus he opted to use olive oil instead of cream and that is how mayonnaise culinary was invented. It was made for rejoicing the conquest of Port Mahon in 1696–1788 by French Marshal Louis Francois de Vignerot's soldiers; it was initially known as maho'nnaise, which was then renamed mayonnaise (Morley *et al.*, 2016).
Mayonnaise condiment sauces are viscoelastic oil-in-water emulsions same as cream or salad dressings (Šterma *et al*., 2001). It is formulated by emulsifying droplets of oil as a dispersion phase in the aqueous phase that also comprises of water, mustard, vinegar, egg yolk, and other optional components including sweeteners. In the mayonnaise emulsion system, the egg's protein and lipoprotein molecules surround the oil droplets and prevent them from combining, which makes the substance unstable (Mahsa *et al*., 2018; Sibele & Myriam.,2018). Unlike phase inversion, which happens when the oil and aqueous phases are mixed simultaneously, they produce an emulsion made up of densely packed "foam" of oil droplets, which has a viscosity comparable to the oil from which it is created (Nahla *et al*., 2011). Mayonnaise displays time-dependent properties, yield stress, and pseudoplastic behavior (Liu *et al*., 2007).

Low fat mayonnaise is formed by increasing the aqueous phase and decreasing the dispersed phase (oil) by use of fat mimetic which are recommended to lower fat content and ultimately calories e.g. gums, proteins and plant starches. A product with the similar qualitative qualities as the original full-fat product can be obtained by using fat mimetics with various functionality. Fat has a vital effect on the final mayonnaise's rheological qualities and sensory attributes since it affects its flavor, texture, taste, palatability, creaminess, appearance and shelf life. However, Low-fat mayonnaise has certain technical hitches, including poor mouthfeel, consistency, flavor, texture, and appearance (Elbeltagy *et al*., 2014).

2.1.2 Formulation and purpose of mayonnaise

Mayonnaise is an emulsion of viscous oil and water. An egg yolk, vinegar, oil, and mustard premix is traditionally carefully mixed to create a densely packed foam of oil droplets; additional optional components of interest, like salt, sugar or sweeteners, pepper, etc., may also be added. The simultaneous mixing of oil and aqueous phase results in a water-in-oil emulsion, so the emulsion is created by blending the two phases gradually (Liu *et al*., 2007). Mayonnaise is a common condiment, spice, sauce, or preparation that is added to food, usually after it has been cooked, to give it a particular flavor and to enrich and balance the dish. As an ingredient in sauces, it is also a food emulsion that may be eaten on its own (Hakansson *et al*., 2016). It is a widely used condiment found in sandwiches, burgers, snacks, and even tacos or rolls. It also serves as a foundation for the creation of additional sauces, including thousand-island salad dressing and tartar sauce. Additionally, mayonnaise offers several commonly consumed benefits, including lower cholesterol levels, reduced food intake, and improvements in heart health.

2.1.3 Mayonnaise ingredients and their functions

A distinctive high-calorie and high-fat food, mayonnaise is a semisolid oil-in-water emulsion. Figure 2 summarizes the structure of mayonnaise, which is formed by the respective components. Egg yolk serves as the emulsifier, oil as the dispersion, and vinegar and water as the dispersed medium. First of all, as fat is the key component of mayonnaise, it significantly impacts the finished product's quality. In food emulsion, fat has a practical purpose. The product's stability, high viscosity, and viscoelastic behavior are all influenced by the amount of fat distributed throughout the mayonnaise. Foods' rheological qualities and sensory attributes, including flavor, mouthfeel, appearance, shelf life, and texture, are influenced by fat.It is quite difficult to reproduce these sensory qualities in fat-free compositions. Using high-quality, it is essential to use fats with a neutral taste, like grapeseed, sunflower, or rapeseed oil. The amount of oil in the product determines its smooth texture and appearance (Alimi *et al*., 2013; Liu *et al*, 2007; Nahla *et al*., 2011; Nikzade *et al,* 2012; Siu *et al*., 2010). The oil gives the mayonnaise its flavor and creaminess, which influences its organoleptic qualities as well.

On the other hand, egg in mayonnaise preparation is key for perfect gelling, whipping, emulsion, taste and color (Karshenas & Goli., 2018; Mohammed & Ragavan., 2022).

The egg york has lecithin, a fat emulsifier that serves as a stabilizer between the two liquids water is the continuous phase and oil is the dispersed phase. The vital egg yolk emulsifying ability is associated with phospholipids, HDL, LDL, and non-bonded proteins e.g. livetine and phosvitin (Zanjani *et al*., 2019). Most important to the product's stability is the egg yolk (Ihsan *et al*., 2021; Nikzade *et al*., 2011) and also performs as a surfactant (Alimi *et al*., 2013). One of the substances most frequently utilized to create an antibacterial barrier is vinegar. Due to its antibacterial properties and ability to stop deterioration and rancidity, it is the most often employed acid in mayonnaise preservation.

In order to keep the pH of mayonnaise low, which ranges from 3.3 to 3.8, vinegar is typically added in combination with other acids, such as lactic acid (Gomes *et al*., 2017). Vinegar strongly affects microbiological stability; a product's stability increases with decreasing pH. The pH of mayonnaises found in the market typically ranges from 3 to 4 (Morley, 2016). Mayonnaise's low pH is almost the same as the isoelectric point of the proteins in egg yolks. Because they have fewer charges, the proteins can be closer to one another and the droplets can be packed more tightly (Duncan, 2004).

In addition to being a preservative, salt enhances the mayonnaise's flavor and taste. According to Gomes et al. (2017), the sole phase in which salt dissolves is the aqueous phase, which is substantially smaller than the oil phase. Because of its high concentration, it prevents microbiological development. Salt aids in neutralization of the charges on the proteins to improve their ability to adsorb to the droplet interface. This is because increased flocculation results from a more neutral droplet interface, which lessens electrostatic repulsion between the droplets. As a consequence, the mayonnaise is packed more tightly and has a higher viscosity. Any charge that is neutralized enables stronger interactions between nearby oil droplets, compensating for pH values that deviate from the isoelectric point.

Furthermore, salt deactivates the electric charge of proteins and facilitates the dispersion of egg yolk granules, increasing their adsorption at the oil droplet surface (Martı´nez et al., 2007).

Salt modifies the hydrophobic interactions between non-polar amino acids by changing the structural configuration of water molecules at the interface layer. However, excessive salt may cause the egg yolk proteins to clump in the aqueous phase of the emulsion rather than coating the oil droplets (Depree & Savage, 2001).

The color and unique flavor of mayonnaise are attributed to mustard because it includes isothiocyanates that are created by the enzyme myrosinase in the presence of water and stabilized in the mixture by the addition of citric acid (Ihsan *et al.*, 2021). Lastly, water acts as dispersed medium together with vinegar while Sugar is added primarily to balance the flavor of vinegar and contributes to the mayonnaise's flavor (Duncan, 2004). The roles of functional ingredients in mayonnaise are summarized in Figure 1.

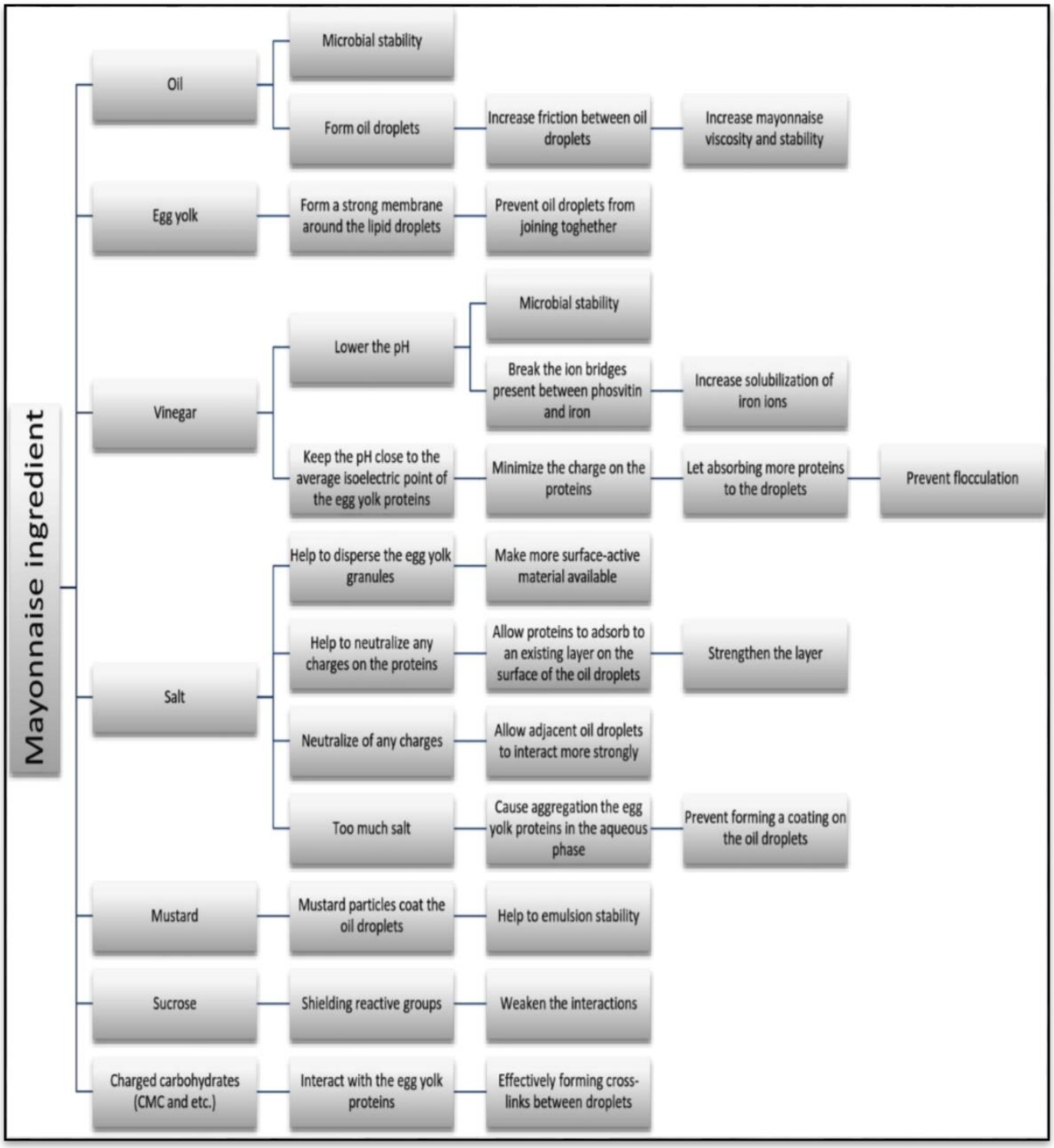

Figure 1: Role of functional mayonnaise ingredients

Source: Zanjani *et al*. (2019)

2.1.4 Nutritional value of mayonnaise

Mayonnaise is a rich source of PUFAS especially omega 6 and omega 3 fatty acids and proteins. Low fat mayonnaise with fat mimics are abundant in ash and fiber. Table 1 illustrates the nutritional composition of traditional mayonnaise.

Table 1: Nutritional composition of mayonnaise

Component	Quantity 100g
Water (g)	56.00
Energy (calories)	769.00
Protein (g)	0.88
Fat (g)	33.3
Sodium (mg)	0.73
Vitamin E (α-tocopherol) mg	0.01
Vitamin K (phylloquinone) μg	0.00
Carbohydrate (g)	6.70
Selenium (μg)	0.00
Potassium (mg)	0.07
Choline (mg)	0.01

Source: Izabela *et al*. (2017)

2.1.5 Factors affecting stability of mayonnaise

In general, mayonnaise stability depends on numerous parameters including temperature, water quality, mixing technique, oil levels, egg yolk content, viscosity, and the proportion of the oil phase to the aqueous phase (Liu *et al.*, 2007). The texture of high-quality mayonnaise is firm, and the droplets are small. First, excessive oil levels makes mayonnaise more prone to quality degradation because it causes unsaturated fats to autoxidize, which can harm food's physicochemical and sensory qualities. Mayonnaise's lipid oxidation results in the formation of reaction products that could be harmful, unwanted off tastes, and a shorter shelf life for mayonnaise (Bruno *et al.*, 2021). When mayonnaise is mixed, its texture achieves its maximum and its droplet size reaches its minimum, depending on the technique of mixing. Longer mixing durations result in worse quality and over-sheared mayonnaise (MBS, 2021). To produce more viscous mayonnaise, the agitation of first added oil ought to be very rapid.

Amount of egg yolk also affect mayonnaise stability in that when a large amount of egg yolk is utilized and the ingredients are cool, high-quality mayonnaise can be produced.
(MBS, 2021). Depending on the mixing method, the droplet size of mayonnaise decreases and its texture reaches its maximum while being mixed. Prolonged mixing durations cause the mayonnaise to become over-sheared and of worse quality.

2.1.6 Phase inversion in mayonnaise

As shown in Figure 2, when the emulsion transforms from an oil-in-water to a water-in-oil emulsion, phase inversion occurs and vice versa. A transition state is a complicated structure such as a water-in-oil-in-water or an oil-in-water-in-oil emulsion, (McClements, 2016). Being mayonnaise when little bits of mayonnaise float in oil during the emulsification phase inversion of an oil in water emulsion, the conversion state O/W/O is visible. Phase inversion can be classified as either transitional or catastrophic.

Transitional phase inversion happens when a change in the formulation, such as temperature or salinity, causes the phase inversion. This kind of inversion can be reversed and exhibits minimal hysteresis; that is, when the temperature is raised over the critical point, phase inversion occurs and the emulsion recovers to its initial state when the temperature is decreased. There will probably be transitional variations in salinity, which will have an impact on the emulsifying proteins in the egg yolk because they offer electrostatic repulsion, a rise in electrolytes may result in a mayonnaise transitory phase inversion as a result of additional counterions screening the proteins' electrical charges (McClements, 2016).
A catastrophic phase inversion happens when the volume of the dispersed phase is very high, which is brought on by a shift in the oil-water ratio. Phase inversion of this kind is irreversible since it depends on the system's hysteresis (Kumar et al., 2015). The pace at which the dispersed phase is added and the degree of agitation determine the phase inversion point. McClements (2016). To prevent a phase inversion, the oil must be added gradually when making mayonnaise. The interfacial coating becomes extremely thin and brittle at increasing concentrations because the droplets are packed too densely.

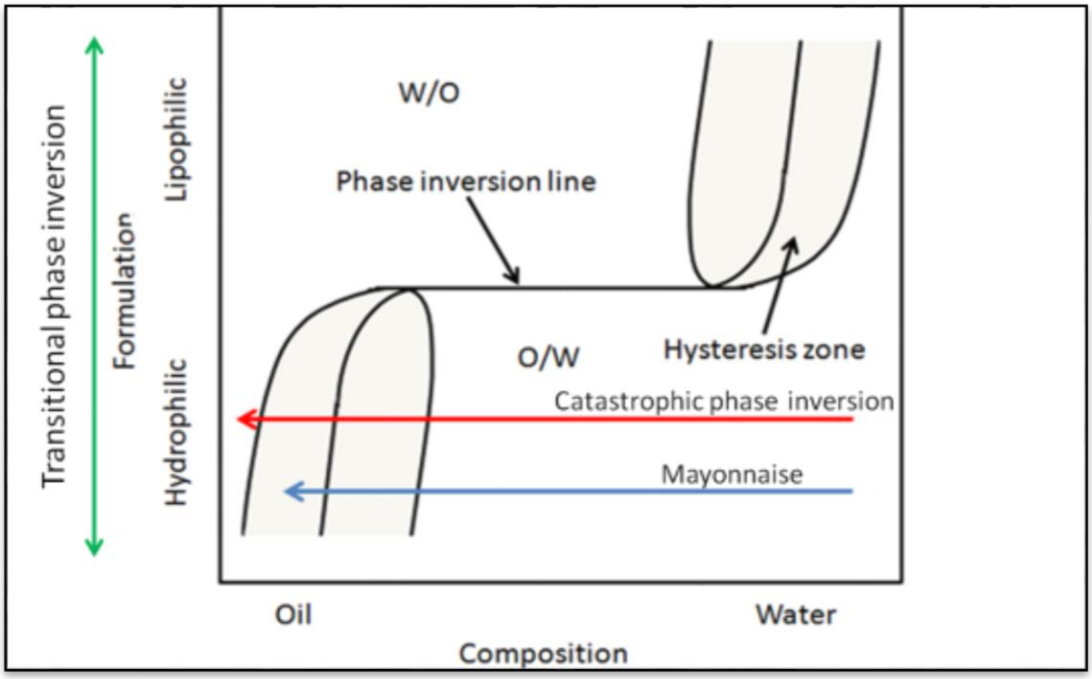

Figure 2*:* Transitional and catastrophic phase inversion

Source: Widerström and Öhman (2017)

KEY:

Illustrates the process of making mayonnaise when oil is added to the system.

Illustrates how mayonnaise that contains too much oil will pass the hysteresis zone and experience a catastrophic phase inversion.

Represent phase inversion during transition

2.2 Gum arabic

2.2.1 Functionality and properties of gum Arabic

Due to its high non-viscous soluble fiber content, gum Arabic, a naturally occurring polysaccharide, is frequently used as a food hydrocolloid. It is made from dried gummy exudates of the stems and branches of the leguminosae family's *Acacia senegal* and *Acacia seyal* trees (Dauqan & Abdullah, 2013; Williams & Phillips, 2009). Compared to gum from *Acacia senegal* var. *Senegal*, gum arabic from *Acacia senegal* var. *Kerensis* has more better functioning qualities (Gakuru *et al*., 2009). For example, the latter gels at lower concentrations due to increased inherent viscosity because to the larger gyration radius and has better emulsification properties linked with the higher protein content. (Gakuru et al., 2019), as indicated in Table 2

Table 2*:* Quality parameters of gum arabic

Components	Quantity
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 compostion of total ash (550^{o}C)	
Copper (ppm)	52-66
Iron (ppm)	730-2490
Manganese (ppm)	69-117
Zinc (ppm)	45

Source: Dauqan and Abdullah (2013).

Gum arabic is a glassy-fractured solid that ranges in color from pale white to orange-brown. High molecular weight polysaccharides and their magnesium, potassium and calcium salts make up gum Arabic chemically. These salts hydrolyze to provide glucuronic acid, galactose, rhamnose, and arabinose.

(Muita *et al*, 2020). The backbone is composed of 1, 3-linked β-D-galactopyranosyl units. The side chains consist of two to five 1, 3-linked β-D-galactopyranosyl units joined by 1, 6-linkages to the main chain (Muita *et al*., 2020).

Gum Arabic is a complex, branched-chain polymer that can be slightly acidic or neutral. It is a polysaccharidic acid made up of salts of calcium, magnesium, and potassium (Abdul-Hadi *et al*., 2010). Arabinogalactan (AG) proteins contain the primary amino acids, and aspartic acid is the most prevalent component of GlycoProtein (GP), while hydroxyproline, serine, and proline make up the Arabinogalactan-Protein Complex (AGP) (Dauqan & Abdullah., 2013). The gum has a mixture of glycoproteins, polysaccharides, and arabinogalactan oligosaccharides.

2.2.2 Sources of gum arabic

There are a lot of gum arabic trees in West Africa, central Africa, and central Sudan. From Senegal and Mauritania in the west to Eritrea and Ethiopia in the northeast and all the way down to the south, Acacia senegal is a typical Sahelian tree found across the arid regions of tropical Africa conditions Africa's south, west coast, which includes southern and central Africa (Eisa *et al*., 2008). Gum Arabic (*Acacia senegal*) originate from African regions of Sudan, Senegal, and Mali (Diego et al., 2020). It is found outside of Africa in places like India, Pakistan, and Oman. Virgin Islands, Puerto Rico, Australia, and Egypt have also been exposed to it. Var. leiorhachis Brenan is distributed throughout East Africa, whereas other varieties, including var. kerensis Schweinf, are found in Kenya, Tanzania, Uganda, Somalia, and Ethiopia**.** Africa, spanning South Africa to Ethiopia; var. rostrata (Sim) the same area is home to Brenan, as well as Namibia, Angola, and possibly Oman, (Dauqan & Abdullah., 2013). Gum Arabic in Kenya is derived from Acacia senegal var kerensis, though it is only marginally used for commercial and industrial purposes, (Muita *et al*., 2020).

2.2.3 Nutritional composition of gum arabic

Acacia senegal's dried exudates are the source of gum arabic, which is high in dietary fiber, (Nasir *et al*., 2008). It comprises heterogeneous gum polysaccharides with a high molecular weight (lipoprotein), (Abd-Razig *et al*, 2010). The gum has a mixture of glycoproteins, polysaccharides, and arabinogalactan oligosaccharides. It's highly soluble in water and stabilizes water and oil combinations as well as emulsions (Morley, 2016). The nutritional composition of gum arabic is shown in Table 3.

Table 3: Nutritional composition of gum arabic/ 100g

Component	Quantity in 100g
Calories (kcal)	174.00
Total fat (g)	0.27
Saturated fats (g)	0.18
Trans fats (g)	0.00
Monounsaturated fat (g)	0.06
Polyunsaturated fat (g)	0.00
Cholesterol (mg)	0.00
Total carbohydrates (g)	85.00
Dietary fiber (g)	85.00
Total sugars (g)	0.00
Includes added sugars (g)	0.0
Proteins (g)	0.80
Water (g)	10.00
Ash (g)	4.00
Vitamin A (IU)	0.00
Vitamin D (mcg)	0.00
Vitamin C (mg)	0.00
Sodium (mg)	561.00
Calcium (mg)	950.00
Iron (mg)	2.40
Potassium (mg)	201.00

Source: www.ingredion.us (2022)

2.2.4 Applications of gum arabic

Gum arabic biopolymer has a vast array of applications in industrial manufacturing traversing from food, pharmaceutics ceramics, lithography, cosmetic, textile, paint, and printing factories, (Verbeken *et al.*, 2003). The versatile hydrocolloids are widely utilized in the food sector with potential to be applied as stabilization, encapsulating agents for bioactive ingredients, gelling, thickening, moisture retention, emulsification, and extending shelf life. They are extensively utilized in the food sector as beverage stabilizers, clarifiers, emulsions, and in the microencapsulation of flavors and pigments. Gum Arabic is frequently utilized in the food and pharmaceutical industries as a stabilizer, emulsifier, thickening agent for insoluble medications, encapsulating, bulking, and thickening in food processing, (Abdul-Hadi *et al*, 2010)

In food companies, gum Arabic is mostly utilized as a microencapsulating agent and in confections, wine, bakeries, dairy products, and beverages. Beer, cola drinks, and citrus juices are among the beverages that use gum arabic as an emulsifier. The capacity of gum arabic to stabilize foams makes it useful in manufacturing soft drinks and beer.

Gum, lozenges, chocolates, and other confections are among the many goods that use it. Gum Arabic serves two vital purposes in these products: it delays or stops the sugar from crystallizing and emulsifies fat to maintain its uniformity all over the product. It creates a greater level of clarity in wine gums than other hydrocolloids can. Moreover, it delays melting in the mouth, inhibits sucrose crystallization, and releases taste in a controlled manner, all of which prolong the wine gum's shelf life. Additionally, it gives these candies the proper texture because they are simply distorted in the mouth but do not stick to the teeth (Arja *et al*., 2011). Gum arabic is broadly utilized in baking because of its low absorption of moisture. Compared to sugar solutions, gum arabic's solubility in cold water permits the production of more transparent solutions. Additionally, it offers advantageous adhesive qualities for application in meringues and glace, and when applied as an emulsion stabilizer, it adds softness. A modest amount of gum arabic can improve the baking qualities of wheat and rye flours because it helps to retain moisture, which slows down the hardening of bread.

Due to its emulsifying properties, low viscosity, and high water solubility, gum Arabic works well as an encapsulating agent to preserve and protect volatile and chemically reactive commercial food flavorings. It is also applied in dessert mixes and soups, (Aires and Silva, 2020). According to Patel and Goyal (2015), when gum arabic was added to strawberries as an encapsulation stabilizer, the critical water activity rose dramatically, increasing the glass transition temperature and decreasing the freeze-dried strawberry powder's hygroscopicity while also improving stability. Arabic gum is typically utilized for fat microencapsulation due to its capacity to form films and its ability to create stable emulsions for the majority of oils across a broad pH range (Montenegro *et al.*, 2014).

Moreover, gum Arabic is utilized to prolong the shelf life of perishable vegetables and fruits by applying an edible coating to their surface that delays further ripening and preserves freshness by holding onto moisture and quality. Gum Arabic is utilized in dairy products as a stabilizer in ice cream and other frozen goods because of its capacity to absorb water. Since its higher melting point is what makes ice cream so appealing, gum arabic's function in these goods is to produce a fine texture and growth by preventing the creation of ice crystals, which is accomplished by mixing a lot of water and holding it as water of hydration (Montenegro *et al.*, 2014).

2.2.5 Characteristics of gum arabic

Gums are water-soluble complex carbohydrates that can solidify into mucilages and gels. Among other substances, xylose, galacturonic acid, galactose, arabinose, and rhamnose can create them. They have a large molar mass. They exhibit thickening, emulsification, moisture retention, gelling, and stabilization (Aires & Silva., 2020).

Up to 50% of gum arabic can dissolve effortlessly in both hot and cold water. Intense gum concentrations can be used in a variety of applications due to the low viscosity of gum arabic solutions, which are characterized by a compact, branching structure and a tiny hydrodynamic volume. Until 40% of the concentration, solutions behave Newtonianly; above that, they become pseudoplastic (Aires & Silva, 2020).

A great emulsifying agent is gum arabic. The hydrophobic polypeptide backbone firmly adsorbs at the oil-water interface, while the connected carbohydrate units stabilize the emulsion through steric and electrostatic repulsion. A gum's ability to stabilize an emulsion depends on its anchoring groups that are big enough in molecular size to cover the surface of scattered droplets and have a significant attraction with the oil's surface. Gum arabic exhibits surface activity and surrounds oil droplets with a thick, sterically stabilizing macromolecular coating (Fennema, 2017). Glycoprotein, polysaccharides, and their calcium, magnesium, and potassium ions make up gum Arabic, making it a complex chemical compound with a slight acidity. Arabic acid, the primary polysaccharide that connects a D-galactose with branches composed of D-glucuronic, L-rhamnose, and Larabinose acids. In essence, the proteins are classified as hydroxproline-rich arabinogalactanes, (Aires & Silva, 2020).

2.2.6 Structure of gum arabic

Gum arabic, which is produced from Acacia senegal, consists of a main chain of β-D-galactopyranose joined by bonds (1➔3), which alternates with highly branched bonds (1➔6), and lateral chains of 4-O-methyl-glucuronic acid (1.5%), glucuronic galactose (39%), arabinose (28%), and rhamnose (14%), and acid (17.5%) (Aires and Silva, 2020). Gum Arabic's structure is seen in Figure 4. Many scholars distinguish gum Arabic because it primarily consists of three fractions (Yael *et al*., 2019). This polymer, which makes up the majority (88–90%) of β-(1, 3) galactose, is extremely branched, with a galactose backbone and connected arabinose and rhamnose branches that end in glucuronic acid, which exist in nature as potassium, calcium, and magnesium salts. This fraction, known as Arabinogalactan (AG), has a molecular weight of 300 kDa and a low protein concentration of 0.35 percent, (Renard *et al.*, 2006; Sanchez *et al*., 2008). A greater molecular weight 10% of the total is made up of the smaller (secondary) arabinogalactan-protein complex (GAGP-GA glycoprotein), which has a molecular weight of 1400 kDa and an 11% protein content. Serine and hydroxyproline groups in this complex form a covalent link between arabinogalactan chains and a protein chain, (Goodrum *et al*., 2000). The complex's associated arabinogalactan contains glucoronic acid. The smallest portion (1% of total) with the highest protein concentration is a glycoprotein (50 weight percent), is different from the complex AGP in the makeup of its amino acids (Yael *et al*., 2019).

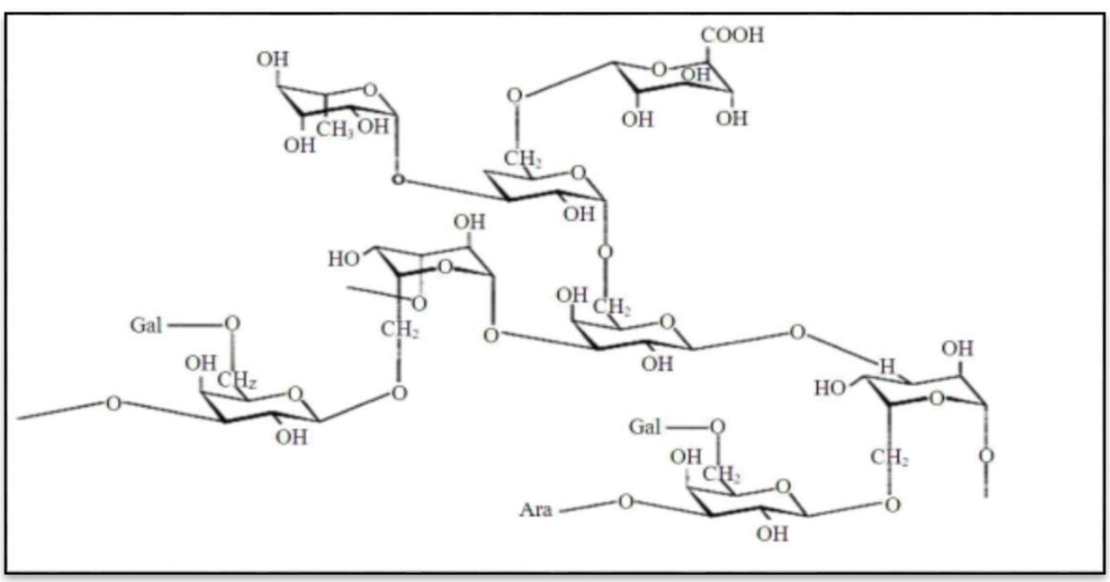

Figure 3*:* Structure of gum arabic

Source: Dauqan and Abdullah (2011)

2.2.7 Physical properties of gum arabic

An emulsifier consisting of hydrophobic protein components and hydrophilic carbohydrates, gum Arabic is a naturally occurring material that adsorbs onto oil droplet surfaces, and food additives and electrostatics stop flocculation and molecular coalescence by using hydrophilic carbohydrates. ' Steric repulses, (Lelon *et al.*, 2010).

Gum Arabic's moisture content makes hydrophilic carbohydrates and hydrophobic proteins more soluble. The critical concentrations of calcium, potassium, magnesium, foreign matter, and acid insoluble matter salts are ascertained using the total ash content. The precise concentrations of heavy metals in gum arabic are ascertained by the cationic compositions of the ash component. (Lelon *et al.*, 2010).

2.2.8 Utilization of gum arabic

2.2.8.1. Utilization of gum arabic in food industry

Gum arabic finds application in the food industry for various purposes, such as enhancing flavors, serving as an emulsifying agent, preventing sugar crystallization in confectionery, and stabilizing frozen dairy products. Its adhesive and viscous properties make it valuable in the baking industry, where it stabilizes mousses and acts as a turbidity agent in beer.

In the confectionery sector, Gum arabic is predominantly utilized, contributing to a range of products. Particularly in wine gums, it has a longstanding tradition, imparting a clarity surpassing that achieved by other hydrocolloids. It not only averts sucrose crystallization but also ensures controlled flavor release and slow melting, extending the longevity of wine gums. Additionally, Gum arabic provides the desired texture, preventing deformation in the mouth without adhering to the teeth (Arja *et al.*, 2011). In lower-calorie candies, it compensates for the texture loss resulting from sugar replacement with artificial sweeteners. Gum arabic works well as a coating agent and pigment stabilizer for chewing gum. It serves as a whipping and stabilizing agent in aerated confections like nougats and marshmallows. Its role extends to emulsification in toffees and caramels, maintaining a uniform fat distribution, and providing a fibrous texture in jelly products (Tadesse *et al.*, 2007).

Gum arabic serves as a significant emulsifier in soft drink manufacturing, displaying high solubility and stability in acidic environments, it can be used in oil emulsions with citrus and cola flavors. Its usage in microencapsulation is noteworthy, as it protects substances from loss of volatile compounds and chemical deterioration, converting liquid food flavors into powders for dry food products. In the realm of dietetic beverages, it is gradually employed as a source of soluble fiber, contributing to opacity, appearance, mouthfeel, and palatability in powdered beverage mixes (Wyasu & Okereke, 2012). Furthermore, gum arabic plays a role in preventing gelation in canned pet foods with gravy, inhibiting protein extraction from meat into the gravy (Verbeken *et al*., 2003).

2.2.8.2 Utilization of gum arabic in non-food industry

In the realm of makeups, gum Arabic stabilizes lotions and protective creams by increasing their viscosity, giving them spreading qualities, and creating a protective layer that makes for a smooth, tactile feel (Arja *et al*., 2011). It functions as a foam stabilizer in liquid soaps and an adhesive in blushers. Additionally, it acts as an adhesive for masks and face powders, contributing to the creaminess and smoothness of lotions. Gum arabic finds application in the lithography industry for preparing etching and plating solutions, as well as in stiffening cloth, coating specific paper types, and preventing corrosion when coating metals. Its versatility extends to the manufacturing of matchsticks and ceramics (ITC, 2008).

Moreover, gum Arabic is employed to stabilize emulsions, serve as coat medications and a binding agent. Its inclusion in eye drops and cough syrups blends is noteworthy. As a dispersion, it ensures that pigments and active ingredients are distributed uniformly in paints and insecticidal/acaricidal emulsions. Gum arabic is used in the textile industry as a thickening ingredient in printing pastes used to color knitted cellulose materials. It can also be used as a preservative and colloid protector in the production of polishes, ceramics, and ink and pigment, (Verbeken *et al*., 2003).

As asserted by Ahmed *et al.* (2015), gum Arabic, along with *A. seyal* and *A. senegal*, contains potent antioxidant properties. Their branched-chain polysaccharides have shown efficacy in reducing experimental toxicity, diminishing lipid peroxidation, and enhancing antioxidant enzyme activities in diabetic rats' liver. This suggests the potential of gum Arabic extracts in protecting against hepatic oxidative stress in diabetic conditions. Research by Priyanka and Choudhry (2013) suggests that incorporating Indian gum Arabic pod powder into the diet of individuals with type 2 diabetes and cardiovascular disease (CVD) can mitigate associated risk factors. Nasir *et al.* (2008) propose that in the prevention and treatment of type 2 diabetes, gum arabic's impact on intestinal glucose transport may be beneficial. It has been shown to reduce fasting blood glucose, lipid profile, low-density lipoprotein (LDL), total cholesterol, very low-density lipoprotein, high-density lipoprotein (HDL) cholesterol, and blood pressure when taken as dietary fiber, especially at a dose of 4 g/day (Salih, 2018). This suggests that it may be beneficial for diabetes and coronary artery disease. According to traditional medicine, gum Arabic's sensitive leaves and pods can help treat diabetes mellitus, (Priyanka & Choudhry, 2013).

2.3 Chia mucilage

2.3.1 Properties of chia mucilage

The herbaceous flowering mint plant known as chia (Salvia hispanica L.) is native to northern Guatemala and southern Mexico, (Capitani *et al*., 2012; Masood., 2022). Chia is grown commercially in many other countries including Peru, Argentina, Australia, and the United States. When chia seeds are sodden in water, they produce a transparent mucilaginous gel known as chia mucilage mostly composed of soluble fiber. It possesses high emulsions, an excellent water-holding capacity, and good viscosities, even at low concentrations (Sibele & Myriam., 2018). Rich in nutrients, chia seed mucilage can be used as a thickening, gelling agent, texture modifier, fat substitute, stabilizer, emulsifier, bulking agent, encapsulant, syneresis inhibitor, film/coating agent, and chelator when added to food, (Capitani *et al*., 2012). Chia mucilage has potential application as fat substitutes in several foods due ability to enhance the stability of the products and rheological properties while reducing calories (Ribes &Talens, 2021; Sibele & Myriam, 2018).

Furthermore, it has a high protein content of 19–23% and dietary fiber of about 30% of total weight. Additionally, chia is high in protein, with a high content of glutamic acid, arginine, and aspartic acid in chia protein isolates. It contains 64.9% globulin, 20.2% glutelins, 10.9% albumins, and 4.0% prolamines, (Julio *et al*., 2016). 60% of α-linolenic acid (ALA) found in chia seeds is associated with a number of health advantages, including a lower risk of cancer and heart disease as well as enhanced cognitive function.
(O’Dwyeret *et al*., 2013).

According to Sibele and Myriam (2018), chia mucilage mayonnaises containing up to 45% chia mucilage instead of oil demonstrated satisfactory sensory acceptance, enhanced stability, and a 50% reduction in lipid content. Chia seeds have health and nutritional benefits for people since they are a fantastic source of protein, dietary fiber, and essential fatty acids. Chia mucilage is a highly branched tetrasaccharide and its main chain is composed of (1→4) For (1→4), -β-d-xylopyranosyl -α-d-glucopyranosyl-[1→4] at its O-2 location The 4-O-methyl-α-dglucuronic acid branches of -β-d-xylopyranosyl, (JFDS, 2017). Chia mucilage exhibits emulsifying qualities linked to the low protein content that is a crucial component of the polysaccharide in the chia mucilage dispersions' surface activity (Sibele & Myriam., 2018; Timilsena *et al*., 2016).

2.3.2 Nutritional composition of chia seed

High in many important amino acids, chia seeds are dense in dietary fiber and proteins. They are mostly composed of globulins, albumins, glutelin, and prolamin, which make up roughly 52–54%, 17.3–18.6%, 13.6%, and 17.9% of the total protein content, respectively (Kulczynski *et al*., 2019) These proteins are rich in endogenous amino acids, mainly glutamic and aspartic acids, alanine, serine, and glycine. Additionally, polyunsaturated fatty acids, primarily α-linolenic acid, which is a member of the omega-3 fatty acid group, are rich in chia seeds. In addition to being a good source of numerous vitamins and minerals, these seeds also contain bioactive substances with robust antioxidant activity, especially polyphenols and tocopherols, (Kulczy´nski *et al*., 2019). Ca, P, and K are around six, eleven, and four times more abundant in chia seeds than in milk, (Coates & Ayerza, 2009). Table 4 elaborates more on nutritional composition of chia seeds.

Table 4*:* Nutritional composition of chia seed

Components	Quantity
Energy (calories)	486
Protein (non-gluten) %	15- 24
Dietary Fiber %	18- 30
Fat (mostly PUFAS and 10% saturated fats) %	30- 35
Carbohydrate %	26- 41
Moisture %	6

Source: Masood (2022) and Ullah *et al.* (2016)

2.3.3 Application of chia seeds in food industry

Chia seeds are utilized as alternatives for fat and egg in foods due to its hydrophilic properties (Ding *et al.*, 2018; Felisberto *et al.*, 2015; Gallo *et al.*, 2018) and this insignificantly impact their physical and technological properties, (Kulczy´nski *et al.*, 2019). Chia seeds have the capacity to absorb up to twelve times as much water as their own bulk, (Munoz *et al.*, 2012), and provide food with characteristic consistency (Kulczy´nski *et al.*, 2019). Chia seeds are used wholly as seeds, ground powder form, gel or mucilage and oil. In baked goods and oi-in-water emulsions, chia seed gel can be used in place of oil or eggs, lowering the items' calorie and fat content. Currently, a number of goods are either grounded on or fortified with chia seeds in the food business throughout numerous nations globally. Cookies, cakes, fruit juices, yogurts, sauces, jams, preserves, and breakfast cereals are a few examples of these (Valdivia-López and Tecante., 2015; Zettel & Hitzmann, 2018).

Gruel made from chia seeds can be used in place of stabilizers and emulsifiers for making ice cream, (Kulczy´nski *et al.*, 2019). A product that was enriched with mono- and polyunsaturated fatty acids, minerals (potassium, magnesium, calcium, and manganese), and dietary fiber was produced by using chia to make frankfurters. Simultaneously, the finished product demonstrated a strong sensory preference and a calorie content reduction of about 26%. In low fat- low calories mayonnaise chia seeds are used mostly in form of freeze dried mucilage due to its high content in PUFAs (Rojas *et al.*, 2019). Fat and egg mimicking features (Fernandes & Mellado, 2017) The mayonnaise has attained a rise in (PUFAs), as well as improved thermal stability and oxidation resistance since chia seeds contain polyphenolics, (Masood, 2022).

According to Borneo et al. (2010), chia seed gel can replace up to 25% of the oil or eggs in cakes, significantly impacting the product's color, flavor, texture, and general acceptability. According to Oliveira et al. (2015), chia seed flour can also be utilized to make pasta as a wheat flour substitute that has a higher nutritional value than the control pasta with noticeably higher protein, mineral, and dietary fiber contents (Menga et al., 2017). They suggested combining mucilage and chia seeds with rice flour to make non-gluten fresh pasta.

They showed that a 10% mucilage or chia seed concentration produced wholesome, non-gluten pasta with stiffness and cooking qualities comparable to those of commercial products. Coelho and Salas-Mellado (2015) found that breads containing chia flour or chia seeds were highly accepted. They found that adding 7.8 g of chia flour per 100 g and, in the second variant, 11.0 g of chia seeds per 100 g produced a final product with a more favorable ratio of saturated fatty acids (SFA) to polyunsaturated fatty acids (PUFA) than the control bread. According to Coelho and Salas-Mellado (2015), the PUFA:SAT ratio for traditional bread was 1:01, whereas it was 3.1 and 3:9 for loaves that had chia flour or chia seeds, respectively. When Fernandes and Salas-Mellado (2017) looked at the technological quality of breads and pound cakes with less fat, they found that chia mucilage was a good way to replace fat while maintaining the quality of food products.

Coorey et al. (2012) found that adding chia flour improved the chips' nutritional content and sensory qualities. They claimed that the best results for the final product's appearance, color, texture, flavor, and general acceptance come from using chia flour at a 5% substitution rate for rice and potato flour. In turn, Campos et al. (2016) demonstrated that chia seed gruel might be utilized in place of stabilizers and emulsifiers while making ice cream. But in that instance, there was a negative alteration in the color of ice cream due to the dark chia gel (Campos *et al.,* 2016). Conversely, Pintado et al. (2016) looked at the possibility of using chia flour or an oil-in-water emulsion made by combining chia flours with water and olive oil to replace some or all of the additional fat in frankfurters. A product enhanced with dietary fiber, minerals (potassium, magnesium, calcium, and manganese), and mono- and polyunsaturated fatty acids was produced when chia was added to frankfurters. At the same time, the finished product had the appropriate sensory attributes and a calorie content that was lowered by about 26% (Pintado *et al*., 2016).

When Ding et al. (2018) investigated the processing characteristics of chia seeds on restructured ham-like products, they discovered that a 1.0% concentration reduced oxidation of lipids and proteins and enhanced the physicochemical and sensory qualities of low-fat meat products while also adding nutritional value.

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2.3.4 The chemical composition of chia

Chia seeds are credited high nutritive value predominantly dietary fiber There are about 30–34 g of dietary fiber in chia seeds, of which 85–93% is insoluble dietary fiber (IDF) and 7–15% is soluble dietary fiber (SDF), (Marineli *et al*., 2015; Reyes-Caudillo *et al*., 2008). It is characterized by high levels of polyunsaturated fatty acids, especially alpha-linolenic acid (ALA), which accounts for around 60% of all fatty acids. The levels of oleic, linoleic, and palmitic acids are lower. Compared to flaxseed, chia seeds have a higher concentration of omega-3 acids. The ratio of omega-6 to omega-3 acids is approximately 0.3:0.35, (Ciftci *et al*., 2012; Villanueva-Bermejo *et al*., 2019). Chia seeds also contain a large amount of plant protein, which makes up about 18–24% of their bulk, (Grancieri *et al*., 2019).

Ten exogenous amino acids were found, according to an analysis of the amino acid composition, with the largest quantities of arginine, leucine, phenylalanine, valine, and lysine. Chia seed proteins are also rich in endogenous amino acids, mainly glutamic and aspartic acids, alanine, serine, and glycine, (Bushway *et al*., 1981; Nitrayova *et al*., 2014; USDA, 2019). Celiac patients can eat chia seeds because they are gluten-free, (Munoz *et al.*, 2013). Moreover, magnesium (335–449 mg/100 g), potassium (407–726 mg/100 g), calcium (456–631 mg/100 g), and phosphorus (860–919 mg/100 g) are the minerals that are most abundant in chia seeds, [USDA, 2019, Jin *et al.*, 2012]. Additionally, studies verified the presence of some vitamins, primarily niacin (8.8 mg/100 g), vitamin B1 (0.6 mg/100 g), and vitamin B2 (0.2 mg/100 g), (Jin *et al*., 2012; USDA, 2019). Additionally, there are several exciting classes of phytocompounds with strong biological activity found in chia seeds (Oliveira-Alves *et al.*, 2017, Rahman *et al*., 2017). The tocopherols found in chia seeds include delta-tocopherol (15 mg/kg of lipids), gamma-tocopherol (422 mg/kg of lipids), and alpha-tocopherol (8 mg/kg of lipids), (Kulcznski *et al.*, 2019)

Most research has focused on the sensory and physicochemical attributes of mayonnaise with low-fat made with soy milk and watermelon rind as fat substitutes. However, there is a scarcity of published research on creating eggless low-fat mayonnaise that mimics the characteristics of commercial mayonnaise. Consequently, this study aims to assess the quality properties of an innovatively developed low-fat and eggless mayonnaise alternative made from chia mucilage (*Salvia hispanica*) combined with gum Arabic from *Acacia senegal* var. Kerensis.

CHAPTER THREE
MATERIALS AND METHODS

3.1 Experimental design

A Complete Randomized Design (CRD) in a 4×4 factorial arrangement was employed in this work. Two variable factors of chia mucilage and oil at four levels each (60, 45, 30, 15) was used and the experiment was done in triplicates. The statistical model used for the experiment was:

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

Where; Y_{ijk} is the observation on the random variables, The overall mean is represented by μ, the effect of the ith level of chia mucilage by αi, and the effect of the jth level of oil by βj. The interaction between the jth level of oil and the ith level of chia mucilage is represented by αβij; The component of random error is εijk.

3.2 Materials and study site

The ingredients needed to make mayonnaise—eggs, oil, sugar, vinegar, sunflower, mustard, salt, and chia seeds—were acquired from a supermarket in Nakuru town. The source of Gum Arabic, *A. senegal* var *Kerensis*, was Acacia EPZ Limited, located off the Nairobi-Namanga Highway near the Athi River. In the chemistry and microbiology labs at Egerton University's dairy and food science and technology department, physicochemical, microbial, and sensory analyses were performed. Monitoring of peroxide value (PV) in the incubators to predict shelf life and extraction of chia mucilage using cold freeze centrifuge was done at the Kenya-China Joint Laboratory for Crop Molecular Biology- Egerton University. The textural properties and viscosity of the mayonnaise products was carried out at the Chemistry laboratory, Makerere University- Uganda.

3.3 Extraction of chia mucilage

This was done in accordance with Brutsch *et al*, (2019). In order to guarantee effective hydration, the chia seeds were hydrated in water at 25°C using a proportion of 1:20 w/v chia seeds to water, and they were constantly mixed with a blender for two hours. A distinct three-layer gel was formed by centrifugation at 6600 g for 50 minutes at a cold freeze temperature of -7oC. The top layer of seeds and excess water, including soluble polysaccharides, was recovered by separation, while the bottom layer contained some mucilage and the remaining chia seeds.

3.4 Preparation of mayonnaise

The recipes of full fat mayonnaise (control) were modified from Fernandes *et al*. (2018) while that of eggless fat reduced were modified from Widerstorm and Ohman (2017) and Soita and Mutinda (2018) with slight modification as shown in Table 5. First, the dispersion phase was made by combining all the ingredients—except for oil—in a glass dish, including chia mucilage, white vinegar, sugar, salt, gum Arabic, mustard powder, white pepper, and citric acid. An industrial mixer was then used to carefully combine the oil with the water phase. As shown in table 5, the control was created by gradually adding 75% oil to a premixed water phase that contained egg yolk, vinegar, sugar, salt, and selected spices. For each sample, the oil was lowered from 75% to four levels of 60%, 45%, 30%, and 15%. Cold-frozen chia mucilage was used in place of the egg yolk at 60%, 45%, 30%, and 15%, and gum Arabic was added at 3% to stabilize the emulsion (Table 5). Prior to testing, the prepared mayonnaise products were aseptically moved to a glass jar covered with polypropylene film and refrigerated at 4°C for 24 hours to prevent spoiling.

Table 5: Recipes for preparation of full fat with egg yolk (control) and fat reduced eggless mayonnaise

Ingredients % (g)	**Full fat with egg yolk mayonnaise**	**Fat reduced eggless mayonnaise**
Sunflower oil	75	60
Water	100	0
Vinegar (4.5%AA)	10	10
Egg yolk	6	0
Salt	1	1
Sugar	2	2
Mustard	1	1
Spices (cardamom and white pepper)	1	1
Citric acid	1	1
Chia mucilage	0	15
Gum Arabic	0	3

3.5 Physicochemical analysis

3.5.1 Moisture content

The oven drying technique, AOAC (2008) Method 985.14, was used to ascertain the moisture content. Ten grams of each sample was put on an aluminum dish and dried in an air-oven at 105°C until constant weight was obtained and cooled in a desiccator for 10mins. The % moisture content was calculated as the difference between the weight before and after drying divided by sample weight multiplied by 100%

$$\text{Moisture content (\%)} = \frac{(\text{weight of pan + wet sample})\ g - (\text{weight of pan + dry sample})\ g}{\text{Weight of sample g}} \times 100$$

3.5.2 Crude protein content

Protein content was analyzed by Kjeldahl method described by AOAC (2005) Method 945. 18-B. In a heating tube containing two copper catalyst tablets, roughly 1g of each sample was combined with 15 mL of concentrated H2SO4 and cooked using a block digester for 1.5 hours at 420°C. After cooling to ambient temperature, the digested solution was moved to a 100 mL volumetric flask and filled to the appropriate level with distilled water. Eighty milliliters of 40% NaOH solution was then added. Following distillation, the mixture's released ammonia was gathered in a 400 mL beaker with 50 mL of 2% boric acid and a few drops of methyl red indicator. Total nitrogen was then determined by titrating the distillate against 0.1 N H2SO4.

The nitrogen content was calculated and multiplied by a conversion factor of 6.25 to obtain the crude protein content.

$$\%N = M\ HCl \times \frac{\text{corrected acid volume}}{\text{Weight of sample g}} \times \frac{14gN}{mol} \times 100$$

3.5.3 Fat content

Themethod of Soxhlet extraction was used with modification to determine the fat content (AOAC 2006 989.05. An automatic hydrolyzing equipment was used to weigh two grams of the homogenized sample into a hydrolyzing capsule for hydrolysis. After hydrolyzing, the material was put into an extraction thimble. Cotton was used as a lid, and an automated fat extraction equipment was utilised to extract the fat using petroleum ether at 40–60 degrees Celsius for two to three hours. After being collected, the petroleum ether was dried for three hours at 105ºC, cooled for one hour in a desiccator, and its fat content was measured.

$$\%\ \text{Crude fat} = \frac{\text{weight of fat in the sample}}{} \times 100$$

Weight of the dry sample

3.5.4 Ash content

AOAC (2005) Method 920-117, the dry ashing method, was used to determine the amount of ash. For five hours, a sanitized silica crucible was heated to 550 degrees Celsius in a muffle furnace. After cooling in a desiccator for an hour, the silica crucible was weighed consistently. After that, 5g of the homogenized material was weighed and placed in the constant weight crucible. at finish the ashing process, the sample was heated in a crucible on a hot plate and then put in a muffle furnace set at 550 degrees Celsius for 6 to 8 hours. After an hour of cooling, the crucible's ash content was measured by weight.

$$\% \text{ Ash content} = \frac{(\text{weight of crucible} + \text{ash})\text{ g} - \text{weight of crucible (g)}}{\text{Weight of sample (g)}} \times 100$$

3.5.5 Carbohydrate content analysis

The amount of carbohydrates was calculated by deducting the percentages of moisture, protein, fat, and ash from 100, (Souci *et al.*, 2000).

3.5.6 Calories content

Caloric values were calculated according Souci *et al.* (2000):

Total calories = (4 x gm protein) + (9 x gm fat) + (4 x gm carbohydrate).

3.5.7 pH determination

AOAC (2005) Method 975.03 used a Cyberscan 500pH meter to detect pH at room temperature. A magnet stirrer was used to mix 20ml of distilled water with around 2g of weighed mayonnaise in a glass beaker until the mixture was homogenous. For standardization, distilled water and pH 4 and pH 7 buffers were made. After that, the sample was placed inside a standardized pH meter, and the reading was obtained.

3.5.8 Titratable acidity determination

The official AOAC (2005) Method 942.15, which was used to determine the titratable acidity, was used. After measuring about 9 milliliters of the samples, they were titrated against 0.1N NaOH while phenolphthalein indicator was present. Three replications of the analysis were conducted. Titratable acidity was determined by multiplying the mean of titre value by 0.1 (the molarity of NaOH).

3.5.9 Emulsion stability test

Emulsion stability test of the samples was calculated according to the method of Maskan and Gogus (2000) with modification. Graduated tubes each comprising 10g of sample were heated in a water bath at 80^{o}C for 30mins and centrifuged at 1006.2g for 15mins. Emulsion stability (ES) was then calculated as:

$$\text{Emulsion stability} = \frac{\text{Height of emulsion layer}}{\text{Height of whole layer in centrifuge tube}} \times 100$$

3.6 Textural analysis

The Texture Analyzer (TA) model (TA-XT plus SMATA, Godalming, England) was applied to study the textural characteristics of mayonnaise. At room temperature, TA had a 10 kg load cell installed. A tube with an inner diameter of 26 mm and a height of 35 mm was filled with the samples, and the top was polished off. At 3 mm·s−1, the male cone entered, and at 10 mm·s, it returned to its initial position. As a measurement probe, a 12.7 mm-diameter plastic cylinder entered the sample at a speed of 1 mm·s−1 and traveled 10 mm before returning to the starting location at the same speed (Karshenas *et al*., 2019) with minimum modifications. This method measured the cohesion, springiness, adhesiveness, and hardness/firmness (g) of mayonnaise samples. Maximum force, or the "peak," was used to gauge how stiff or hard the sample was; the higher the value, the firmer the sample. Consistency was measured by taking the area of the curve up to this point; the thicker the sample, the higher the value. When the probe returned, the weight of the sample was lifted mostly on the upper surface of the disc, i.e., by back extrusion, causing in the negative region of the graph. This gives another indicator of consistency or resistance to flow off the disc.

The stickiness (or cohesiveness, as it may be called in this context) of the sample was influenced by the greatest negative force; the higher negative the value, the more "sticky" or "cohesive" the sample was. The size of the curve's negative section is frequently referred to as the "work of adhesion"; the larger the value, the more resistant the sample is to withdrawal, which may be another sign of its cohesiveness, consistency, and viscosity.

3.7 Viscosity determination

Using a spindle size of 4 at 100 rpm in 150 mL of mayonnaise, the apparent viscosity of the prepared mayonnaise was determined using a Brook-field digital rotating viscometer (model DV-II+, Brookfield Engineering Laboratories Inc., Middleboro, MA). After the indicator stabilized and the spindle revolved in the sample for one minute at room temperature (22 °C), readings were obtained. Centipoise was used to express the viscosity values.

3.8 Microbiological analysis

Total viable, coliform, salmonella, yeast, and mold counts were performed, with modifications, in accordance with Parajuli et al. (2022). To create a 10-1 dilution, 225 mL of 0.1% sterilized peptone water was used to homogenize around 25g of mayonnaise sample from five treatments. The dilutions were distributed over a particular growth medium after this homogenate was diluted in sequence with 0.1% sterile peptone water. Salmonella was cultivated on salmonella-shigella agar, yeast and molds on potato dextrose agar, coliforms on MacConkey agar, and total viable counts on plate count agar. All of these cultures were maintained at 37 OC for 48 hours prior to counting. At dilutions up to 10-3, the number of colony forming units (CFU) per gram on plates was measured.

3.9 Sensory analysis

3.9.1 Consumer acceptability test

Consumer acceptability test was carried out on the five mayonnaise samples after 1 day of storage at 4^{o}C. Forty five (45) untrained panelists comprising of 25female and 20male were selected as test evaluators on a 9-point hedonic scale (Worrasinchai *et al*., 2006). The assessment criteria included color, aroma, consistency, flavor, taste, thickness, and general appeal. The samples were organized and labeled with three-digit random numbers and served alongside bread in a random order. The details of the evaluation form were thoroughly described prior to the assessment, and warm water was offered as a palate cleanser.

3.9.2 Quantitative descriptive sensory analysis

3.9.2.1 Recruitment and pre-screening of panel

Over the course of four days, academic personnel and students from Department of Dairy and Food Science and Technology, Egerton University conducted sensory training and evaluation. Twenty callers who had been pre-screened to follow the ISO 3972, ISO 8586-1, and ISO 8586-2 guidelines attended the overview session. After that, they had additional screening to determine their sensory perception of tastes and their intensities (salty, sweet, sour, and eggy). The fifteen demonstrated the ability to do sensory evaluation and passed the last round. ISO 8589 was followed in the design of the sensory laboratory, and sensory descriptive analysis was used for sensory analysis. Following a pre-screening procedure based on health concerns, allergy to eggs, and dislike of overly fatty foods, the twenty people were then whittled down to fifteen. Of the fifteen assessors who had experience with sensory evaluation and were not allergic to mayonnaise products, they were eager to eat the prepared eggless reduced fat mayonnaise.

3.9.2.2 Training of the panel and development of lexicon

Using the generic descriptive method outlined by Elliot and Timulak (2021), the descriptive sensory panel was taught for five days in two-hour sessions each day. Each panelist gave two explanations of the variations among the mayonnaises during the training. For evaluation reasons, a lexicon was created, and each description was given a specified and agreed-upon scale anchor along with descriptive phrases (Table 1). During the training sessions, the panel created a list of qualities and reached an agreement on how to rate each one. They also created explanations of the alleged sensory qualities of the mayonnaise products. Selected qualities were trained using reference materials such as acid taste, yellow hue, and eggy flavor.

3.9.2.3 Descriptive sensory evaluation

Five coded samples of mayonnaise were given to the fifteen panelists. The samples were served randomly. The panel was asked to score the intensities of the various sample qualities in relation to the vocabulary given in Table 6 using the training and produced lexicon. Each attribute's intensity for a particular sample was measured using a five-point line scale. The lowest rating, 1, indicated that the substance was not shiny, viscous, or perceived. Five was the highest possible score, signifying highly perceived, extremely viscous, or highly glossy.

Table 6: Quantitative descriptive sensory evaluation lexicon

Attribute		Reference	Ratings
	Appearance		
Shinny	Having smooth glossy surface	5- a piece of broken glass exposed to sun rays	5=intense 1=mild
Bubbles	Globule of gas in the product (emulsion)	5- bubbles as seen in ice cream	5= very visible 1= not visible
Spreadability	Ability to easily spread for uniform application on a surface	5- easily spread as medium fat magarine	5= very intense 1= not intense
Yellow	Progression from a weak to a strong tone of custard yellow	5- yellow of egg yolk/ mustard powder	5= very intense 1= not intense
Stability of emulsion	Ability to resist physicochemical changes eg separation	5= spreads	5= very stable 1= very unstable
Consistency	Ability to hold together in terms of thickness and viscosity		5= highly perceived 1= not perceived
	Texture		

Adhesive	Amount of mayonnaise clinging on the spoon when held vertically	7= peanut butter	5= intense 1= mild
Cohesiveness	Particles tend to agglomerate together		5= intense 1= mild
Oily/ creamy	containing a lot of oil	5= full fat mayonnaise	5= intense 1= mild
Homogeneous	Of similar structure and composition throughout.		5= even 1= uneven
Slippery	Grisy and slimy in texture		5= intense 1= mild
Lumpy	None smooth or uneven texture		
Viscous/dense	Resistance to flow easily	Commercial mayonnaise	5= thick 1= thin
Gritty	Rough and tough. Coarse and grainy		5= rough 1= smooth
Firmness	Degree of resistance when stirring with a spoon		5= intense 1=mild
	Taste		
Acidity/sour	Basic taste evoked by citric/ acetic acid	Citric acid	5= intense

			1= mild
Saltiness	Basic taste elicited by sodium chloride		5= intense 1= not intense
Sweetness	Basic taste evoked by sucrose	Candy	5= intense 1= not intense
Astringent	Drying and puckering sensation evoked by strong black tea	Tamarind juice	5= intense 1= mild
Tangy	Sharp acidic flavor	Lemon juice	5=intense 1= not iintense
	Aroma		
Vinegar	Aroma evoked by vinegar	Commercial vinegar	5= intense 1= not intense
Eggy	Aroma evoked by eggs	boiled eggs	5= very intense 1= not intense
Mustard	Aroma evoked by mustard powder	Mustard powder spice	5= very intense 1= not intense
Caramelized	Aroma due to caramelization		5= very intense 1= not intense

3.10 Peroxide value analysis

Peroxide value (PV) determines the concentration of primary oxidation products, specifically hydroperoxides, (Nielsen, 2017). To calculate the amounts of iodine released from potassium iodide in an acidic media in milliequivalents of iodine per kilogram of fat (meq/kg), the PV is usually carried out using a titration-based technique. With minor adjustments, PV was examined using AOAC (2005) Method 965.33. After weighing two grams of the material, it was put in a beaker with 28 milliliters of a 3:2 glacial acetic acid and chloroform solution, and the mixture was stirred. After adding 1 mL of saturated potassium iodide solution and giving it a good shake, it was left in a dark location for 15 minutes. 50 milliliters of distilled water were added and stirred. A filter paper was then used to filter the resultant combination. One milliliter of 1% starch was added to the filtrate. Titration against standardised 0.01 N sodium thiosulphate was carried out until the blue colour disappeared. A blank was also run and the peroxide value was calculated from the following formulae (Shahidi & Zhong, 2005).

$$PV = \frac{(Va - Vb) \times N \times 1000}{W}$$

Where Va= titratable value of sample, Vb= titratable volume of blank, N= normality of sodium thiosuphate solution and W= weight of the sample.

3.11 Accelerated shelf life determination

The mayonnaise samples were stored at different temperatures (5, 25, 45) ^{o}C and PV determined for each sample on days 0,7,14, and 21 according to Robertson (2016) with modification. Reaction kinetics and order of reaction was determined by plotting concentration (PV) vs time. Arrhenius equation was be used to calculate the shelf life (Parajuli *et al.*, 2022).

$$k = Ae^{-Ea/RT}$$

Where k= chemical reaction rate, A= Pre-exponential factor, Ea=activation energy, R= rate constant and T= temperature in kelvin

The shelf life of each sample was determined using a linear regression equation and a maximum limit of acid value of 10 0_2 meq kg-1, (Parajuli *et al.*, 2022). The peroxide value-based.

$$\text{Ln } k = \ln k_o - E_a/RT$$

Where k is the reaction rate constant, k_0 is the pre-exponential factor of the frequency factor, R is the molar gas constant (8.31 J/K mol), T is the absolute temperature (K), and Ea is the activation energy (J/mol).

The predicted shelf life was then calculated as:

$$SL=(PV_{lim} - PV_{TO})/k_T$$

Where PV_{lim}= is the peroxide value corresponding to the limit of breadstick sensory

Acceptability limit. Ie 10 O_2 meq/kg of fat, PV_{T0} =is the peroxide value at zero storage time and K_T = represents the pseudo-zero-order rate constant at the selected storage temperature *T*.

3.12 Statistical analysis

SAS software version 9.4 was applied to statistically process the data and use an F-test at a 5% level of significance to assess the significance of individual differences. PROC UNIVARIATE was used to perform basic statistical measurements (central tendency, where mean = median), histogram, and goodness-of-Fit tests (skewdness/kjurtosis) to determine whether the data was normally distributed. The impact of oil proportions and chia mucilage levels on the the prepared mayonnaise samples' physicochemical quality which was examined by the use of analysis of variance (ANOVA). When comparing the means, a 95% confidence level was applied using Duncan's Multiple Range Test (DMRT). The data were expressed using the mean ± SD, and each experiment was conducted in triplicate.

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CHAPTER FOUR
RESULTS AND DISCUSSIONS

4.1 Effects of oil and chia mucilage levels on physico-chemical parameters of mayonnaise

Figures 5 and 6 show the effects of oil and chia mucilage levels to physical chemical properties of mayonnaise respectively. Generally, the fat reduced mayonnaise formulation had higher moisture content than the full fat mayonnaise ($P \leq 0.05$), and vice versa as moisture content reduced with increased oil levels (Figure 4). Liu *et al.* (2007) found that adding fat substitutes, especially those based on carbohydrates or proteins, increased the emulsion product's moisture content.

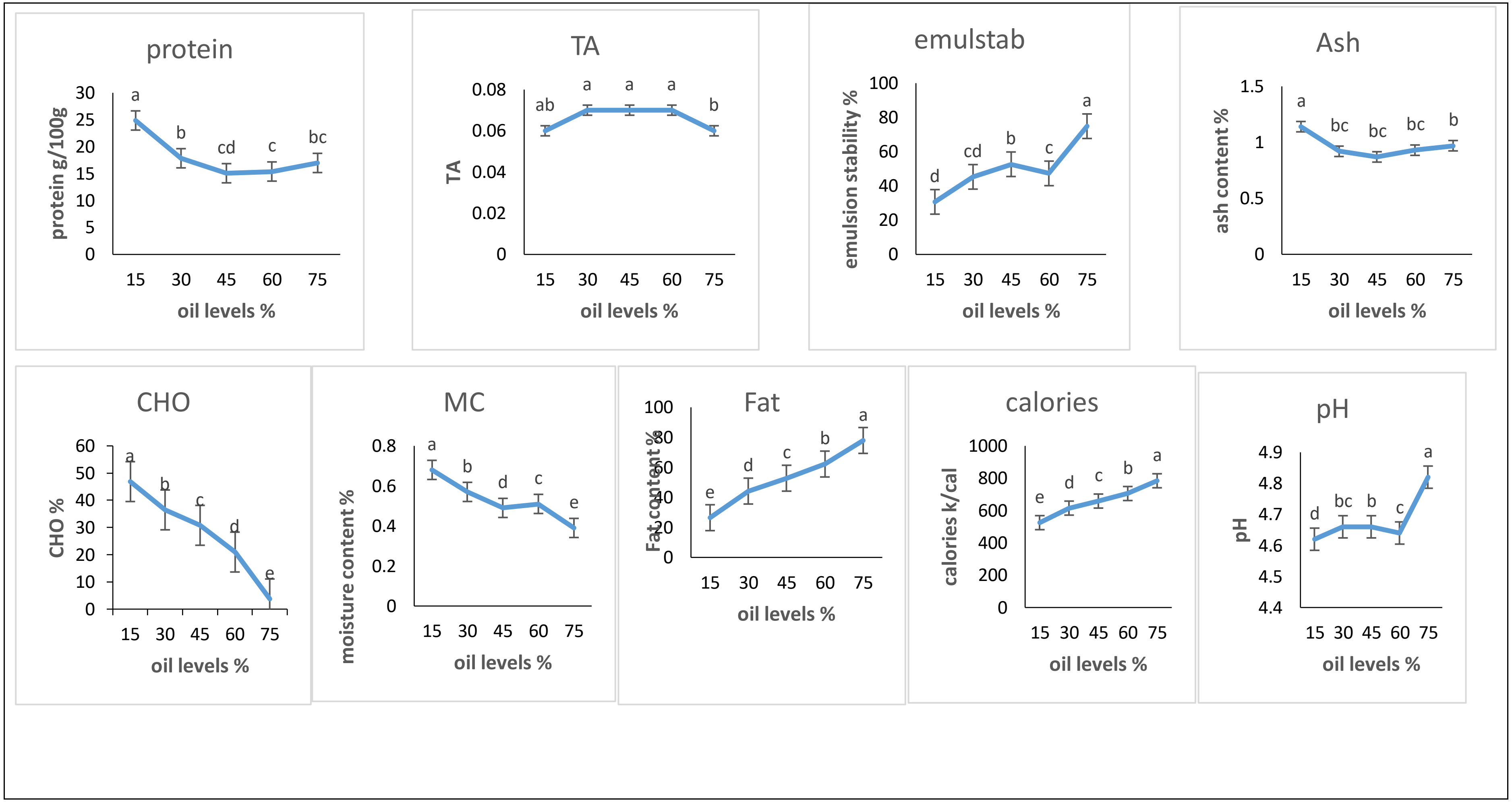

Figure 4: Effects of oil levels on physical chemical properties of fat reduced eggless and full fat egg mayonnaises

Values are means ± SD. Means with the same letters are not significantly different at ($p \leq 0.05$)

All the formulations had a reduced pH related to the vinegar content in which all samples had same amount of vinegar, which increased the acidity and consequently decreased the pH value. (Rojas-Martin *et al*., 2023). The pH values of the control samples were higher (4.82) than those of the low-fat mayonnaise formulations (4.62 to 4.66). The reason for this phenomena is that because undissociated acetic acid is only weakly soluble in oil, the pH of mayonnaise would rise as the oil content rose, especially after the oil content reached 50%. (Worrasinchai *et al*., 2006).

The pH readings rise as the amount of chia mucilage increases. It is believed that the diluting of the acetic acid in the fat-reduced formulations' aqueous state is what causes the pH rise. Furthermore, the polar and non-polar groups of hydrocolloids and proteins exhibit repulsive interactions (electrostatic repulsion) and attractive forces (hydrogen bonding) that may be responsible for the pH fluctuation in fat-reduction therapy. According to reports, the breakdown of ester groups in hydrocolloid structures resulted in the creation of carboxylic groups, which in turn caused the pH to drop (Ihsan *et al.*, 2021). Since chia mucilage and gum Arabic contain a carboxyl functional group (–COOH), which can release hydrogen ions (H^+) into the solution, thereby increasing its acidity. This reduction in pH can be accredited to the increase in acidic components in the mayonnaise.

Higher degrees of fat substitution resulted in a decrease in the fat mayonnaise ($P \leq 0.05$). The mayonnaise formulation with the lowest caloric values ($P \leq 0.05$) was the fat reduced mayonnaise made with oil at a 15% level. The substitution of chia mucilage and hydrocolloid gums for oil in full fat mayonnaise may have contributed to the decrease in caloric values by raising the product's water content. The reason for the additional variation in fat-reduced calorie treatments is the varying amounts of chia mucilage, which rose as chia mucilage levels fell.

Compared to other macronutrients like proteins or carbs, fat has a higher calorie density. Even if chia mucilage is used in place of fat, it might not have the same caloric density as oil, which would lessen the total number of calories in the fat-reduced mayonnaise.

Compared to the full fat samples, which had a carbohydrate content of 3.75% at $p \leq 0.5$, the fat reduced samples had significantly greater carbohydrate levels, ranging from 46.87% to 20.97%. Gum Arabic and chia mucilage, which were added to the fat-reduced mayonnaise and contributed to the final greater carbohydrate content, are examples of carbohydrate base stabilizers and emulsifiers that could explain this phenomena. Gum arabic's side chains were blamed for this, as they raised the percentage of carbs (Aubadi *et al*., 2021).

The reduced fat samples' emulsion stability ranged from 38% to 51%, while the control exhibited a greater emulsion stability of almost 75%. Although emulsion stability is affected by reduced oil content, higher oil content leads to better emulsion stability (Evanuarini *et al.*, 2019). According to Zanjani *et al*., (2019). The proportionate size of the fat phase relative to the aqueous phase determines stability. The inclusion of gum produced a weak gel network and increased the viscosity of the continuous phase, which resulted in the stability of fat-reduced mayonnaise (Aubadi *et al*., 2021). Gum promotes stability because it causes fat droplets to flocculate, but creaming in fat-reduced mayonnaise prevents creaming because the continuous phase is more viscous and the fat droplets move less (Nikzade *et al*., 2012). Emulsion stability normally decreases with a decrease in viscosity (Herald *et al*., 2009).

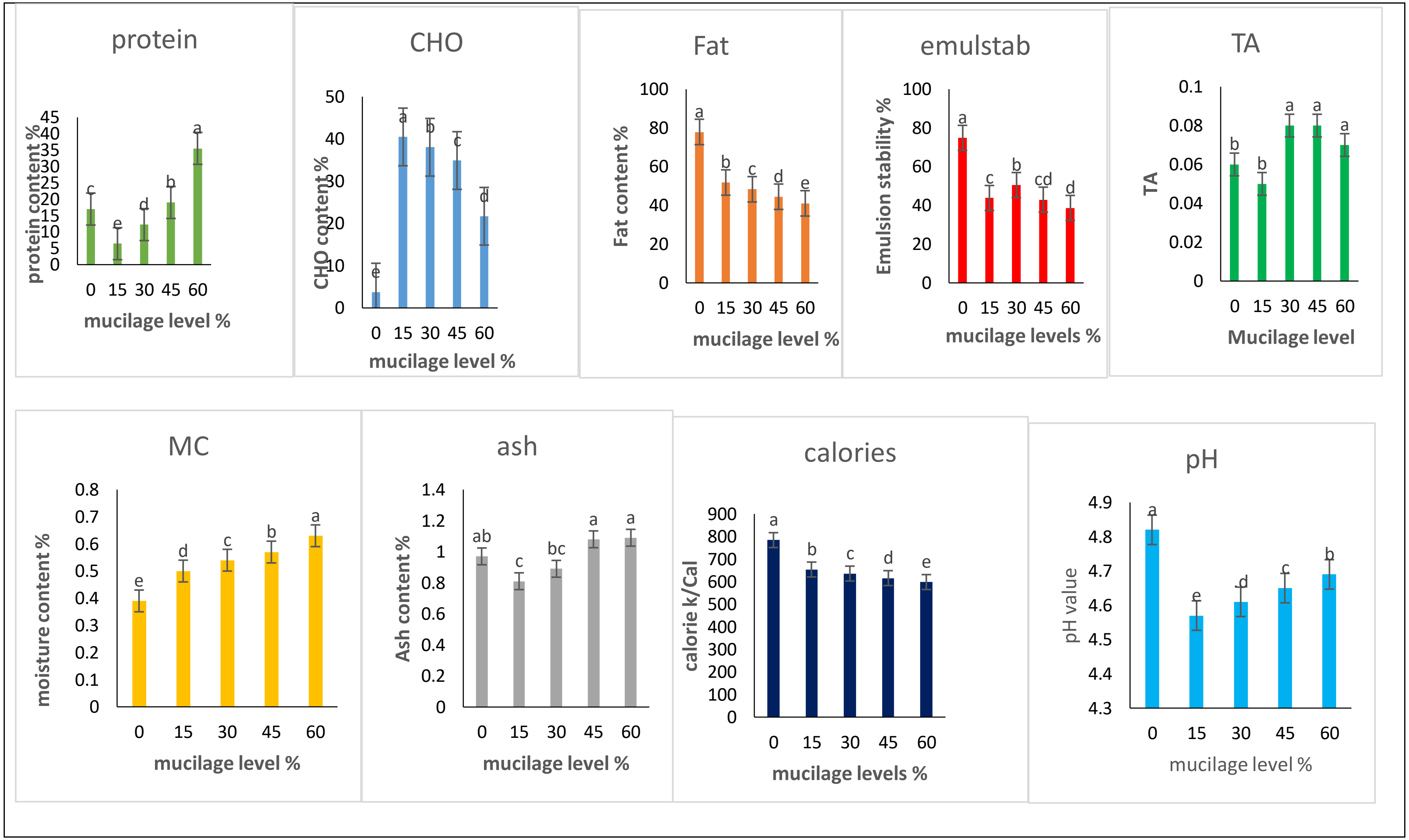

Figure 5: Effelevels on physical chemical properties of full fat and fat reduced eggless mayonnaise

Values are means± SD. Means with the same letters are not significantly different at ($p \leq 0.05$)

Full fat mayonnaise had remarkably increased fat contents of about 78% as compared to fat reduced mayonnaise which ranged from 41% to 52% fat. The rise in chia mucilage, which was employed to replace the fat, caused a noticeable drop in fat in all reduced fat regimens. Emulsifiers, treatment, and the usage of vegetable oils all affect the amount of fat in mayonnaise (Evanuarini *et al.*, 2021). All therapies that lowered fat showed an overall increase in protein. The protein content increased simultaneously with increasing chia mucilage levels from 4.61 to 35.53%. Control treatment had a significantly lower protein value of 16.98% as compared to other fat reduced treatments with 15% oil and 60 % chia mucilage having the highest protein content of 44.88%. This was contributed to by the addition of gums and mucilage which also have protein residue. The protein content in the fat reduced mayonnaise increased with increasing chia mucilage and reduced with increased oil levels. With the exception of the fat and chia mucilage, whose quantities varied, the types and amounts of the fixed components in all treatments may be the cause of the small but significant change in ash values that was noted.

4.1.1 Effects of interaction between oil and mucilage levels on physicochemical parameters of mayonnaise

Table 7 shows the effects of interaction between oil and mucilage levels on physicochemical properties of full fat mayonnaise with egg yolk and fat reduced eggless mayonnaise.

Table 7: Effects of interaction between oil and mucilage levels on physical chemical properties

Oil level	Mucilage level	Protein %	Carbohydrate %	Fat %	MC %	Ash %	Calories k/Cal	Emulsion stability %	Ph	TA
15	15	9.35^{e}±0.15	56.76^{a}±0.64	32.36±0.56^{j}	0.61^{cde}±0.01	0.93^{bc}±0.06	555.65±2.90^{j}	37.83^{ghi} ±1.17	4.42^{k} ±0.01	0.04^{g} ±0.00
	30	16.95^{d}±1.78	53.16^{a}±2.16	28.22±0.40^{jk}	0.69^{ab}±0.00	0.98^{bc}±0.02	534.451±2.04^{jk}	31.72±1.64^{hij}	4.68±0.00^{de}	0.10±0.01^{a}
	45	28.26^{c}±0.55	45.03^{b}±3.49	24.79^{kl}±3.51	0.67^{bc}±0.00	1.26^{ab}±0.13	516.26±18.04^{kl}	25.84±3.33^{k}	4.72±0.00^{c}	0.06±0.00^{defg}
	60	44.88^{a}±1.51	32.52^{de}±1.48	20.46^{l}±0.98	0.74^{a}±0.00	1.39^{a}±0.00	493.78±4.91^{l}	27.39±1.24^{ijk}	4.67±0.01^{def}	0.05±0.00 ^{efg}
30	15	5.82^{ef}±0.36	44.18^{bc}±0.28	48.72^{g}±0.38	0.47^{gh}±0.01	0.80^{c}±0.00	638.54±1.87^{fg}	55.36±1.52^{bcde}	4.64±0.00^{fg}	0.06±0.00 ^{defg}
	30	14.50^{d}±0.29	37.48^{d}±1.05	46.67^{gh}±0.77	0.56^{ef}±0.00	0.79^{c}±0.00	627.97±3.87^{gh}	48.00±2.00^{defg}	4.56±0.01^{i}	0.08±0.00 ^{bcd}
	45	18.04^{d}±0.64	38.06^{cd}±0.62	42.24^{hi}±0.06	0.62^{cd}±0.00	1.04±0.06^{abc}	604.56±0.50^{hi}	40.28±1.39^{fgh}	4.65±0.01^{efg}	0.09±0.01^{abc}
	60	33.04^{b}±0.60	26.15^{ef}±1.55	39.13^{i}±0.80	0.63^{cd}±0.01	1.06±0.18^{abc}	588.90±3.37^{i}	37.50±2.41^{ghij}	4.77±0.00^{b}	0.06±0.01^{defg}
45	15	4.31^{f}±0.13	35.82^{d}±0.38	58.66^{de}±0.32	0.36^{j}±0.00	0.84±0.07^{c}	688.50±1.85^{de}	66.24±0.43^{ab}	4.52±0.00^{j}	0.05±0.00^{efg}
	30	8.57^{e}±0.07	36.14^{d}±0.43	54.00^{ef}±0.36	0.48^{gh}±0.00	0.81±0.02^{c}	664.87±1.82^{ef}	59.50±1.12^{bcd}	4.76±0.00^{b}	0.06±0.00^{defg}
	45	14.97^{d}±0.36	33.04^{d}±0.63	50.50^{fg}±0.61	0.52^{fg}±0.01	0.97±0.02^{bc}	646.56±3.05^{fg}	45.96±4.29^{efg}	4.63±0.01^{g}	0.09±0.01^{ab}
	60	32.42^{b}±0.27	18.18^{g}±0.49	47.96^{g}±0.45	0.59^{de}±0.00	0.85±0.06^{bc}	634.02±2.36^{g}	38.89±1.39^{ghi}	4.73±0.00^{c}	0.08±0.00^{bcd}
60	15	6.16^{ef}±0.02	25.13^{f}±0.79	67.49^{b}±0.82	0.56^{ef}±0.01	0.65±0.06^{c}	732.63±4.16^{b}	15.78±0.99^{k}	4.68±0.00^{d}	0.05±0.00^{fg}
	30	8.93^{e}±0.28	25.34^{f}±0.33	64.32^{bc}±0.26	0.42^{hi}±0.01	0.99±0.15^{abc}	715.96±1.65^{bc}	62.77±2.54^{b}	4.68±0.01^{d}	0.07±0.00^{cdef}
	45	14.67^{d}±1.55	23.44^{fg}±1.99	60.35^{cd}±0.55	0.49^{g}±0.04	1.04±0.06^{abc}	695.62±2.76^{cd}	59.72±1.39^{bc}	4.59±0.00^{hi}	0.07±0.00^{bcde}
	60	31.78^{bc}±0.30	9.97^{h}±0.38	56.63^{de}±0.50	0.57^{ef}±0.00	1.05±0.07^{abc}	676.67±2.32^{de}	50.97±4.11^{cdef}	4.60±0.00^{h}	0.09±0.01^{ab}
75	0	16.98^{d}±0.62	3.75^{i}±0.33	77.91^{a}±0.32	0.39^{ij}±0.01	0.97±0.00 ^{bc}	784.14±1.58^{a}	74.86±0.14^{a}	4.82±0.00^{a}	0.06±0.00 ^{defg}

Mean scores ± standard deviation of physical-chemical properties of mayonnaise samples. Means followed by different superscript letters in the same column are significantly different ($p < 0.05$)

All of the mayonnaises' physico-chemical characteristics were meaningfully different at $p \leq 0.05$ on the interactions between oil and mucilage levels (table 7). Because chia seeds are high in proteins, the combination of 15% oil and 60% chia mucilage produced the highest protein levels, which in turn increased the final product's protein content. For all oil levels, the protein content rose as the amount of chia mucilage increased. In comparison to the control, the combination of 15% oil and 15% mucilage produced the highest carbohydrate concentration. Since stability is dependent on the proportions of the dispersed phase to the continuous phase, emulsion stability rose as oil levels rose, reaching its maximum in the complete fat sample (Zanjani *et al.*, 2019). Control had the highest calorie value as amount of fat is directly proportional to calorie levels.

Table 8: Correlation coefficient for the different physicochemical properties of mayonnaise analogue

	Protein	**CHO**	**Fat**	**Mc**	**ash**	**Calories**	**Emulstab**	**pH**	**TA**
protein	1.00	-0.29**	-0.50***	0.67***	0.01	-0.51***	-0.39**	0.32**	0.15*
CHO		1.00	-0.68***	0.37**	-0.49***	-0.65***	-0.36**	-0.45***	-0.07 ns
Fat			1.00	-0.83***	0.44***	0.99***	0.62***	0.17*	-0.05 ns
Mc				1.00	0.44***	-0.83***	-0.82***	0.006	0.19 ns
Ash					1.00	-0.50***	-0.14 ns	0.11*	0.02 ns
calories						1.00	0.62***	0.17**	-0.05 ns
emulstab							1.00	0.005 ns	-0.004 ns
pH								1.00	0.05 ns
TA									1.00

Key: ***significant at $p < 0.001$, **significant at $p < 0.01$, *significant at $p < 0.05$, ns: Not significant at $p < 0.05$.

Table 8 demonstrates that the strongest correlation (r=0.99) was found between fat and calories, with an increase of one unit in fat content translating into a 99% increase in calories. Because fat has nine calories per gram, it is the most calorie-dense macronutrient. As a result, fat content directly affects calorie content. The smallest connection (r=0.0042) was found between TA and emulsion stability. There was a significant inverse relationship between moisture and fat content. This uses the fact that a one-unit increase in moisture content resulted in an 83% decrease in fat content. Positively correlated elements suggest that raising the intensity of any one of the parameters would inevitably raise the correlated parameter and vice versa (Appendix 2).

4.2 Effects of oil and mucilage levels on textural properties of mayonnaise

The textural properties of the mayonnaise samples are shown in Table 9. The viscosity and adhesiveness of the mayonnaise significantly decreased ($p < 0.05$) as the oil substitution levels increased, however there was no significant difference in the hardness ($p > 0.05$). Both oil and mucilage levels has similar effect of hardness across all the treatments. The product's hardness, which rises with the force needed for penetration, is its resistance to deformation or breaking. Higher emulsion hardness makes it more difficult for the mouth to break up and swallow the sample. It is well known that mayonnaise hardness is increased by the network-structured interactions between proteins and oils (Mohammed *et al.*, 2022). Full fat mayonnaise made with sunflower oil at 75% and 0% mucilage level had the highest adhesiveness and cohesive force values.

The results clearly indicates that viscosity increased with increasing oil levels and was significantly different across all the samples at ($p< 0.05$). Higher oil content generally results in a thicker and more viscous product, and this viscosity contributes to the adhesiveness. On the other hand, the highest consistency were noted in fat reduced mayonnaise formulated with sunflower oil at 30% and mucilage at 15% level.

The fat reduced samples had significant higher consistency at ($P \leq 0.05$) than the control. The inclusion of hydrocolloid gums causes a gel-like structure that traps oil droplets, slows down their motion, and raises the emulsion's viscosity. Because gum forms a strong gel-like structure in the continuous phase, it may make the emulsion more elastic. Due to a decreased coalescence process during emulsification, this produces an extremely sticky and solid structure and smaller oil droplet diameters (Worrasinchai *et al.*, 2005). The inclusion of hydrocolloid gums to the FR formulations most likely increased the emulsion's viscosity, which is what led to this outcome.

Table 9: Effects of oil and mucilage levels on textural properties of full fat and fat reduced eggless mayonnaise

Oil levels	Hardness(N)	Cohesiveness(N)	Adhesiveness	Consistency	Viscosity
15	$0.11^{a} \pm 0.00$	$0.08^{d} \pm 0.01$	$3.47^{b} \pm 0.08$	$0.05^{c} \pm 0.00$	$1640^{e} \pm 97.36$
30	$0.11^{a} \pm 0.00$	$0.09^{c} \pm 0.01$	$3.12^{d} \pm 0.11$	$0.74^{a} \pm 0\ .37$	$2180^{d} \pm 0.00$
45	$0.11^{a} \pm 0.00$	$0.10^{b} \pm 0.01$	$3.06^{de} \pm 0.10$	$0.05^{c} \pm 0.00$	$2320^{c} \pm 297.80$
60	$0.11^{a} \pm 0.00$	$0.09^{c} \pm 0.01$	$3.22^{c} \pm 0.16$	$0.05^{c} \pm 0.00$	$2843^{b} \pm 341.25$
75	$0.11^{a} \pm 0.00$	$0.14^{a} \pm 0.01$	$3.86^{a} \pm 0.21$	$0.06^{b} \pm 0.00$	$2863^{a} \pm 0.00$
Mucilage levels					
0	$0.11^{a} \pm 0.00$	$0.14^{a} \pm 0.01$	$3.86^{a} \pm 0.21$	$0.06^{b} \pm 0.00$	$2863^{a} \pm 0.00$
15	$0.11^{a} \pm 0.00$	$0.10^{bc} \pm 0.01$	$3.27^{c} \pm 0.16$	$0.74^{a} \pm 0.37$	$2109^{c} \pm 0.00$
30	$0.11^{a} \pm 0.00$	$0.11^{b} \pm 0.01$	$3.01^{d} \pm 0.13$	$0.05^{bc} \pm 0.00$	$2484.25^{b} \pm 425.36$
45	$0.11^{a} \pm 0.00$	$0.08^{c} \pm 0.00$	$3.28^{c} \pm 0.10$	$0.05^{bc} \pm 0.00$	$1486.75^{d} \pm 288.40$
60	$0.11^{a} \pm 0.00$	$0.07^{cd} \pm 0.00$	$3.31^{b} \pm 0.08$	$0.05^{bc} \pm 0.00$	$1372.50^{e} \pm 306.96$

Values are means ± SD. Values with different superscripts in rows are significantly ($p < 0.05$) different

Generally, all the FR samples had a lower adhesiveness ranging from 3.01 to 4.47 as compared to FFM with highest level of 3.86. Texture variations in mayonnaise have been linked to emulsification strength and droplet size, as reported in prior studies (Olsson *et al.*, 2018). The size of mayonnaise droplets has been suggested to have an inverse relationship with sensory attributes like adhesiveness and hardness, (Maruyama *et al.*, 2007). The enlarged contact surface area among oil droplets in mayonnaise has been associated with increased friction, contrary to the free flow during shearing, thereby enhancing adhesiveness. Due to the superior emulsifying activity of lecithin in egg yolk compared to chia mucilage, substituting chia mucilage for egg yolk alters the oil-in-water structure and enlarges mayonnaise droplets (Golchoobi *et al.*, 2016). This increase in droplet diameter reduces the contact surface area between oil droplets, leading to decreased adhesiveness. Additionally, the diminished adhesiveness in mayonnaise can be explained by considering the active viscoelastic parameters. Chia mucilage substitution for egg yolk elevates the moisture content in mayonnaise, resulting in reduced apparent viscosity ultimately leading to a decrease in mayonnaise adhesiveness (Olsson *et al*., 2018).

Table 10: Correlation coefficient for the different textural properties of mayonnaise

	Hardness	Cohesiveness	Adhesiveness	Consistency	Viscosity
Hardness	1.000	-0.530**	0.479**	0.078ns	0.367*
Cohesiveness		1	-0.950***	0.764***	-0.819***
Adhesiveness			1	-0.749***	0.721***
Consistency				1	-0.704***
Viscosity					1

Key: ***significant at $p < 0.001$, **significant at $p < 0.01$, *significant at $p < 0.05$, ns: Not significant at $p < 0.05$

Table 10 represents the correlation coefficients for the different textural properties of mayonnaise. When the intensity of any one of the parameters increases, the correlated parameter also increases, and vice versa, according to elements with positive correlation. Cohesion and consistency had the strongest association (r = 0.76), increasing cohesiveness content by one unit increased consistency by 76%. This was closely followed by a positive correlation between adhesiveness and viscosity. This phenomenon can be contributed to by the viscous mayonnaise which tends to have higher adhesiveness, meaning it sticks better to surfaces. The correlation between hardness and consistency was reported to be the weakest (r=0.078). There was a strong negative correlation existing between cohesiveness and adhesiveness (r= -0.95). This implies that increasing cohesiveness by one unit reduced the adhesiveness by 95%. This could be attributed to the balance between the emulsifying agents and the oil-water ratio. When mayonnaise may have a lower cohesiveness, leading to a looser or less stable internal structure. Equally, a mayonnaise with higher cohesiveness may hold together well internally but might not stick as effectively to surfaces.

4.3 Microbial quality of mayonnaise samples selected for sensory analysis

The results for microbial analysis for mayonnaise samples used for sensory as presented in Table 11. Four mayonnaise formulations and a control were chosen from the population based on the intended physicochemical characteristics, which include a higher protein and carbohydrate content and a lower fat and calorie content. Products with desired textural qualities, such consistency and viscosity, also had an impact on the choice.

Table 11: Microbial counts on mayonnaises samples

Treatments	**TVC(CFU/g)**	**Yeast and molds(CFU/g)**	**Coliforms (CFU/g)**	**Salmonella (CFU/g)**
ABC(control)	<50	<15	ND	ND
LNM	<50	<10	ND	ND
MLG	<50	<10	ND	ND
FGI	<50	<10	ND	ND
CBE	<50	<10	ND	ND

Key: CBE-30% oil, 15% mucilage, MLG- 60% oil, 30% mucilage, LNM- 45% oil 30% mucilage FGI- 45% oil 15% mucilage and ABC (control)- 75% oil, 0% mucilage. ND= not detectable

Because fat reduced mayonnaises did not contain egg yolks, which are more prone to microbial contamination, their yeast and mold counts were considerably different from the control sample ($P < 0.05$), but the total viable counts of mayonnaises with the desired textural properties were similar to the control sample at ($P > 0.05$). Salmonella/25g = nil, Listeria monocytogens/25g = nil, aerobic plater counts (APC)<100 CFU/g, and yeast and mold counts (YMC)<100 CFU/g are the standards for emulsified sauces as mayonnaise products established up by FDA Circular No. 2013-010 II 2013. Furthermore, the Codex Alimentarius Commission, in collaboration with the FAO and WHO (CX/NEA 03/16), established the following standards for mayonnaise: APC <10000cfu/g, coliforms <100cfu/g, YMC< 100cfu/g, Salmonella= nil, and Escherichia coli= nil. Since the levels were below the predetermined thresholds, there was no doubt regarding the microbiological quality of any of the mayonnaise samples. The product's high acidity (pH of roughly 4.0), which is corrected by adding acetic and citric acid to the aqueous phase, is the cause of the low levels since it creates an environment that is not conducive to the growth of the aforementioned bacteria. This is also a result of mayonnaise's high fat and low water content. (Lin *et al.*, 2014). Salmonella was not detected as the egg yolk used was pasteurized at 65°C for 5mins. There were no coliforms detected due to good hygienic practice used during production and aseptic packaging of the products.

4.4 Effects of oil and chia mucilage levels on consumer acceptability of mayonnaise

4.4.1 Effects of oil and mucilage levels on consumer acceptability test

Table 12 shows scores of the sensory attribute for consumer acceptability of mayonnaise samples. Sample CBE (15% mucilage, 30% oil) was most preferred while MLG was least preferred followed closely by ABC (control). The eggy flavor in the control led to its low acceptable despite having very high colour intensities which most consumers prefer. The control sample (ABC) had a better color than the mayonnaise samples that contained gum Arabic and chia mucilage. Carotenoids found in egg yolks are primarily responsible for mayonnaise's yellow hue (Abu-Salem and Abou-Arab, 2008). In contrast to the yellow hue of full-fat mayonnaise, chia mucilage and gum Arabic had no significant effect on the color of fat-reduced mayonnaise, making it more responsive to assessors. Salt, vinegar, and spices (cardamon, mustard, and white pepper) are said to be responsible for the unique flavor. Because vinegar is a component of mayonnaise, it has a sour flavor (Abu-Salem & Abou-Arab, 2008). The RFM produced a product with the desired texture and viscosity because of the occurrence of gum Arabic, which has stabilizing and emulsifying qualities.

Table 12: Consumer acceptability test for formulated eggless reduced fat mayonnaise prepared using chia mucilage and gum Arabic

Samples	Viscosity	Colour	Smell	Flavor	Texture	Taste	Overall acceptability
ABC(control)	$7^{a} \pm 0.22$	$7.09^{a} \pm 0.21$	$5.09^{d} \pm 0.28$	$5.16^{c} \pm 0.26$	$5.96^{b} \pm 0.31$	$5.47^{c} \pm 0.3$	$5.87^{bc} \pm 0.27$
CBE	$6.51^{b} \pm 0.22$	$5.93^{b} \pm 0.21$	$6^{a} \pm 0.21$	$5.96^{a} \pm 0.22$	$6.64^{a} \pm 0.22$	$6.24^{a} \pm 0.21$	$6.47^{a} \pm 0.19$
FGI	$6.36^{bc} \pm 0.17$	$5.87^{b} \pm 0.21$	$5.8^{b} \pm 0.21$	$5.64^{b} \pm 0.17$	$5.93^{b} \pm 0.2$	$5.73^{bc} \pm 0.19$	$5.98^{b} \pm 0.15$
LNM	$5.93^{c} \pm 0.23$	$5.64^{bc} \pm 0.22$	$5.98^{ab} \pm 0.22$	$5.76^{ab} \pm 0.17$	$5.96^{b} \pm 0.2$	$6.16^{ab} \pm 0.2$	$6^{b} \pm 0.16$
MLG	$5.6^{cd} \pm 0.17$	$5.69^{c} \pm 0.22$	$5.53^{c} \pm 0.22$	$5.44^{bc} \pm 0.23$	$5.87^{bc} \pm 0.24$	$5.58^{b} \pm 0.22$	$5.82^{c} \pm 0.19$

Values are the means (n=45) ± SD. Values with different superscript in the same column are significantly different ($p < 0.05$)

Key: CBE-30% oil, and 15% mucilage, MLG- 60% oil, and 30% mucilage, LNM- 45% oil, and 30% mucilage FGI- 45% oil and 15% mucilage and ABC (control)- 75% oil, 0% mucilage

Flavor and total acceptability had the best correlation (r = 0.78), with taste and overall acceptability coming in second (r = 0.76). It is clear that people preferred flavor and taste over general acceptability. This was explained by the addition of vinegar and citric acid, which produced sour and acidic flavors. Smell and viscosity showed the poorest association (r=0.35). A positive correlation indicates that while one attribute's intensity increased, general acceptability also increased (Table 13). Every parameter has a positive relationship with total acceptability.

Table 13: Pearson correlation coefficients for consumer acceptability test

	Viscosity	**Colour**	**Smell**	**flavour**	**Texture**	**taste**	**Overall acceptability**
Viscosity	1.00	0.58***	0.35***	0.42***	0.58***	0.42***	0.61***
Colour		1.00	0.39***	0.47***	0.50***	0.39***	0.59***
Smell			1.00	0.61***	0.44***	0.59***	0.64***
Flavor				1.00	0.58***	0.69***	0.77***
Texture					1.00	0.58***	0.74***
Overall acceptability							1.00

Key: ***significant at p < 0.001, **significant at p < 0.01, *significant at p < 0.05, ns: Not significant at p < 0.05

With the exception of gritty, lumpy, slippery, astringent, caramelized, and sweet (appendix 5), all the characteristics had a significantly positive link with overall acceptance. Because of the positive correlation, an increase in one attribute's intensity was followed by an increase in total acceptance. Conversely, a negative correlation suggests that a rise in one attribute's intensity led to a corresponding fall in another attribute. Emulsion stability and consistency showed the strongest correlation (r=0.74). This suggests that a highly stable emulsion did not undergo syneresis because it was consistent in appearance. Consistency and overall acceptability (r = 0.66), closely followed by texture qualities of viscosity and appearance attribute of consistency, also showed a strong link (r = 0.67).

It is evident that consumers' preference on overall acceptability leaned towards viscosity, consistency and emulsion stability. This was explained by the addition of gum Arabic, egg yolk, and chia mucilage, which created a stable, thick, and uniform emulsion. The association between creamlike appearance and salty flavor was the weakest (r=0.001). There was a high correlation between vinegar taste and tangy and sour (r=0.62) and (r=0.68). Since vinegar dilutes the yellow color of mustard powder rather than changing the color of mayonnaise, adding vinegar to mayonnaise results in an increase in its sour and tangy flavor while having a negative correlation with color. Additionally, there was a great correlation between color and the eggy taste (r=0.62). This phenomena is brought about by the presence of egg yolk, which gives it its yellow color and eggy flavor due to the lecithin it contains.

4.4.2 Effects of oil and mucilage levels on quantitative descriptive sensory of mayonnaise

Table 14 is the varimax rotated principal component factor loading of the mayonnaise sensory attribute used to determine the multicollinearity of the descriptors

Table 14: Varimax rotated principal component factor loading of the mayonnaise sensory attributes

	Prin1	Prin2	Prin3
Vinegar			0.64623
Eggy	0.59065		
Mustard			
Caramelized		0.62282	
Salty			
Sweet		0.72315	
Sour			0.48825
Astringent			0.46597
Tangy			0.64005
Slippery	0.52089		
Homogenous		-0.50174	
Viscous	0.77666		
Gritty		0.63238	
Firm		0.60687	
Lumpy		0.63268	
Creamy			

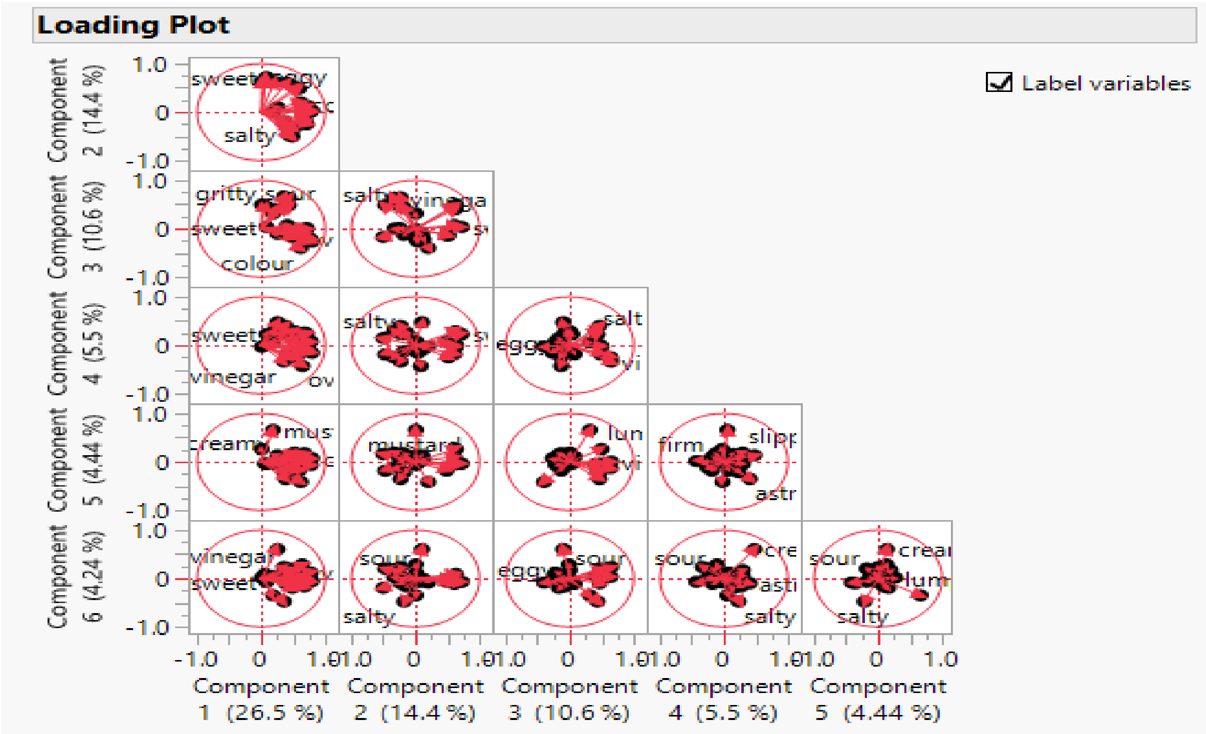

Figure 6: Loading plot of principle components

Factor one was characterized by (eggy flavor, sliperry and viscous. Factor two was related to (caramelized, sweet, homogenenous, gritty, firm, and lumpy). On the other hand, factor three was correlated to (vinegar, sour, astringent, and tangy). Factor 5 was branded as mustard while factor 6 was characterized by (salty and creamy). Table 15 summarizes the principle component analysis results of the first six principle components factor loadings of the mayonnaise sensory quality attributes.

Table 15: Principal component analysis results of the first three principle components factor loadings of the mayonnaise sensory quality attributes

Pricipal	Eigen value	Variability (%)	Cumulative (%)
Principal 1	6.62	26.5	26.5
Principal 2	3.60	14.4	40.9
Principal 3	2.65	10.6	51.5

In quantitative descriptive analysis, Principal Component Analysis (PCA) is a statistical multivariate analytical method that explains the variability in the initial data set (Borgognone *et al*., 2001). Depending on the correlation of the initial set of variables, PCA assists in reducing a set of dependent variables into factors (Ghosh & Chattopadhyay, 2012).

In decreasing order of variation, the variables are further divided into unrelated principal components. There are a lot more elements in the first principal component. Similar to descriptive sensory evaluation, PCA is crucial for connecting items and their attributes (Chapman et al., 2001). According to Mwove et al. (2018), in the multivariate space of three PC score vectors, a score plot displays the loadings of sensory attributes. Through the use of PCA characteristics of the sensory attributes of the manufactured eggless reduced fat mayonnaise, important information was extracted from the heterogeneous data and the set of correlated variables was reduced to uncorrelated measures (principal components) without compromising the original information.

Table 14 displays the loading matrix of descriptive features on principal components. The multicollinearity of the descriptors loaded on the various principal components was assessed using Varimax rotation, and Table 11 displays the table representation. As shown in Figure 6, it was determined that there was no multicollinearity between the three principal components because the descriptors were loaded on each one separately. The first three major components accounted for 51.5% of the overall variation that was observed.

26.5% came from Principal Component one, 14.4% from Principal Component two, and 10.6% from Principal Component three. In order to obtain three main components with eigenvalues greater than 1.0 and a Kaiser-Meyer-Olkin (KMO) value of 0.515, factors such as cohesiveness, adhesiveness, color, bubbles, shininess, spreadability, emulsion stability, consistency, and overall acceptability were removed during factor reduction (Figure 3). With a 0.515 KMO value, the residual sensory characteristics following factor reduction accounted for 51.5% of the treatments (i.e., raising the amounts of both chia mucilage and oil), with random error accounting for the remaining 48.5%.

Strong positive coefficients for eggy flavor (0.59), slippery texture (0.52), and viscous texture (0.78) were found in principal component one. Strong positive coefficients for caramelization (0.62), sweet (0.73), grainy (0.63), firm (0.61), and lumpy (0.63) were found in principal component two. Furthermore, for homogenous, main component two had a significant negative coefficient. Strong positive correlations were found for vinegar (0.65), sour (0.49), astringent (0.47), and tangy (0.64), according to principal component three. Sweet taste demonstrated the greatest association (0.73) among the six sensory qualities put on principle component two.

4.5 Effects of reduced oil and chia mucilage on peroxide value to predict the shelf life of mayonnaise

The sample's primary oxidation constituents, or hydroperoxides, are measured by the peroxide value (PV). At the start of the storage duration and at regular intervals throughout the ambient (25°C), high/accelerated (45°C), and cold (5°C) storage temperatures, the PV of the produced control and mayonnaise samples were calculated. As storage time extended, the PVs of oils isolated from mayonnaise products rose noticeably (Table 16).

Table 16: Peroxide values for mayonnaise samples stored under different temperatures for 21days

Samples	Hours	5ºC	25ºC	45ºC
CBE	0	0.6	0.6	0.6
	168	1.2	1.8	3.3
	336	1.5	2.9	6.6
	504	3.3	7	10.3
MLG	0	0.2	0.2	0.2
	168	1.2	2.6	5
	336	2.4	3.4	7.7
	504	4.6	8.2	11.8
LNM	0	0.5	0.5	0.5
	168	1.4	2.2	3.8
	336	2	3.3	7.4
	504	4.3	7.8	11.4
FGI	0	0.2	0.2	0.2
	168	1.1	2.2	4
	336	1.8	3.1	7.1
	504	3.8	7.6	11.1
ABC	0	0.4	0.5	0.5
	168	1.2	2.9	5.7
	336	2.6	3.9	8.5
	504	4.8	8.7	12.6

Values are means of PV of samples stored at 5ºC , 25ºC and 45ºC for 21 days

Key: CBE-30% oil, and 15% mucilage, MLG- 60% oil, and 30% mucilage, LNM- 45% oil. and 30% mucilage FGI- 45% oil, and 15% mucilage and ABC (control)- 75% oil, 0% mucilage

The rate at which PVs increased for mayonnaise samples kept at room temperature was greater than that of samples kept at a cold temperature for 21 days. None of the formulations' peroxide readings at day 0 storage differed significantly ($P<0.05$). For all samples kept under ambient, accelerated, and cold settings, between the start of the storage period at time zero and the completion of the storage period, the findings showed a statistically significant difference ($p < 0.05$), at 21 days, as PV varied with temperature and then rose with storage length.

Because peroxides break down into secondary oxidative intermediates, peroxide values in both full fat and fat reduced mayonnaise increased noticeably with higher storage temperatures. The maximum PVs of 8.7 meq/kg oil that were obtained from all the samples at room temperature fell within the acceptable bounds of the Malawian standards for PV for mayonnaise (ISO 3960 method) of 10 meq/kg oil as well as the Egyptian standard specifications (less than 15 meq.O2/kg oil). The PV indicates the degree of rancidity and provides an estimate of the oil's potential life. The physical characteristics of emulsion droplets, heat, light, the molecular composition of lipids, and processing conditions are some of the factors that influence how quickly lipids oxidize in an emulsion, (De Bruno *et al*., 2021). It displays how air, light, and time affect the oil and determines how much oxidation is brought on by each of these variables at any one moment. It is believed that oxygen attacks the -CH- group between carbon double bonds in vegetable oils, forming peroxides. When these two hydrogen atoms interact, peroxides are created. The breakdown of peroxide, which can be triggered by heat or acids, results in a variety of additional breakdown products that affect the flavor of oxidized oils—or lack thereof. This could be the outcome of triglyceride hydrolysis to free fatty acids, which could be triggered by oil moisture and the infecting microbe's lipase enzyme activity, (Parajuli *et al.*, 2022).

It was discovered that as the amount of chia mucilage increased, the lipid oxidation of the prepared mayonnaise samples decreased; that is, the lower the oil content, the lower the lipid oxidation. Lipid hydrolysis, which is aided by the presence of water, explains this phenomenon by converting triglycerides into diglycerides and monoglycerides. These compounds are prone to oxidation and typically have a negative effect on emulsion stability, increasing the stability of hydroperoxide, hydrating transition metals, facilitating the diffusion and mobilization of metals, and diluting the prooxidant (Hunsakul *et al*., 2016). Additionally, in emulsion systems, such as mayonnaise, transition metals mainly encourage oxidation by breaking down lipid hydroperoxides at the droplet surface into free radicals (Nuchi *et al*., 2021). The processes on the surface of the oil-water emulsion droplets speed up the oxidation of lipids (El-Waseif *et al.*, 2022). The membrane of emulsifier molecules that envelops emulsion droplets keeps them from clumping together and shields lipids from oxidation by obstructing the entry and diffusion of chemical species that encourage lipid oxidation into the droplets (Hunsakul *et al.*, 2016). It was clear that more chia mucilage reduced the interactions between prooxidants in the lipid and aqueous phases, which in turn reduced the amount of lipid oxidation product.

Table 17: Summary for the reaction kinetics, acceptable PV limits, PV at zero time and predicted shelf life of mayonnaise samples

Samples	k constant rate	PV at 0day	PV_{lim}	Predicted shelf life (hours)	Predicted shelf life (days)
ABC	0.0084	0.45	10	1136.904762	47.37103175
FGI	0.0079	0.20	10	1240.506329	51.68776371
CBE	0.0075	0.60	10	1253.333333	52.22222222
MLG	0.009	0.20	10	1088.888889	45.37037037
LNM	0.008	0.50	10	1187.500000	49.47916667

Key: CBE-30% oil, 15% mucilage, MLG- 60% oil, 30% mucilage, LNM- 45% oil 30% mucilage FGI- 45% oil 15% mucilage and ABC (control)- 75% oil, 0% mucilage

Figure 7 shows the predicted shelf life of mayonnaise samples used for sensory evaluation.

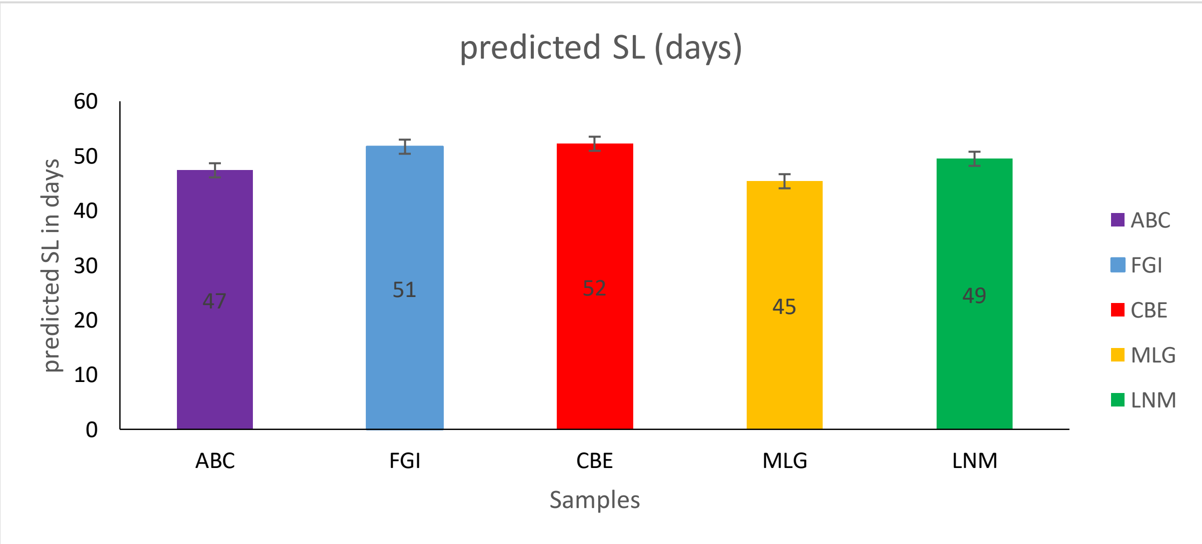

Figure 7: Predicted shelf life of mayonnaise samples

Key: SL- shelf life, CBE-30% oil, and 15% chia mucilage, MLG- 60% oil, and 30% chia mucilage, LNM- 45% oil, and 30% chia mucilage, FGI- 45% oil, and 15% chia mucilage and ABC (control)- 75% oil, 0% mucilage

The predicted shelf life of mayonnaise samples as shown on Figure 8 were ranging from 45 to 52 days with the control having 47days. Sample CBE had a prolonged predicted shelf life of 52days closely followed by FGI with 51days. The mayonnaise’s shelf life reduced with rising temperature according to the peroxide value-based shelf life analysis (Chukwu and Sadiq, 2008). Mayonnaise's susceptibility to rancidity rises due to the rise in free fatty acid levels, as shown by the peroxide value, which shortens its shelf life. Mayonnaise's storage stability is higher at room temperature than it is at refrigeration, suggesting that low temperatures improve storage stability (Pradhananga, 2011). Mayonnaise's peroxide value rose more quickly at 45°C than it did at 25°C, and climbed more quickly at 25°C than it did at 5°C. According to this, the peroxide value rises as the temperature rises. Equally, these results match the discovery of Pradhananga (2011) who found that during the storage period, mayonnaise's peroxide value increased as the temperature rose.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary

To sum up, this research work has given us information that might be applied to the value addition of emulsion foods and to the improved usage of Arabic gum in the food sector. The data from this study can also be utilized to create new products and enhance the value chain of emulsion sauces. Agronomists would be encouraged to cultivate more acacia trees since it would better their socioeconomic circumstances, and this would also increase the use of chia mucilage and gum Arabic in Kenyan enterprises.

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5.2 Conclusions

i. Varying the levels of oil and chia mucilage significantly affect physico-chemical properties of mayonnaise analogue at ($p \leq 0.05$). The results indicate that formulated eggless fat reduced mayonnaise analogue made from chia mucilage and gum Arabic greatly enhanced the textural properties of the product at ($p \leq 0.05$). Mayonnaise with 30% oil and 15% mucilage gave the highest consistency and viscosity.

ii. As compared to full fat mayonnaise with egg yolk as stabilizer, which had an unpleasant eggy flavor, the sensory quality of eggless fat reduction mayonnaise was enhanced by gum Arabic and chia mucilage because it had the desired flavor, was less oily, and tasted better. There was no discernible difference between the FF and RF mayonnaises' sensory characteristics in terms of texture.

iii. The results for microbial analysis indicated that both TVC and TMC were below detection limit while salmonella and coliform counts were not detected in any of the samples as the egg yolk used for the control was pasteurized at 65^{o}C for 5 minutes while for the coliforms the manufacture was done following good manufacturing practices, (GMP) and package was done aseptically. The predicted shelf life of the mayonnaise determined by Arrhenius equation were not significantly different.

5.3 Recommendations

i. Industries producing emulsion products to discover the utilization of gum Arabic from *Acacia Senegal var. kerensis* as an alternative stabilizer and also employ chia mucilage as fat mimetic and egg yolk substitute offering a healthier and more nutritious products to the consumers.

ii. Extraction of chia mucilage was done using a cold freeze centrifuge which produce small quantities and time consuming, a more efficient method of extraction such as ultra-filtration should be employed to maximize production.

5.4 Suggestions for further study

The predicted shelf life conducted in the research study was determined by PV as a spoilage indicator under different temperature for 21 days. I would recommend further research based on other spoilage determinations such as acidity value and microbial load for a given storage period. Additional research may be conducted to ascertain the suitability of gum Arabic in various emulsion sauces like margarine.

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APPENDICES

Appendix I: Eigen values for PCA results

Eigenvalues

Number	Eigenvalue	Percent	20 40 60 80	Cum Percent
1	6.621953	26.488		26.488
2	3.602081	14.408		40.896
3	2.649299	10.597		51.493
4	1.374937	5.500		56.993
5	1.108958	4.436		61.429
6	1.061123	4.244		65.673
7	0.913499	3.654		69.327
8	0.831074	3.324		72.652
9	0.748245	2.993		75.645
10	0.680359	2.721		78.366
11	0.643382	2.574		80.940
12	0.545751	2.183		83.123
13	0.512273	2.049		85.172
14	0.485264	1.941		87.113
15	0.445743	1.783		88.896
16	0.427145	1.709		90.604
17	0.368042	1.472		92.077
18	0.345647	1.383		93.459
19	0.335946	1.344		94.803
20	0.301712	1.207		96.010
21	0.268465	1.074		97.084
22	0.226141	0.905		97.988
23	0.190162	0.761		98.749
24	0.159647	0.639		99.387
25	0.153152	0.613		100.000

Appendix II: **ANOVA table for the effect of oil and chia mucilage and their interaction effects on physicochemical properties of mayonnaise**

Source of variation	Df	Protein	CHO	Fat	Mc	Ash	Calories	Emulstion stability	pH	TA
Oil level	4	187.677***	1690.563***	2778.993***	0.0875***	0.126***	70604.880***	1466.246***	0.0241***	0.000196**
Mucilage level	3	19.2.081***	839.832***	261.178***	0.0382***	0.235***	6962.691***	286.155***	0.0361***	0.00174***
Oil*mucilage levels	9	18.522***	19.374**	1.044ns	0.00931***	0.0337ns	28.541ns	620.455***	0.0285***	0.000798***
ER	34	1.760	5.184	3.067	0.000367	0.0177	79.298	13.904	0.0000758	0.000051
CV		7.284	7.114	3.629	3.486	13.766	1.402	8.141	0.187	10.555
R2		0.991	0.982	0.991	0.978	0.716	0.991	0.963	0.994	0.884

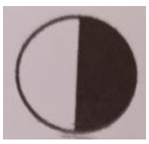
Key: ***significant at $p < 0.001$, **significant at $p < 0.01$, *significant at $p < 0.05$, ns: Not significant at $p < 0.05$

Appendix III: Pre-screening questionnaire for mayonnaise analogue quality sensory analysis

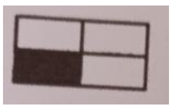
1. Name: ____
2. Phone Number: ____
3. Are there any weekdays (M-F) that you will not be available on a regular basis? ____
4. Do you have any of the following? Dentures________ Diabetes _________Oral or gum disease_________ Hypoglycemia___________Food allergies Hypertension__________
5. Do you take any medications which affect the senses, especially taste and smell? ____
6. Are you currently on a restricted diet? If yes explain. ____
7. How frequently in a month do you take mayonnaise? ______________________________
8. What is (are) your favorite food (s)? _______________________________________
9. What is (are) your least favorite food (s)? ___________________________________
10. What foods can't you eat? ____
11. What foods don't you like to eat? ____
12. Is your ability to distinguish smell and tastes: Above average________ Average_______ Below average______________
13. If a recipe calls for vinegar and there is none available, what would you substitute? ____
14. Are you conversant with food products called 'mayonnaise'? ____________________
15. How would you differentiate between flavour and aroma? ____
16. How would you define the difference between flavour and texture? ____
17. What is the best word description of cookies? ____
18. Describe some of the perceptible flavours in roasted nuts. ____
19. Describe some of the noticeable flavours in foods____

20. Is your sensitivity to textural characteristics in foods: above average___________ average_________ or below average___________
21. Describe some of the textural properties of foods in common.
22. Define some of the particles one finds in foods.
23. Describe some of the properties which are obvious when one spreads mayonnaise.
24. Describe the differences between spongy and rubbery.
25. What are some textural properties of potato chips?
26. What are some of the textural properties of biscuits?
27. What are some of the textural characteristics of toffee/eclairs?
28. For what type of foodstuffs is texture significant?
29. Instructions: Mark on the line at the right to show the percentage of the area that is shaded.

EXAMPLES



None -------------------/---------------------All



None --------/-------------------------------All

3.  None---All

4.  None--All

 None ---All

Contract

I ________________________________consent to participate in a one-week panel for a descriptive quality sensory analysis of mayonnaise.

I consent to conform to the terms and conditions.

Signature: ……………………………

Date: ……………………………

Appendix IV: **Consumer Sensory Evaluation Score Sheet**

Panelist Name………………………………… Number of Panelist…………………………….

Date……………………. Gender……………………………………….

Score sheet for a 9 Point Hedonic Scale Rating where 1=Extremely Dislike 2=dislike very much 3=dislike moderately 4=dislike slightly 5=neither dislike nor like 6=like slightly 7= like moderately 8=like very much 9= Extremely Like)

Instructions

You are presented with five coded samples randomly in individual sensory booths provided with fresh warm water to rinse their mouths after every single test. Kindly evaluate and indicate degree of liking for the products attribute listed from the left to the proper box on the right side of the table.

Attribute	CBE	ABC	LNM	MLG	FGI
Viscosity					
Colour					
Odour					
Flavour					
Texture					
Taste					
Overall Acceptability					

Appendix V: Quantitative Descriptive Analysis Score Sheet

Panelist Name ……………………………………… Date ……………………………………

Instructions

You have been assigned with coded samples, kindly evaluate and assign an appropriate score to each attribute on a 1-5 rating scale. (1=least score and 5=highest score)

Attribute	Descriptor	Description	ABC	LNM	MLG	FGI	CBE
Aromatic	Vinegar	Aroma evoked by vinegar					
	Eggy	Aroma evoked by eggs					
	Mustard	Aroma evoked by mustard powder					
	Caramelized	Aroma due to caramelization					
Taste & flavour	Salty	The basic taste that sodium chloride produces					
	Sweet	Simple taste evoked by sucrose					
	Sour	Acids like citric and acetic provide a basic taste.					
	Astringent	A feeling of drying and puckering brought on by strong black tea					
	Tangy	Sharp acidic flavor					
Texture	Slippery	Grisy and slimy in texture					
	Homogeneous	Of similar structure and composition throughout.					

	Viscous/ dense	Resistance to flow easily					
	Gritty	Rough and tough. Coarse and grainy					
	Firm	Degree of rigidity/ hardness					
	Lumpy	None smooth or uneven texture					
	Oily/ creamy	containing a lot of oil					
	Cohesive	Particles tend to agglomerate together					
	Adhesive	Tend to hold/ adhere to surface to resist separation					
Appearance	Yellow(5)-very white(1)	Colour of mayonnaise					
	Bubbles	Globule of gas in the product (emulsion)					
	Shinny	Having smooth glossy surface					
	Spreadability	Ability to easily spread for uniform application on a surface					
	Stability of emulsion	Ability to resist physicochemical changes eg separation					
	Consistency	Ability to hold together in terms of thickness and viscosity					
Overall acceptability							

Give a general comment(s)……………………………………………………………………………

………………………………………………………………………………………………
………………………………………………………………………………………………
………………

Appendix VI: **NACOSTI Research Permit**

REPUBLIC OF KENYA

NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

Ref No: 793561

Date of Issue: 13/March/2024

RESEARCH LICENSE

This is to Certify that Ms.. Lydia Apondi Odep of Egerton University, has been licensed to conduct research as per the provision of the Science, Technology and Innovation Act, 2013 (Rev.2014) in Nakuru on the topic: QUALITY PROPERTIES OF MAYONNAISE SUBSTITUTE FROM CHIA MUCILAGE (Salvia hispanica ' L.) CONTAINING GUM ARABIC FROM Acacia Senegal Var. Kerensis ON RHEOLOGICAL AND SENSORY PROPERTIES for the period ending : 13/March/2025.

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See overleaf for conditions

Appendix **VII**: **Publication abstract**

Physico-Chemical, and Sensory Properties of Mayonnaise Substitute Prepared from Chia Mucilage (*Salvia hispanica* L.) and Gum Arabic from *Acacia senegal* var. *kerensis*

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Abstract

Gum Arabic (GA) from *Acacia senegal* var. *kerensis* has been approved as an emulsifier, stabilizer, thickener, and encapsulator in food processing industry. Chia mucilage, on the other hand, has been approved to be used as a fat and egg yolk mimic. However, both chia mucilage and gum Arabic are underutilized locally in Kenya; thus, marginal reports have been published despite their potential to alter functional properties in food products. In this study, the potential use of chia mucilage and gum Arabic was evaluated in the development of an eggless fat-reduced mayonnaise (FRM). The mayonnaise substitute was prepared by replacing eggs and partially substituting sunflower oil with chia mucilage at 15%, 30%, 45%, and 60% levels and gum Arabic at 3% while reducing the oil levels to 15%, 30%, 45%, and 60%. The effect of different concentrations of oil and chia mucilage on the physicochemical properties, for example, pH, emulsion stability, moisture content, protein, carbohydrate, fats, calories, ash, and titratable acidity using AOAC methods and sensory properties for both consumer acceptability and quantitative descriptive analysis of mayonnaise were evaluated and compared to the control with eggs and 75% sunflower oil. The results indicated that all fat-reduced mayonnaises had significantly lower energy to 493 kcal/100g and 20% fat content but higher water content of 0.74 than the control with 784 Kcal/100g calories, 77% fat and 0.39 moisture. These differences increased with increasing substitution levels of chia mucilage, as impacted on pH, carbohydrate, and protein. There was no significant difference between ash content for both fat-reduced mayonnaise and control. Sensory evaluation demonstrated that mayonnaises substituted with *chia seeds* mucilage and gum Arabic were accepted. All the parameters are positively correlated to overall acceptability, with flavor having the