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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 strongest correlation of r = 0.78. Loadings from principal component analysis (PCA) of 16 sensory attributes of mayonnaise showed that approximately over 66% of the variations in sensory attributes were explained by the first six principal components. This study shows good potential for chia mucilage and gum Arabic to be used as fat and egg mimetics and stabilizers, respectively, in mayonnaise with functional properties.

Keywords

Mayonnaise, Chia Mucilage, Gum Arabic, Physicochemical, Sensory Properties

1. Introduction

Mayonnaise is a viscous oil-in-water emulsion used as condiment sauce [1] because its structure consists of dispersed oil droplets within a continuous water phase, stabilized by emulsifiers, homogenization, and stabilizers. It is used on salads, as dips, and on burgers. The emulsion is formed by slowly blending oil with a pre-mix of egg yolk, water, vinegar, and mustard to maintain a closely packed foam of oil droplets. Mixing of oil and aqueous phase at the same time results in the formation of an emulsion that easily undergoes phase inversion [2] from oil in water to water in oil. To develop reduced-fat mayonnaise that imitates the quality characteristics of traditional mayonnaise, non-fat functional ingredients such as starches, gums, and proteins are incorporated, resulting to loss of quality attribute.

Globally, North America is leading in the production and marketing of mayonnaise due to its extreme popularity in fast foods and snacks, particularly in the United States and Canada. It is closely followed by Asia Pacific, Europe, the Middle East, and South Africa. (GMMS, 2022) Mayonnaise production, consumption, and market growth are fueled by the growth in convenient food consumption and thriving fast food chains that use mayonnaise as a dip for many dishes.

Most people shun consumption of mayonnaise due to its high oil content of 65-80% [3] [4] and high cholesterol from egg yolk, which is associated with increased risk of Cardio Vascular Diseases (CVD), diabetes, obesity, and other types of cancers. Due to the high-fat content in mayonnaise and consumers' health concerns, food industries are compelled to develop low-fat products containing natural ingredients for the growing niche market and pressure from consumers. Excess consumption of high-fat and cholesterol foods leads to adverse health.

Egg yolk stabilizes emulsion by preventing flocculation, thus forming the desired texture of mayonnaise. However, the use of eggs poses the risk of salmonella species contamination and increased cholesterol [5]. According to [6], substituting egg yolk with chia mucilage reduces fat and cholesterol content and increases microbiological stability. This may also lead to greater emulsion stability, consistency, viscosity, firmness, adhesiveness, and overall acceptance. Likewise, substituting egg yolk with chia mucilage and gum Arabic as fat mimicking improves processing functionalities, emulsification stabilization, and dietary fiber [7].

Chia mucilage is a clear gel formed when *chia seeds* (*Salvia hispanica* L.) are soaked in water [8]. It is a rich source of essential fatty acids, dietary fiber, and proteins [9], therefore important in human health and nutrition. Chia mucilage is used as a thickener, gelling agent, chelator, texture modification, stabilizer, emulsifier, bulking agent, encapsulant, syneresis inhibitor, and film/ coating agent [10]. Furthermore, chia mucilage serves as a fat and egg substitute in most food products with rich ability to hydrate, increase viscosity, and maintain freshness, thus applied on salads, mayonnaise sauce, and baked products [9]. Chia mucilage is gluten free; therefore good for celiac prone individuals [9].

Gum Arabic is a dried exudate obtained from the stem and branches of *Acacia senegal*. [11]. In the food industries, gum Arabic is applied for stabilization, formation of coatings, water retention, gelling, emulsifying, and thickening. Gums are biopolymers with hydrophilic polymers which contain polar or charged functional groups of high molecular weight that have the properties to stabilize texture of emulsion and give desirable sensory properties in mayonnaise [12]. Production of gum Arabic in Kenya comes mainly from *Acacia senegal* var. *kerenesis*.

Most studies have been conducted on physiochemical and sensory properties of low-fat mayonnaise with soy milk and watermelon rind used as fat mimics. However, there are limited published reports on formulation of eggless fat-reduced mayonnaise with similar characteristics as commercial mayonnaise. Therefore, the aim of this study was to evaluate the quality properties of an innovatively produced low-fat and eggless mayonnaise substitute from chia mucilage (*Salvia hispanica* L.) and containing gum Arabic from *Acacia senegal* var. *kerensis*.

2. Materials and Methods

2.1. Materials

Eggs, sunflower oil, vinegar, mustard, salt, sugar and *chia seeds* used in preparation of mayonnaise were purchased from a supermarket in Nakuru town. Gum Arabic; *Acacia senegal* var. *kerensis* was obtained from Kenya Forestry Research Institute (KEFRI) laboratories. Physicochemical, microbial and sensory analyses were carried out in the microbiological and chemistry laboratories at the department of dairy and food science and technology, Egerton University.

2.1.1. Extraction of Chia Mucilage Gel

Chia mucilage was extracted according to [13]. The *chia seeds* were hydrated in water in the ration 1:20 w/v of *chia seeds* to water at 25˚C, stirred continuously for two hours using a stirrer to ensure effective hydration. The gel extraction was done by centrifugation at 6600 g for 50 mins at cold freeze temperature of −7˚C resulting to formation of distinguishable three layers; the top layer of seeds and excess water inclusive of soluble polysaccharides was recovered together with the bottom layer having remaining *chia seeds* and some mucilage.

2.1.2. Preparation of Mayonnaise

The water phase was prepared first by mixing all of the ingredients (chia mucilage, white vinegar, sugar, salt, gum Arabic, mustard powder, white pepper, citric acid) excluding oil in a glass bowl. The oil was then carefully mixed with water phase using a commercial blender. The control was made by slowly adding 75% oil into a premixed water phase containing egg yolk, vinegar, sugar, salt, and preferred spices. The oil was reduced from 75% to four levels of 60%, 45%, 30% and 15% and egg yolk substituted with cold freeze chia mucilage at, 60%, 45%, 30% and 15% with added gum Arabic at 3% as an emulsion stabilizer for every sample. The mayonnaise products formulated were aseptically transferred to a glass jar sealed with polypropylene film and kept under refrigeration at 4˚C for 24 hrs to avoid spoilage before tests were carried out.

2.2. Experimental Design

A CRD in a 4 × 4 factorial arrangement was employed in this study. Two variable factor of chia mucilage and oil at four levels each (60, 45, 30, 15) was used and the experiment was carried out 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, μ is the overall mean; α_i is the effect of *i*th level of chia mucilage; β_j is the effect due of *j*th level of oil; $\alpha\beta_{ij}$ is the effect of interaction between the *i*th level of chia mucilage and the *j*th level of oil; ε_{ijk} is the random error component.

2.3. Methodology

The approximate nutritional composition of mayonnaise samples, which is the moisture, fat, protein, ash, and carbohydrate content were studied in 3 replicates and corresponded to the official methods of AOAC [14]. The moisture content was determined by oven drying method; ash content was analyzed by the dry ashing method; crude protein content was analyzed by the Kjeldahl method; fat content was evaluated by the modified soxhlet method; the carbohydrate was determined by subtracting the sum of moisture, protein, fat, and ash percentages from 100%. Caloric values were calculated as: total calories = (4 × g protein) + (9 × g fat) + (4 × g carbohydrate).

pH Test

pH was measured by AOAC 2006 Method 975.03 at ambient temperature using cyber scan 500 pH meter. About 2 g of mayonnaise was weighed in a glass beaker and dissolved with 20 ml distilled water then stirred until homogeneous. Buffers of pH 4 and pH 7 and distilled water were prepared for standardization. A standardized pH meter was inserted into the sample and the reading taken.

Titratable Acidity Determination

The titratable acidity was determined using the official AOAC 2006 Method 942.15. Approximately 9ml of the samples was measured and then titrated against

0.1 N NaOH in the presence of phenolphthalein indicator. The analysis was replicated thrice. The average titre values were multiplied by 0.1 (molarity of NaOH) to get titratable acidity.

Emulsion Stability Test

Emulsion stability test of the samples was evaluated according to the method of [15] with modification. Graduated tubes each containing 10 g of sample were heated in a water bath at 80˚C for 30mins and centrifuged at 3000 rpm for 15 mins. Emulsion stability was then calculated as: (Height of emulsion layer/Height of whole layer in centrifuge tube) × 100.

Microbiological Analysis

Counts of total viable, coliforms, salmonella and yeasts and molds were carried out. Approximately 25 g of mayonnaise sample from five treatments were homogenized in 225 mL of 0.1% sterilized peptone water to obtain 10-1 dilution. This homogenate was serially diluted with 0.1% sterile peptone water and the dilutions were spread over a specific culture medium. Total Viable Counts was cultured on plate count agar, yeast and molds on potato dextrose agar, salmonella on samonella shigella agar and coliforms on MacConkey agar, each at 37˚C for 48 hrs before numeration. Colony forming units (CFU) per gram on plates were counted, at a dilution of up to 10-3.

Sensory Analysis

Consumer acceptability test

Consumer acceptability was conducted on the five mayonnaise samples after 1 day of storage at 4˚C. Forty five (45) semi trained panelists were selected as test evaluators on a 9 point hedonic scale [16]. The factors used for the evaluation included colour, smell, texture, flavour, taste, viscosity, and overall acceptability. The samples were arranged and coded with three-digit random numbers and served with bread randomly. The contents of the evaluation form were fully explained before the evaluation, and warm water was provided as palate cleanser.

Quantitative Descriptive sensory analysis

Recruitment and pre-screening of panel

Sensory training and evaluation were carried out over a period of four days by academic staff and students from Department of Dairy and Food Science and Technology, Egerton University. The introduction session was attended to by twenty persons who responded to the call who were pre-screened to undertake descriptive sensory evaluation of the mayonnaise samples. The twenty individuals were then reduced to fifteen after pre-screening process based on allergenicity to eggs, non-preference to foods which are too oily and health issues. Of the fifteen assessors, who were not allergic to mayonnaise product and were so willing to consume the formulated eggless reduced-fat mayonnaise and had an experience with sensory evaluation were selected and trained according to the following guidelines: ISO 3972, ISO8586-1, and ISO8586-2. They were then further screened for sensory acuity on identification tastes and their intensities (salty, sweet, sour, eggy). The fifteen passed the final stage and showed potential to carry out sensory evaluation. The sensory laboratory was designed according to ISO 8589 and sensory analysis performed using sensory descriptive analysis.

Training of the panel and development of lexicon

The descriptive sensory panel was trained for five days in a two-hour sessions per day, according to generic descriptive method described by [17]. During the training, each panelist described the differences between the mayonnaises twice. A lexicon was developed for the purposes of evaluation, descriptive terms and scale anchors were developed to each descriptor, defined and agreed (**Table 1**). In the training sessions, the panel developed descriptions of the perceived sensory attributes of the mayonnaise products, generating a set of attributes and developing a consensus regarding the evaluation of each attribute. Yellow color, acid taste, and eggy flavor were some of the reference materials used in training for selected attributes.

Descriptive Sensory Evaluation

The fifteen panelists were presented with five coded mayonnaise samples. The order of presentation of the samples was randomized. With reference to the training and the developed lexicon, the panel was tasked to rate the intensities of the different attributes of the samples against the lexicon provided in **Table 1**. A five-point line scale was used to measure the intensity of each attribute for a given sample. The minimum value was 1 denoting not perceived, not viscous or not shinny. The maximum point was 5 denoting strongly perceived, very viscous or very shiny.

Table 1. 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	Gradation 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 remaining 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

Continued

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

2.4. Statistical Analysis

Data was statistically processed by SAS software version 9.4 to determine the significance of individual differences using an F-test at a 5% level of significance. The mean comparison was be done using DMRT (Duncan's Multiple Range Test) at a 95% confidence interval. All experiments were performed in triplicate, and data were expressed as the mean ± SD.

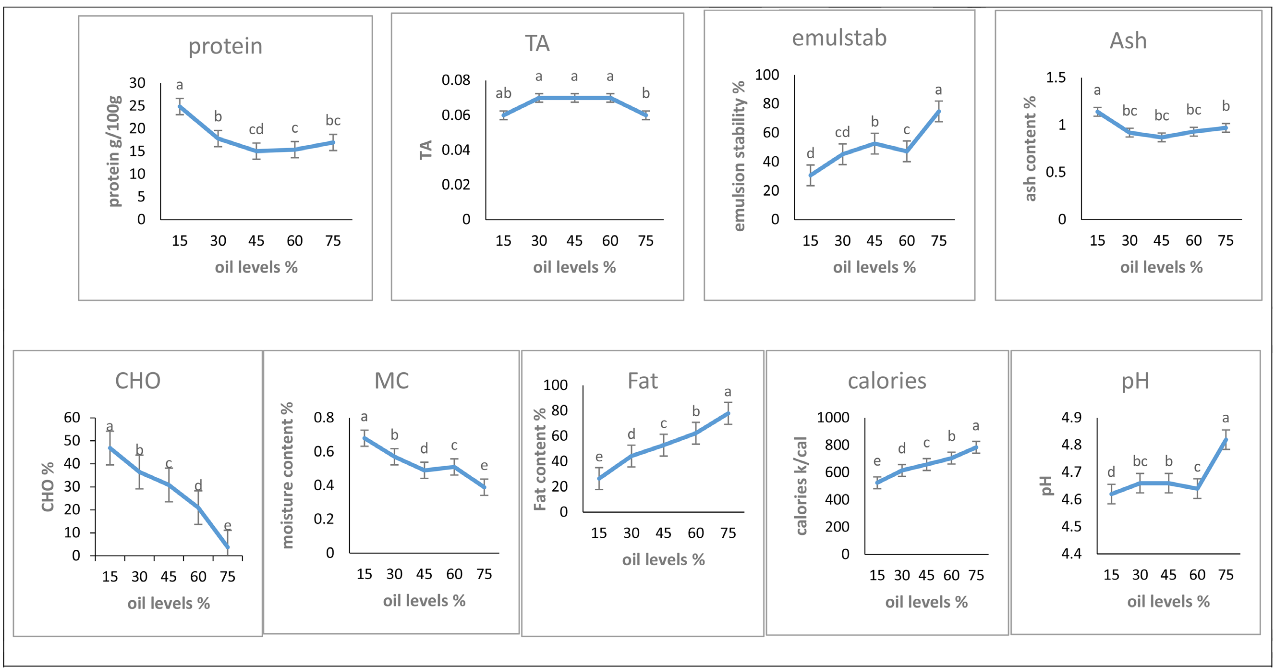
3. Results and Discussion

3.1. Effects of Oil and Chia Mucilage Levels on Physicochemical Properties of Mayonnaise

Figure 1 and Figure 2 show the effects of oil and chia mucilage levels to physical chemical parameters of mayonnaise respectively. Generally, the fat-reduced mayonnaise formulations 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 1**). Ref [2] reported that the moisture content of emulsion product increased with addition of fat replacers particularly carbohydrate or protein-based fat replacers.

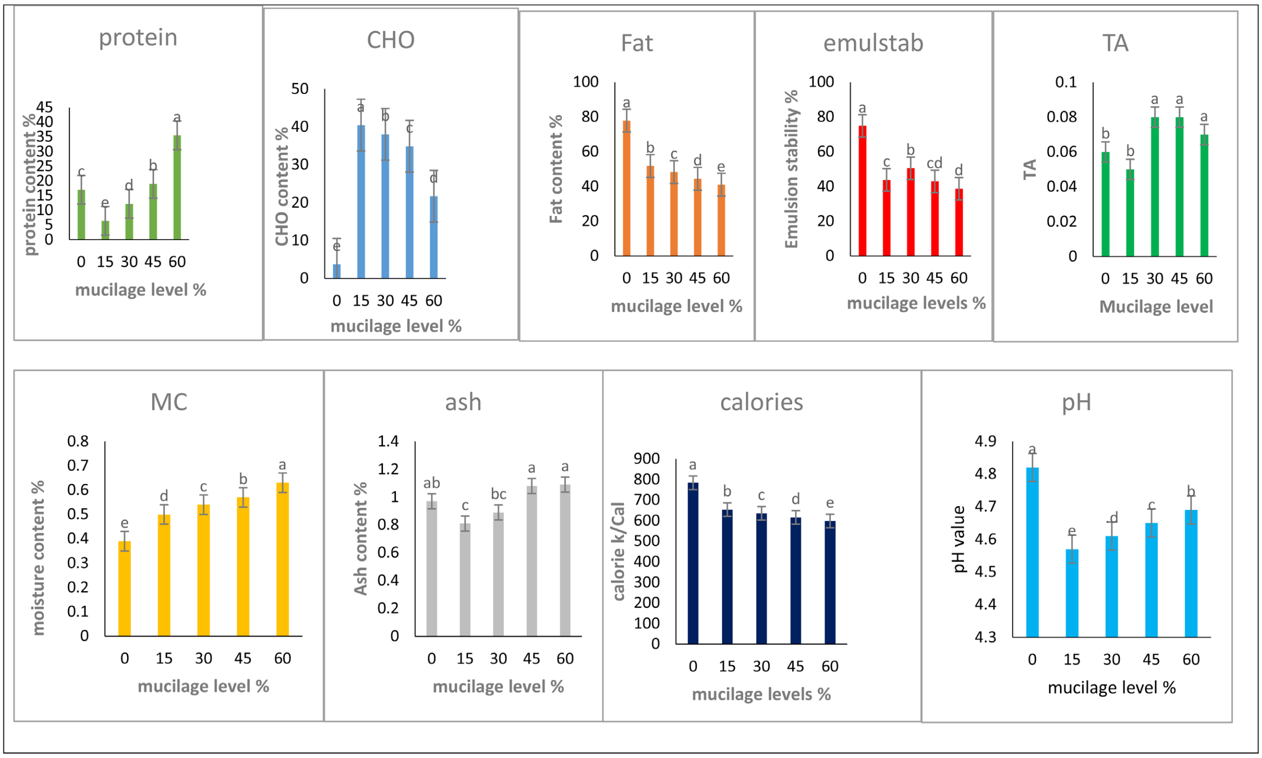
All the formulations had a lower pH related to the vinegar content, which increases the acidity and consequently decreases the pH value, [18]. The control samples had higher pH values (4.82) than formulated low-fat mayonnaise (4.62 to 4.66). This phenomenon would be explained by the undissociated acetic acid which is slightly soluble in oil, therefore, the pH of mayonnaise would increase as the percentage of oil increase, particularly after the oil reach 50% levels [16].

As the level of chia mucilage increases the pH values increase. The dilution of the acetic acid while it is in aqueous form of the fat-reduced formulations is considered to be responsible for the pH increase. Moreover, this fluctuation of pH in RF treatment could be attributed to the attractive (hydrogen bonding) and repulsive forces (electrostatic repulsion) between the polar and non- polar groups of hydrocolloids and protein. It has been reported that formation of carboxylic groups due to the breakdown of ester groups present in the structure of hydrocolloids contributed to decrease in pH [19]. 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 decrease in pH can be attributed to the increase in acidic components in the mayonnaise.



Values are means ± SD. Means with the same letters are not significantly different at $\alpha = 0.05$.

Figure 1. Effects of oil levels on physical chemical properties of fat-reduced eggless and full fat egg mayonnaises.



Means with the same letters are not significantly different at $\alpha = 0.05$.

Figure 2. Effects of mucilage levels on physical chemical properties of reduced-fat eggless and full fat egg mayonnaises.

The caloric value of the fat-reduced mayonnaise significantly ($P \leq 0.05$) reduced with increased level of fat substitution. The fat-reduced mayonnaise prepared with oil at 15% level showed the lowest ($P \leq 0.05$) caloric values among all mayonnaise formulations. The reduction in caloric values could be attributed to the substitution of oil in full fat mayonnaise with chia mucilage and hydrocolloid gums which increases the water content in the product. Further fluctuation in treatments of fat-reduced calories is due to different level of chia mucilage levels which increased with decreased levels of chia mucilage. Fat is more calorie-dense than other macronutrients, like carbohydrates or proteins. Even if fat is substituted with chia mucilage, chia mucilage may not provide the same caloric density as oil, resulting in a lower overall calorie content in the fat-reduced mayonnaise.

The carbohydrate contents in fat-reduced samples were significantly higher ranging from 46.87% to 20.97% than the full fat samples with 3.75% at $p \leq 0.5$. This phenomenon could be explained by addition of carbohydrate base stabilizers and emulsifiers in this case, gum Arabic and chia mucilage that were added in the fat-reduced mayonnaise thus attributing to final higher carbohydrate content. This was attributed to by the side chains of gum Arabic, which increased the proportion of carbohydrates [20].

The control had a higher emulsion stability of about 75% as compared to the reduced-fat samples which had a lower emulsion stability ranging from 38% to 51%. The use of a higher oil result in good emulsion stability, but if the amount of oil is reduced, the emulsion stability is affected [21]. This is because stability depends on the relative size of the fat phase to the aqueous phase [4]. The stability of fat-reduced mayonnaise was due to increase in the viscosity of the continuous phase and the formation of a weak gel network due to the addition of gum [20]. The use of gum increases stability as fat droplets are flocculated while creaming does not occur in fat-reduced mayonnaise due to increased viscosity of the continuous phase and reduced movement of the fat droplets [6]. Emulsion stability often decreases with a decrease in viscosity [22].

Effects of interaction between oil and mucilage levels on physical chemical parameters of mayonnaise

Table 2 below shows the effects of interaction between oil and mucilage levels on physico-chemical properties of full fat and fat-reduced eggless mayonnaise.

Full fat mayonnaise had significantly higher fat contents of about 78% as compared to fat-reduced mayonnaise which ranged from 41% to 52% fat. All reduced-fat treatments showed notably decrease in fat due to increase in level of chia mucilage which was used to replace the fat. The fat content of mayonnaise is influenced by the use of vegetable oils, emulsifiers, and the treatment given [21]. Overall increase in protein was noticed in all fat-reduced treatments. Control treatment had a significantly lower protein value as compared to other fat-reduced treatments with 45% oil and 60 % mucilage having the highest protein content because of 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. A slight significant differences was observed for ash values, this might be attributed to the types and levels of the fixed components in all treatments except for the fat and chia mucilage whose levels were varying.

Table 2. Effects of interaction between oil and mucilage levels on physical chemical properties.

Oil level %	Mucilage level %	Protein %	Carbohydrate %	Fat %	MC %	Ash %	Calories %	Emulsion stability %	Ph	TA
15	15	9.35 ± 0.15^{e}	56.76 ± 0.64^{a}	32.36 ± 0.56^{j}	0.61 ± 0.01^{cde}	0.93 ± 0.06^{bc}	555.65 ± 2.90^{j}	37.83 ± 1.17^{ghi}	4.42 ± 0.01^{k}	0.04 ± 0.00^{g}
	30	16.95 ± 1.78^{d}	53.16 ± 2.16^{a}	28.22 ± 0.40^{jk}	0.69 ± 0.00^{ab}	0.98 ± 0.02^{bc}	534.451 ± 2.04^{jk}	31.72 ± 1.64^{hij}	4.68 ± 0.00^{de}	0.10 ± 0.01^{a}
	45	28.26 ± 0.55^{c}	45.03 ± 3.49^{b}	24.79 ± 3.51^{kl}	0.67 ± 0.00^{bc}	1.26 ± 0.13^{ab}	516.26 ± 18.04^{kl}	25.84 ± 3.33^{jk}	4.72 ± 0.00^{c}	0.06 ± 0.00^{defg}
	60	44.88 ± 1.51^{a}	32.52 ± 1.48^{de}	20.46 ± 0.98^{l}	0.74 ± 0.00^{a}	1.39 ± 0.00^{a}	493.78 ± 4.91^{l}	27.39 ± 1.24^{ijk}	4.67 ± 0.01^{def}	0.05 ± 0.00^{efg}
30	15	5.82 ± 0.36^{ef}	44.18 ± 0.28^{bc}	48.72 ± 0.38^{g}	0.47 ± 0.01^{gh}	0.80 ± 0.00^{c}	638.54 ± 1.87^{fg}	55.36 ± 1.52^{bcde}	4.64 ± 0.00^{fg}	0.06 ± 0.00^{defg}
	30	14.50 ± 0.29^{d}	37.48 ± 1.05^{d}	46.67 ± 0.77^{gh}	0.56 ± 0.00^{ef}	0.79 ± 0.00^{c}	627.97 ± 3.87^{gh}	48.00 ± 2.00^{defg}	4.56 ± 0.01^{i}	0.08 ± 0.00^{bcd}

Continued

	45	18.04 ± 0.64^{d}	38.06 ± 0.62^{cd}	42.24 ± 0.06^{hi}	0.62 ± 0.00^{cd}	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 ± 0.60^{b}	26.15 ± 1.55^{ef}	39.13 ± 0.80^{i}	0.63 ± 0.01^{cd}	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 ± 0.13^{f}	35.82 ± 0.38^{d}	58.66 ± 0.32^{de}	0.36 ± 0.00^{j}	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 ± 0.07^{e}	36.14 ± 0.43^{d}	54.00 ± 0.36^{ef}	0.48 ± 0.00^{gh}	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 ± 0.36^{d}	33.04 ± 0.63^{d}	50.50 ± 0.61^{fg}	0.52 ± 0.01^{fg}	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 ± 0.27^{b}	18.18 ± 0.49^{g}	47.96 ± 0.45^{g}	0.59 ± 0.00^{de}	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 ± 0.02^{ef}	25.13 ± 0.79^{f}	67.49 ± 0.82^{b}	0.56 ± 0.01^{ef}	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 ± 0.28^{e}	25.34 ± 0.33^{f}	64.32 ± 0.26^{bc}	0.42 ± 0.01^{hi}	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 ± 1.55^{d}	23.44 ± 1.99^{fg}	60.35 ± 0.55^{cd}	0.49 ± 0.04^{g}	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 ± 0.30^{bc}	9.97 ± 0.38^{h}	56.63 ± 0.50^{de}	0.57 ± 0.00^{ef}	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 ± 0.62^{d}	3.75 ± 0.33^{h}	77.91 ± 0.32^{a}	0.39 ± 0.01^{ij}	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 ($p < 0.05$).

The interactions between oil and mucilage levels, Table 2 showed that all the physico-chemical properties of the mayonnaises were significantly different at $p \leq 0.05$ across. The interaction between 15% oil, 60% chia mucilage gave the highest protein levels as *chia seeds* are rich in proteins contributing to higher protein content in the final product while 15% oil, 15% mucilage gave highest carbohydrate content compared to control. Emulsion stability increased with increasing oil levels thus highest in the full fat sample as stability depends on the relative size of the fat phase to the aqueous phase [4].

Table 3 below shows means values for the effect of oil and mucilage levels and their interaction effects on physico-chemical properties of mayonnaises.

The interactions between oil and mucilage levels have significant effects on protein, carbohydrate, moisture, emulsion stability, pH and TA. Oil and mucilage levels had significant effects across all the physicochemical properties of mayonnaise products.

Table 4 represents the correlation coefficients for the different physical-chemical parameters. The strongest correlation existed between fat and calories ($r = 0.99$), increasing fat content by one unit increase calories by 99%. This is because fat is the most calorie-dense macronutrient, providing 9 calories per gram thus amount of fat directly contributes to calorie content. The correlation between emulsion stability and TA was reported to be the weakest (r = 0.0042). There was a strong negative correlation existing between moisture content and fat. This employs that increasing moisture content by one unit reduced the fat content by 83%. This was attributed by the fact that moisture content level in the formulated mayonnaise with chia mucilage increased significantly since the reduction of oil level is compensated by raising the moisture level [23]. Elements with positive correlation implies that an increase in the intensity of any of the parameters would consequently cause an increase in the correlated parameter and vice versa.

Table 3. ANOVA table for the effect of oil and mucilage and their interaction effect on physical-chemical properties of mayonnaise.

Source of variation	Df	Protein	CHO	Fat	Mc	ash	Calories	Emulsion 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**	1.044^{ns}	0.00931***	0.0337^{ns}	28.541^{ns}	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
R^2		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.

Table 4. Correlation coefficient for the different physical chemical properties Pearson Correlation Coefficients, N = 51 Prob > |r| under H0: Rho = 0.

	Protein	CHO	Fat	Mc	ash	Calories	Emulsion stability	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 5 shows microbial counts of mayonnaise samples used in the sensory evaluation. Four formulated mayonnaises together with control were selected from the population based on desired physicochemical properties that is reduced-fat and calories with increased protein and carbohydrates content. The selection was also influenced by products with desired textural properties such as consistency, and viscosity.

Table 5. 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.

The total viable counts of formulated mayonnaises with desired textural properties were similar to the control sample at ($P > 0.05$), but the yeast and mold count of fat-reduced mayonnaise was significantly different from the control sample ($P < 0.05$) as they did not contain egg yolks, which are more susceptible to microbial contamination. FDA Circular No. 2013-010 II 2013, standard for emulsified sauce as mayonnaise products set up aerobic plater counts (APC) < 100 CFU/g, yeast and moulds counts (YMC) < 100 CFU/g, salmonella/25 g = nil and Listeria monocytogens/25 g = nil. In addition, Codex Alimentarius Commission, joint FAO and WHO CX/NEA 03/16, [24] set the mayonnaise standard as APC < 10000 cfu/g, coliforms < 100 cfu/g, YMC < 100 cfu/g, Escherichia coli = nil and Salmonella = nil. Therefore, there was no doubt on the microbiological quality of all the mayonnaise samples since the levels were lower than the set levels. The low levels are attributed to by the high acidity of the product at pH about 4.0 as adjusted with addition of acetic and citric acid in the water phase which forms unfavorable conditions for the above microorganisms to thrive. This is also due to high-fat and low water content in mayonnaise [25]. Salmonella was not detected as the egg yolk used was pasteurized at 65˚C for 5 mins. There were no coliforms detected due to good hygienic practice used during production and aseptic packaging of the products.

3.2. Effects of Oil and Chia Mucilage Levels on Sensory Attributes of Mayonnaise

Table 6. Sensory attribute scores 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	$5.6^{cd} \pm 0.17$	$5.69^{c} \pm 0.22$	$5.53^{c} \pm 0.22$	$5.44^{bc} \pm 0.23$	$5.87^{b} \pm 0.24$	$5.58^{b} \pm 0.22$	$5.82^{c} \pm 0.19$

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.

Sample CBE (15% mucilage, 30% oil) was most preferred while MLG was least preferred followed closely by ABC (control) led to its low acceptable despite having very high colour intensities which most consumers prefer (**Table 6**). The colour of the control sample (ABC) was better than the mayonnaise samples with chia mucilage and gum Arabic. The yellow color of mayonnaise is mainly attributed to egg yolk carotenoids [26]. Chia mucilage and gum Arabic did not impact colour on reduced-fat mayonnaise rendering it more receptive to assessors compared to the yellow color of FFM. The distinct flavour is attributed to by salt, vinegar, and spices (mustard, white pepper, cardamon). Mayonnaise has a sour taste due to the presence of vinegar in its composition [26]. Presence of gum Arabic with its emulsifying and stabilizing properties in the RFM resulted in a product with a desirable texture and viscosity.

Table 7. Pearson Correlation Coefficients of consumer sensory attributes Prob > |r| under H0: Rho = 0.

	Viscosity	Colour	Smell	Flavour	Texture	Taste	Overall acceptability
Viscosity	1	0.58***	0.35***	0.42***	0.58***	0.42***	0.61***
Colour		1	0.39***	0.47***	0.50***	0.39***	0.59***
Smell			1	0.61***	0.44***	0.59***	0.64***
Flavour				1	0.58***	0.69***	0.77***
Texture					1	0.58***	0.74***
Taste						1	0.76***
Overall acceptability							1

Key: *** significance at ($p < 0.001$).

Table 7 represents the correlation coefficients for the different sensory attributes scores. The strongest correlation existed between flavour and overall acceptability (r = 0.78) closely followed by taste and overall acceptability (r = 0.76). It is evident that consumers' preference on overall acceptability leaned towards flavour and taste. This was attributed by the sour and acidic flavours due to addition of vinegar and citric acid. The weakest correlation was observed between smell and viscosity (r = 0.35). The positive correlation means that an increase in the intensity of one attribute led to subsequent increase in overall acceptability (**Table 7**). All the parameters are positively correlated to overall acceptability.

Effects of Oil and Mucilage Levels on Quantitative Descriptive Sensory of Mayonnaise

The different quantitative descriptive for sensory attributes scores of mayonnaise were correlated. The correlation coefficients showed that all the parameters are significantly positively correlated at ($p = 0.05$) to overall acceptability except for gritty, lumpy, slippery, astringent, caramelized and sweet. The positive correlation means that an increase in the intensity of one attribute led to subsequent increase in overall acceptability. On the other hand, a negative correlation implies that an increase in the intensity of one attributes caused a consequent decrease in another attribute. The strongest correlation existed between emulsion stability and consistency (r = 0.74). This implies that an emulsion with strong stability was consistence in regarding appearance thus did not undergo syneresis. Textural properties of viscosity and appearance attribute of consistency had also a strong correlation of (r = 0.67) closely followed by consistency and overall acceptability (r = 0.66). It is evident that consumers preference on overall acceptability leaned towards viscosity, consistency and emulsion stability. This was attributed to by the stable, viscous and consistent emulsion brought by addition of gum Arabic, egg yolk and chia mucilage. The weakest correlation was observed between salty taste and dreamy appearance (r = 0.001). Vinegar taste strongly correlated to sour and tangy at (r = 0.62) and (r = 0.68). Addition of vinegar to mayonnaise subsequently causes increase in sour and tangy taste while it negatively correlates to colour because addition of vinegar does not impact on the colour of mayonnaise instead dilutes the yellow colour of mustard powder. Furthermore, the eggy taste strongly correlated to colour at (r = 0.62). This phenomenon is brought by presence of egg yolk which results to the eggy flavor and yellow colour contributed to by the lecithin in the egg yolk.

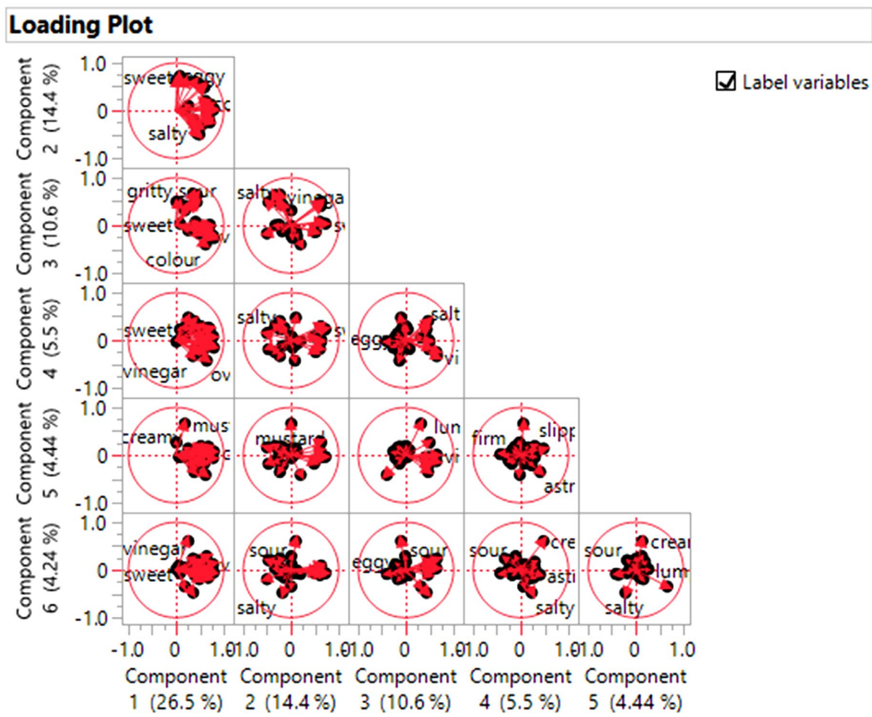


Figure 3. Loading plot of principle components.

Factor 1 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 3 was correlated to (vinegar, sour, astringent, and tangy). Factor 5 was branded as mustard while factor 6 was characterized by (salty and creamy).

Principal Component Analysis (PCA) is a statistical multivariate analytical technique used in quantitative descriptive analysis to explain the variability in the original set of data [27]. PCA helps reduce a set of dependent variables into factors, depending on the correlation of the original set of variables [28]. The factors are further categorized into unrelated principal components in the order of decreasing variation. The first principal component is loaded with more factors. PCA is essential in linking products and their attributes as in descriptive sensory evaluation [29]. Score plot represents loadings of sensory attributes in the multivariate space of two PC score vectors [30]. PCA characteristics of sensory attributes of formulated eggless reduced-fat mayonnaise was used to extract important information from the heterogeneous data, and reduce set of correlated variables to uncorrelated measures (principal components) without loss of original information. Varimax rotation was used to determine the multicollinearity of the descriptors loaded on the different principal components. The descriptors were independently loaded on the six principal components as depicted in **Figure 3** and hence the conclusion that there was no multicollinearity among the descriptors. The first six principal components accounted for approximately 66% of the total variation observed. (Principal Component 1 accounted for 26.5%, Principal Component two accounted for 14.4%, Principal Component three accounted for 10.6 %, Principal Component four accounted for 5.5 %, Principal Component five accounted for 4.44%, and Principal Component six accounted for 4.24%).

Cohesive. Adhesive, colour, bubbles, shinny, spreadability, emulsion stability, consistency and overall acceptability were eliminated on factor reduction to obtain a Kaiser-Meyer-Olkin (KMO) value of 0.6567 and 6 principal components with eigenvalues of above 1.0 (**Figure 3**). The 0.6567 KMO value meant that the remaining sensory attributes after factor reduction explained 65.67% of the treatments (that is, increasing both chia mucilage and oil levels) while the remaining 35.33% would be as a result of other factors such as random error. Principal component one had strong positive coefficients for eggy flavour (0.59), slippery texture (0.52) and viscous texture (0.78). Principal component two had strong positive coefficients for caramelization (0.62), sweet (0.73),), gritty (0.63), firm (0.61) and lumpy (0.63). Additionally PC two had a strong negative coefficient for homogeneous). Principal component three had a strong positive correlation for Vinegar (0.65), sour (0.49), astringent (0.47), and tangy (0.64). On the other hand, Principle Component five had a strong positive correlation for mustard (0.66) while PC six had a strong positive correlation for salty (0.47) and creamy (0.60). Of the six principal component, component two had the most sensory attributes loaded on compared to the other five. Of the six sensory attributes loaded on principle component two, sweet taste had taste the strongest correlation (0.73).

4. Conclusion

In conclusion, mayonnaise prepared from chia mucilage and gum Arabic showed potential use as a substitute for fats and eggs in the manufacture of mayonnaise and as a stabilizer for the emulsion, respectively. Decreasing the oil levels while increasing the mucilage level at ($p \leq 0.05$) significantly decreased calories levels from 784 kJ for control (75% oil, 0% mucilage) up to 493 kJ for (15% oil and 60% mucilage). The RF mayonnaise had higher carbohydrate content due to high dietary fiber in chia and gum Arabic, thus more nutritious and allergen free. Increasing mucilage, levels increased the moisture content and reduced the protein content. Sensory quality of eggless reduced-fat was improved by gum Arabic and chia mucilage as it had desired flavour, less oily, and improved taste as compared to FF mayonnaise with egg yolk as stabilizer, which had an unpleasant eggy flavor. Sensory parameters in terms of texture of both FF and RF mayonnaises were not significantly different. Therefore, the information provided by this research work can be used to add value chain to emulsion sauces and develop new products without changing the properties of the final product. This would also enhance utilization of chia mucilage and gum Arabic in Kenya industries, and agronomists would be motivated to grow more acacia trees as this would improve their socioeconomic lives.

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Conflicts of Interest

The authors declare that they have no conflict of interest regarding publishing of this paper.

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