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Comparative Study of the Impact of Stearin-Modified Starches from Maize, Ginger, and Sweet Potato on the Physicochemical Properties of Low-Fat Mayonnaise †

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Abstract: The utilization of modified starches derived from ginger, sweet potatoes, and maize has been employed as a strategy to reduce the oil content in mayonnaise formulations. Amylose–lipid complexes and the native starches were synthesized, characterized, and subsequently incorporated into various mayonnaise formulations, replacing 50 and 80 percent of the oil. The sensory analysis showed that the mayonnaises produced with 50% and 80% modified corn starch were particularly well received. However, when compared to conventional mayonnaises, the viscosity of the mayonnaises prepared with 50% and 80% modified maize starch was found to be remarkably low. This outcome demonstrates that when preparing low-fat mayonnaise, it is not possible to substitute tuber starches for fat.

Keywords: mayonnaise; fat substitute; viscosity measurements; ginger; maize; sweet potato

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1. Introduction

Mayonnaise is an emulsion based on egg yolk, with vegetable oil and vinegar as unavoidable ingredients. It is considered a high-calorie food, as it can contain over 70% oil [1]. It is widely used as a sauce and condiment in a variety of dishes and in most fast-food outlets [2]. Consumption of high-fat foods like mayonnaise may have a direct impact on human health through the onset of certain diseases such as cardiovascular disease, hypertension, obesity, and diabetes [3].

In view of the high fat content of mayonnaise and the health problems associated with its consumption, low-calorie alternatives have been developed due to the positive association between a high-calorie diet and lifestyle-related diseases [4]. The design of hypocaloric foods requires the use of fat replacers to mimic some of the functional properties of fat; otherwise, low-calorie foods will have inferior sensory properties [5]. Starch is a natural biopolymer which can be used as a fat substitute [6]. Cereals and tubers are sources of starch acquired through their different cultivation, structure, and functional properties [7]. It has been suggested that cereal starch is a good fat mimetic [8]. Although native starch can sometimes be used as a fat substitute, it is usually modified by physical or chemical methods for this purpose.

Indeed, native starch presents certain limitations for food use, such as low heat resistance, a strong tendency to retrograde, and a tendency to form low-bodied rubbery

gels [9]. Chemical and physical modification of starch can improve properties such as thickening, binding, mouthfeel, gelation, dispersion, or cloud formation [10]. Stearic acid has been found to modify the pasting properties of starch at a level of around 1.5% (w/w starch) and can increase pasting viscosity twice during pasting for more than 1 h [11]. D'Silva et al. [12] also found that modified cereal with added stearic acid pastes exhibited a non-gelling behavior compared to the gelling behavior of unmodified starches. Corn and teff starches modified with stearic acid could substitute oil in mayonnaise at a level of 80% [8]. However, this has been proven exclusively with cereal starches, and among these cereals, teff starches are not available locally in Cameroon. This raises the question of whether it would be possible to use another available source of starch? Hence, the aim of the present study is to compare the use of different starch sources for the development of a low-calorie mayonnaise by substituting fat with modified starches from local tubers and cereals.

2. Material and Methods

2.1. Starch Extraction

Maize, potato, and ginger were cleaned, cut into small pieces, and soaked in distilled water containing sodium metabisulfite (0.2% v/v) for 24 h while refrigerated. To extract the starch, the raw material was crushed for five minutes in an industrial mixer using a 0.2% (v/v) sodium metabisulfite solution. After homogenization, the material was sieved through 200 mesh (0.074 mm). Following a 24 h decantation period, the sample was resuspended in 0.2% sodium metabisulfite solution (v/v), and the supernatant was extracted following 12 min of centrifugation at 1105$\times$ g. The residue's surface was cleared of the mucilage that had developed there. After that, the starch residue was dried in oven at 40 °C [13]. The yield of starch was calculated according to the following formula:

$$Yields = \frac{Me(g) * 100}{Mc\ (g)} \quad (1)$$

where *Me* is the mass of dry starch after extraction and *Mc* is the mass of the raw material.

2.2. Determination of Amylose Content

An iodine binding method was used to assess the amylose content of starches [14]. A total of 5 g of starch was weighed into a 25 mL volumetric flask to the nearest 0.1 mg in order to determine the amount of amylose. Afterward, 1 mL of ethanol was used to spread the starch; then, 2.7 mL of 0.1 M NaOH was added and swirled to further enhance the dispersion. The contents were brought to a boil at 75 °C for fifteen minutes, during which the starch fully gelatinized. After cooling, distilled water was added to the flask until it reached the 25 mL threshold using a vortex mixer. Separate test tubes were used to collect duplicate 2.5 mL samples, which were neutralized with 2 mL of 0.15 M citric acid, followed by 1 mL of fresh iodine solution (0–2 g 12 + 2 g KI + 250 mL distilled water). After adding 14.5 mL of water, the sample was refrigerated for 20 min. After the tubes were combined using a vortex mixer, the duplicate subsamples' optical densities were measured at 620 nm using a spectrophotometer.

2.3. Production of Starch–Lipid Complexes

The Figure 1 shows the method of starch–lipid complex production according to D'Silva et al. (2011) [12].

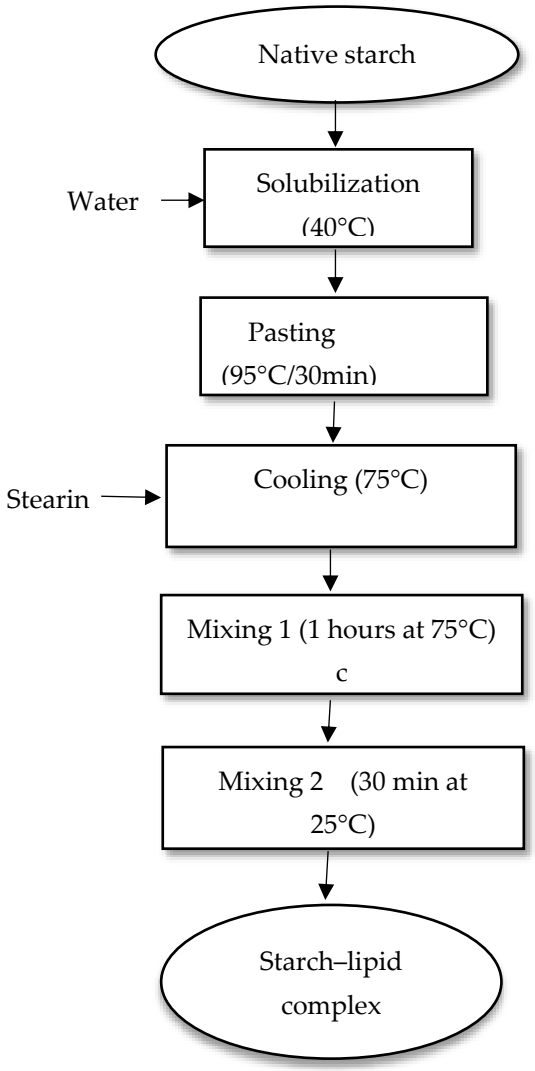


Figure 1. Method of starch–lipid complex production according to D'Silva et al. (2011) [12].

2.4. Complexation Indexes (CIs) of Amylose–Lipid Complexes

The complexation index (CI) was measured using an iodine solution to assess the degree of starch in the lipid complex formation [15]. A total of 2 g of potassium iodine and 1.3 g of I_2 were dissolved in 50 milliliters of distilled water and left to dissolve overnight to create the iodine solution utilized for the analysis. The capacity was then increased to 100 mL by adding distilled water. In a test tube, a 5 g sample of the amylose–lipid complex was combined with 25 mL of distilled water. The test tube was centrifuged at 1500× *g* for 20 min after being vortexed for two minutes. In a 15 mL test tube, distilled water (7.5 mL) was combined with the supernatant (250 µL) and 1 mL of iodine solution. At 690 nm, the absorbance was measured after the tube was vortexed. The following formula was used to determine the CI:

$$\mathrm{CI}(\%) = \frac{\text{control absorbance} - \text{sample absorbance}}{\text{control absorbance}}$$

2.5. Texture

Texture is the set of rheological and structural properties perceptible by mechanical, tactile, visual, and auditory receptors. It represents a property of the food that is perceived at a sensory level and which evolves from the moment the food is placed in the mouth until the formation of the food bolus conducive to swallowing. The parameter measured in this

work is the hardness of native starch. Hardness (H) is the force opposed by the product to the advancement of the probe. It can also be defined as the force in Newtons required to obtain a given deformation or penetration. In this work, a texturometer equipped with various probes was used. The following conditions were chosen for this test: a cylindrical probe with a diameter of 1mm, a detection force on the surface of the product of 5 g, and a probe displacement speed of 1mm/deformation of 40%.

2.6. Syneresis

Syneresis is the expulsion or rejection of water after starch cooking. The syneresis protocol was described by Gonzalez et al. [16]. A total of 10 g of native starch was mixed in 100 mL of distilled water and then heated to 90 °C for 10 min. The gel obtained was left to stand for 24 h at 4 °C and the water released was measured using a test tube or pipette.

2.7. Paste Viscosity (RVA)

Using a Rapid Visco Analyzer 4 RVA (Newport Scientific Pty Ltd., Warriewood, Australia), the paste viscosity of the starch suspension (14% moisture on a wet basis) (3 g starch in 25 mL of water) was measured. The time–temperature profile involved blending using the spoons, rotating for the first ten seconds at 960 rpm, and finishing at 160 rpm. After being heated steadily at a rate of 6 °C per minute between 50 and 90 °C, the samples were cooled to 50 °C. The maximum peak viscosity, paste temperature, rupture viscosity, final viscosity, and regress or retrograde viscosity were the values obtained from the bonding curve.

2.8. Viscosity

A BROOKFIELD DV-III rheoviscosimeter coupled to a thermostatic water bath was used to carry out the rheological analyses. A duvet geometry was observed in which a volume of 7 mL was used. The following quantities were evaluated to deduce the subsequent behavior of the pastes: the viscosity and flow curves. These viscosities were evaluated at a different shear rate of 0.4–186 s^{-1}.

2.9. Sensory Analysis

The sensory analysis is defined as incorporating the five senses (sight, hearing, smell, taste, and touch); human beings are the measuring instrument for sensory analysis methods to characterize and evaluate products. In this section, consumer preference is the focus of the study. It thus involves hedonic tests intended for naive consumers made up of 15 to 20 individuals who are in the town of Ngaoundéré. The approach used for this study is the hedonic ranking test.

The test took place in the sensory analysis room, somewhat isolated from the outside environment (sounds, people, and smells). After the instructions were explained, the subject was presented with eleven samples at the same time, which they had to classify (after tasting) in order of their preference. They had to analyze the samples in the order given and as many times as they deemed necessary to establish a ranking. Each sample was ordered in the same way, in the same quantity, and at the same temperature. They were all represented by a code. The panelists were not trained in sensory analysis. The panelists then entered the product numbers in the code section of each sheet provided.

2.10. Statistical Analysis

For the determination of the level of significance and comparison of means, statistical analysis was applied to the data that were obtained from each parameter. Experimental data were analyzed using two-way ANOVA. The significant difference between means was revealed by the LSD method. Principal component analysis (PCA) were used to plot the

sensory analysis data. The data were analyzed using Minitab 16 (manufactured by UNIFI company, headquartered in Greesboro, N.C) software to validate the outcomes of the study.

3. Result and Discussion

3.1. Sweet Potato, Maize, and Ginger Starch Production Yields

The starches were produced using successive unit operations to obtain the yields shown in Figure 2. Maize, sweet potato, and ginger starch yields vary widely. Ginger had a higher starch yield than maize and sweet potatoes. The results for maize and sweet potato starches are significantly higher than the yields of Chinese sweet potatoes varieties reported by Wang et al. [17]. The starch yield of ginger is similar to the starch yield reported by Madeneni et al. [18]. This variation may be due to genetic and environmental factors [19].

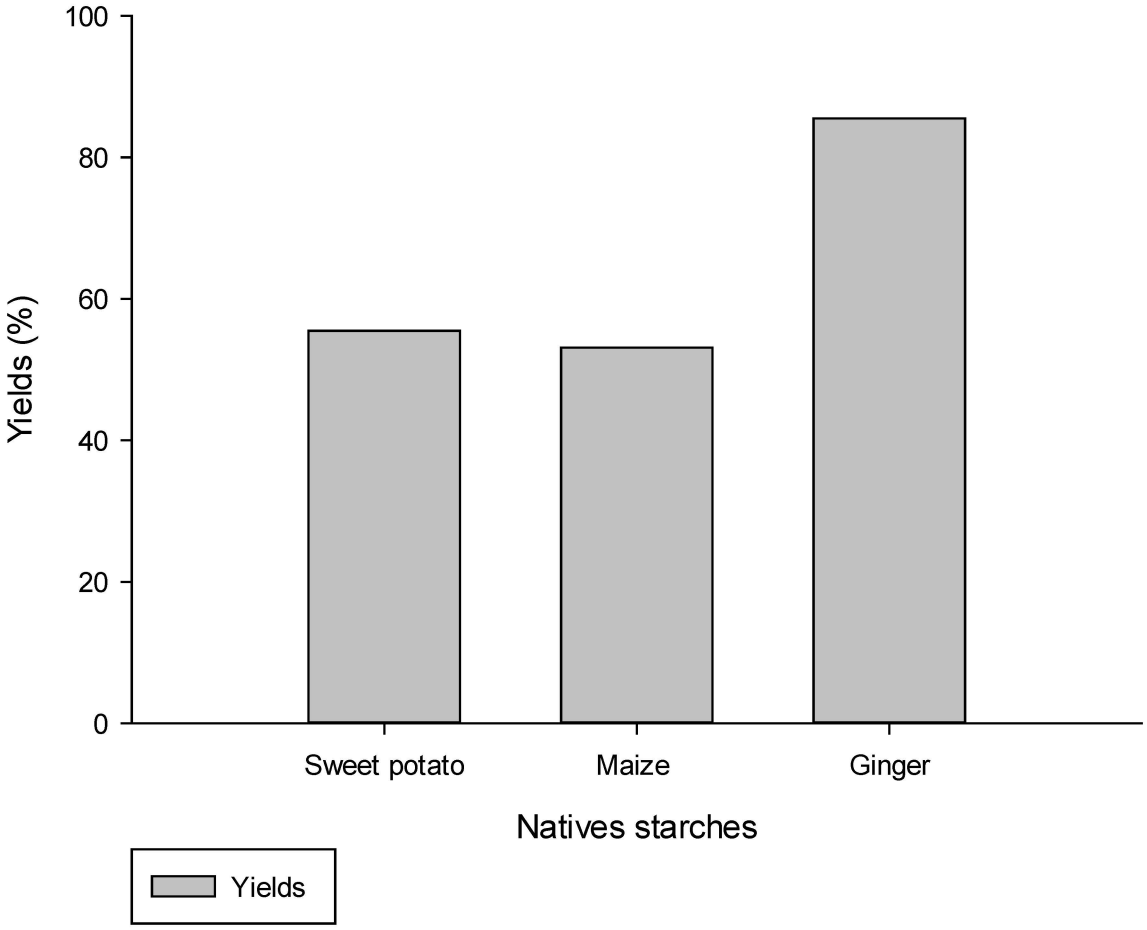


Figure 2. Yields of native starches of sweet potato, maize, and ginger.

3.2. Amylose Content of Native Starches

The amount of amylose in starches affects their functional characteristics; when amylose content rises, starch's transparency and swelling decreases [20]. Table 1 shows the amylose content of cereals (maize) and tubers (sweet potato and ginger); the values range from 21.35% to 29.45%. Indeed, the highest value was observed for maize with 29.45%, followed by ginger with a value of 28.91%, and finally, potatoes had the lowest value of 21.35%. Emmambux and Taylor [7] have shown that the amylose content of cereals and tubers can range from 18 to 30%. This variation may be due to the starch source or molecular variation in the starch granules.

Table 1. Amylose content, volume of syneresis, and gel hardness of native starches (maize, sweet potato, and ginger).

Starch	Amylose Content	Volume of Syneresis (mL)	Gel Hardness (N)
Maize	29.45 ± 0.38 ^{b}	17.15 ± 0.21 ^{b}	0.10 ± 0.03 ^{a}
Sweet potato	21.35 ± 1.91 ^{a}	1.3 ± 0.14 ^{a}	0.07 ± 0.03 ^{a}
Ginger	28.91 ± 0.38 ^{b}	36.25 ± 0.35 ^{c}	1.27 ± 0.54 ^{b}

Means with different superscripts differ significantly per sample ($p < 0.05$).

3.3. Rapid Viscosity Analysis (RVA)

Figure 3 shows the pasting properties of maize, ginger, and potato starches during RVA. Pasting properties are the most important properties when considering starches for use as gelling and thickening agents. Starches with relatively high peak viscosities, like sweet potato starch, could be used as thickening or gelling agents. However, low peak viscosities, like those seen in ginger and maize starches, would be suitable for the manufacture of weaning foods, where food ingredients with a low paste viscosity are required. It can be seen that the gelatinization temperature of sweet potato starch was 75 °C, ginger was 72 °C, and maize was 90 °C. The peak viscosity of potato starch is higher than that of ginger and maize starch, and consequently, potato starch retrogrades more than ginger and maize starch. This could be explained by the fact that potato starch has a low amylose content. Studies have shown that the peak viscosity of starch is influenced by its amylose content [21]. Since linear amylose chains can reassociate at a faster rate than highly branched amylopectin molecules, a high amylose content is linked to a higher rate of retrogradation in starches. Several authors have shown that starches with longer amylopectin chains (potatoes and peas) retrograde faster than those with short amylopectin chains (cereals) [22].

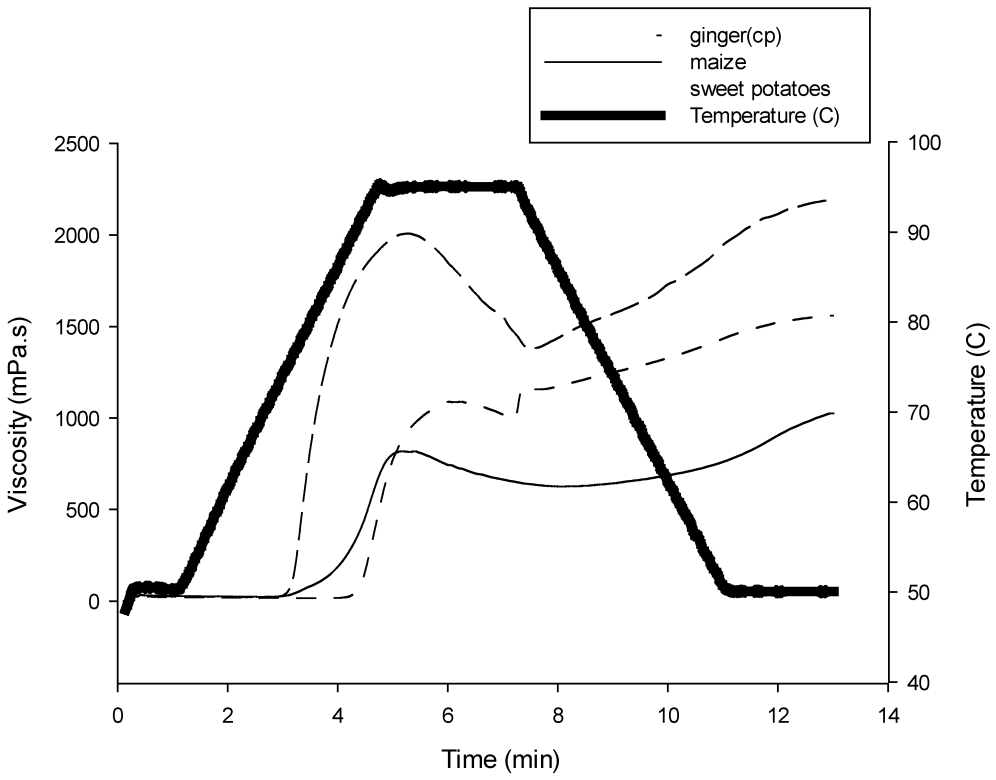


Figure 3. Rapid viscosity analysis (RVA) of ginger, maize, and sweet potatoes starches.

3.4. Syneresis

Table 1 shows the different volumes obtained after syneresis. Indeed, during amylose reorganization, the water that had been absorbed during cooking is released [23]; the syneresis of the various samples varies between 36.25 mL and 1.3 mL. However, the lowest value was observed in sweet potato with a volume of 1.3 mL, which was lower than for maize (17.15 mL) and ginger (36.25 mL). These differences in values could be explained by the fact that sweet potato has a low amylose content, as found in Table 1, and therefore expels less water into the medium after prolonged storage compared to ginger and maize which, being rich in amylose, expel very high quantities of water; this is because the amylose molecule presents a rigid and compact structure which limits the gel's capacity to retain water, resulting in significant syneresis [24].

3.5. Gel Hardness

Table 1 shows the different gel hardnesses of maize, ginger, and sweet potato starches. The hardnesses of the different samples vary between 1.27 and 0.07. The lowest value was observed for sweet potato, while the highest value was for ginger. These results may be due to the fact that sweet potatoes have a low amylose content, favoring the formation of a brittle, less compact gels, whereas ginger and maize have high amylose contents, favoring the formation of a rigid, more compact gel.

3.6. Complexation Indexes of the Amylose–Lipid Complexes

Table 2 shows the complexation indexes of starches according to the different starch sources. The complexation index represents the ability of starches to form a complex with the lipid. The complexation index values varied from 43% for sweet potato starches to 69% for ginger starches. This variation may be due to the amylose content. Indeed, the higher a starch source's amylose percentage, the more it will be able to form complexes with lipids [25].

Table 2. Texture and complexation index (CI) of the amylose–lipid complex (ALC).

Sample	Hardness (N)	IC (%)
ALC ginger	0.097 ± 0.001^{b}	69.13 ± 1.41^{c}
ALC sweet potato	0.081 ± 0.002^{a}	43.98 ± 1.55^{a}
ALC maize	0.101 ± 0.002^{a}	61.92 ± 0.28^{b}

Means with different superscripts differ significantly per sample ($p < 0.05$).

3.7. Viscosity of the Modified Starches with Lipids and Without Lipids

Figure 4 shows the viscosity results for starches with and without complexation. The viscosity of complexed ginger starch is high compared with the viscosity of uncomplexed ginger starch, and the same applies to corn starch. On the other hand, complexed sweet potato starch has a low viscosity compared with the viscosity of non-complexed potato starch. This could be explained by the fact that the more complex a starch is, the higher its viscosity will consequently be [12]. Specifically, potato starch with an amylose–lipid complex has a high viscosity compared to ginger and corn starches with amylose–lipid complexes but a low viscosity compared to the same potato starch without an amylose–lipid complex. As potatoes have a low amylose content, this is in agreement with the work of Chung and Liu [26], who stated that the formation of an amylose–lipid complex requires the presence of high amylose content in a cereal or tuber in order to promote interaction between the lipid ligand and the amylose helices.

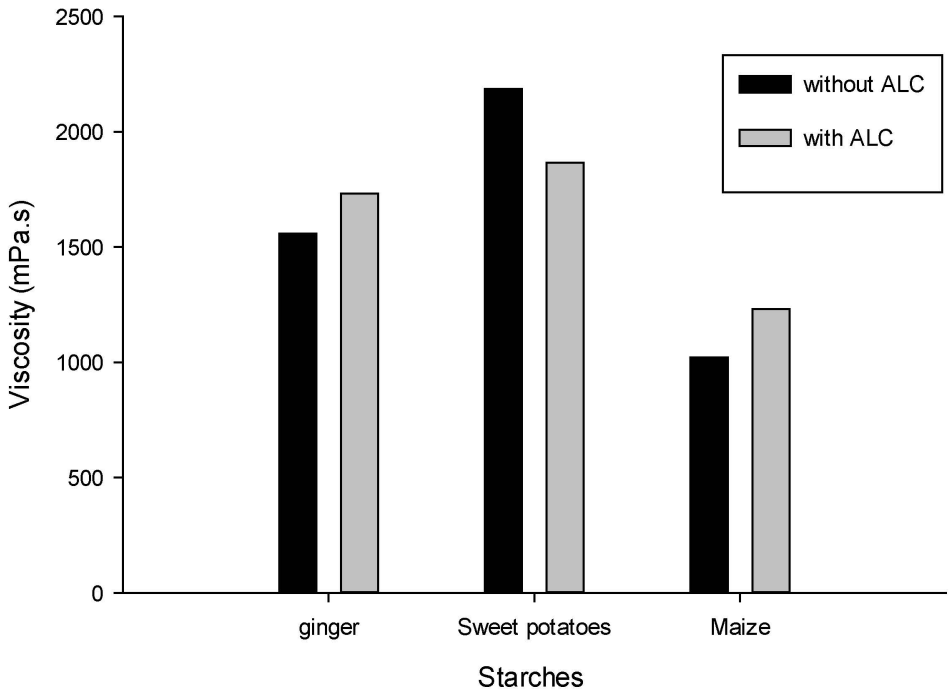


Figure 4. Viscosity of modified and native starches. Legend: ALC: amylose–lipid complex. Legend: ALC: amylose–lipid complex.

3.8. Texture of the Amylose–Lipid Complex (ALC)

Table 2 shows the different textures of the corn, ginger, and sweet potato amylose–lipid complexes. The textures of the different samples varied between 0.101 and 0.081. However, the lowest value was observed in the sweet potato amylose–lipid complex (0.081), while the highest value was for maize (0.101). As potatoes have a low amylose content, the amylose–lipid complex had a brittle, less compact texture; meanwhile, maize and ginger starches have a high amylose content, favoring a rigid, more compact amylose–lipid complex texture in maize starch and a less rigid, less compact texture in ginger starch.

3.9. Influence of Modified Starch Substitution on Mayonnaise Viscosity

Figure 5 shows the viscosity of the various mayonnaises formulated as a function of shear stress. Viscosity describes the physical property of a liquid's resistance to flow. The figure shows that apparent viscosity decreases with increasing shear rate for all samples. Please note that MS was our reference sample. It can be seen that the highest viscosity is observed in ginger with 50% oil substitution and the lowest viscosity is observed in the sample with water. This may be explained by the fact that, at the time of formulation, sample G50 contained 50% oil, having been reduced by the addition of modified ginger starch (amylose–lipid complex), which made the viscosity more resistant than that of the other samples, and also the formation of the complex was more accentuated on ginger starch due to its high amylose content. This sample also showed phase separation immediately after preparation, with an oily phase at the top, an aqueous phase at the bottom, and a small phase in the middle showing emulsion instability. This shows the importance of adding modified starches during mayonnaise preparation.

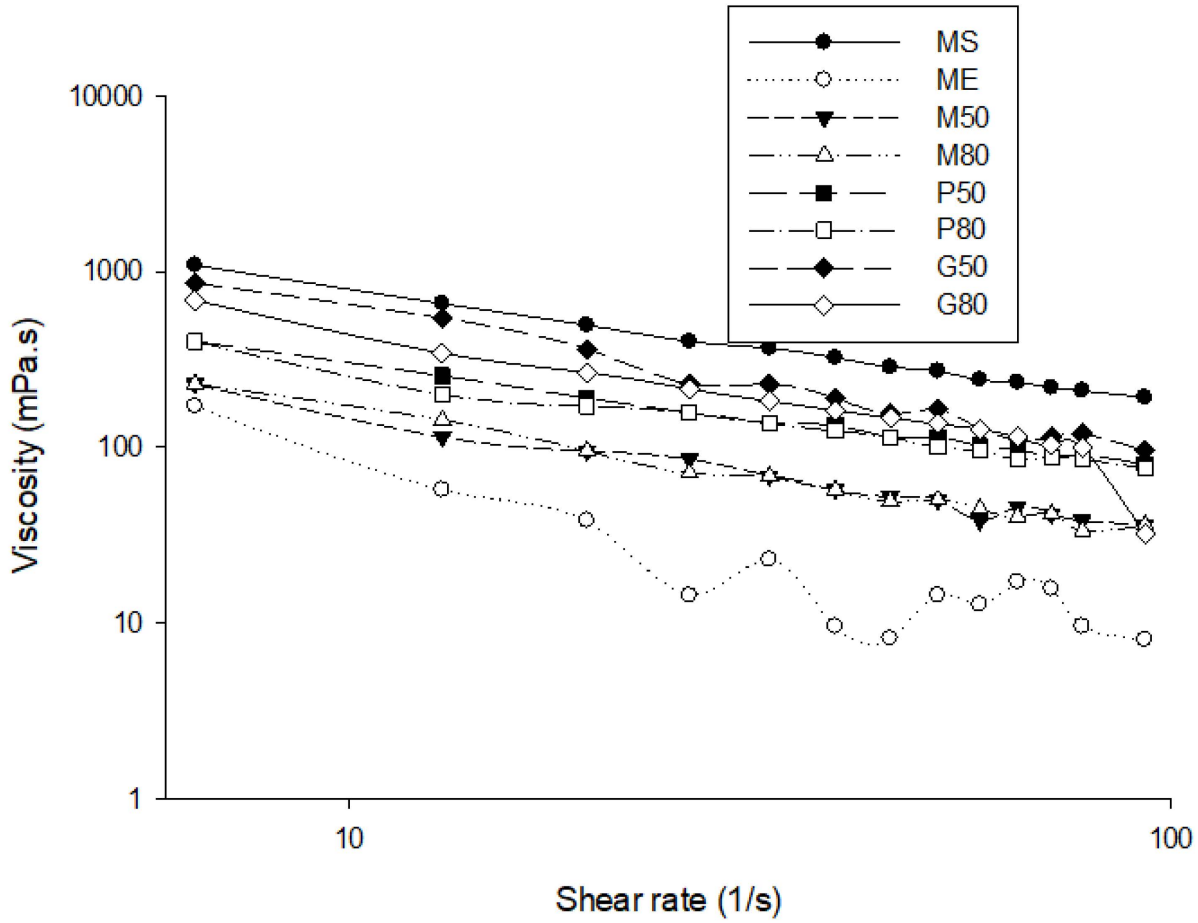


Figure 5. Influence of modified starch substitution on mayonnaise viscosity. **Legend: MS**: full-fat mayonnaise; **ME**: mayonnaise with 50% oil replacement + water; **M50**: mayonnaise with 50% oil replacement + modified maize starch; **M80**: mayonnaise with 80% oil replacement + modified maize starch; **P50**: mayonnaise with 50% oil replacement + modified sweet potato starch; **P80**: mayonnaise with 80% oil replacement + modified sweet potato starch; **G50**: mayonnaise with 50% oil replacement + modified ginger starch; **G80**: mayonnaise with 80% oil replacement + modified ginger starch.

3.10. Influence of Substitution on Sensory Analysis of Mayonnaises

Figure 6 shows the effect of substitutions on the sensory analysis of mayonnaises. In order to select the most widely accepted formulation, a hedonic test based on seven criteria, namely homogeneity, color, viscosity, creaminess, aroma, texture, and general acceptability, was carried out. According to Figure 6, the formulations were organized into two main components (F1 and F2) which explain 79.85% of the variability between different foods, i.e., 52.46% for F1 and 27.39% for F2. Indeed, consumer acceptability of a food product is extremely closely linked to its organoleptic properties. Using the hedonic scores for mayonnaises, as well as principal component analysis, helped us to visualize correlations and understand consumer preferences. The following analysis reflects panelists' behavior during the sensory evaluation. It shows that the ME sample was the least appreciated by the panel. On the other hand, the M50 and M80 samples represent those validated according to the descriptors. Sample M50 was accepted for its smooth texture, homogeneity, and viscosity, while sample M80 was accepted for its aroma and general acceptability.

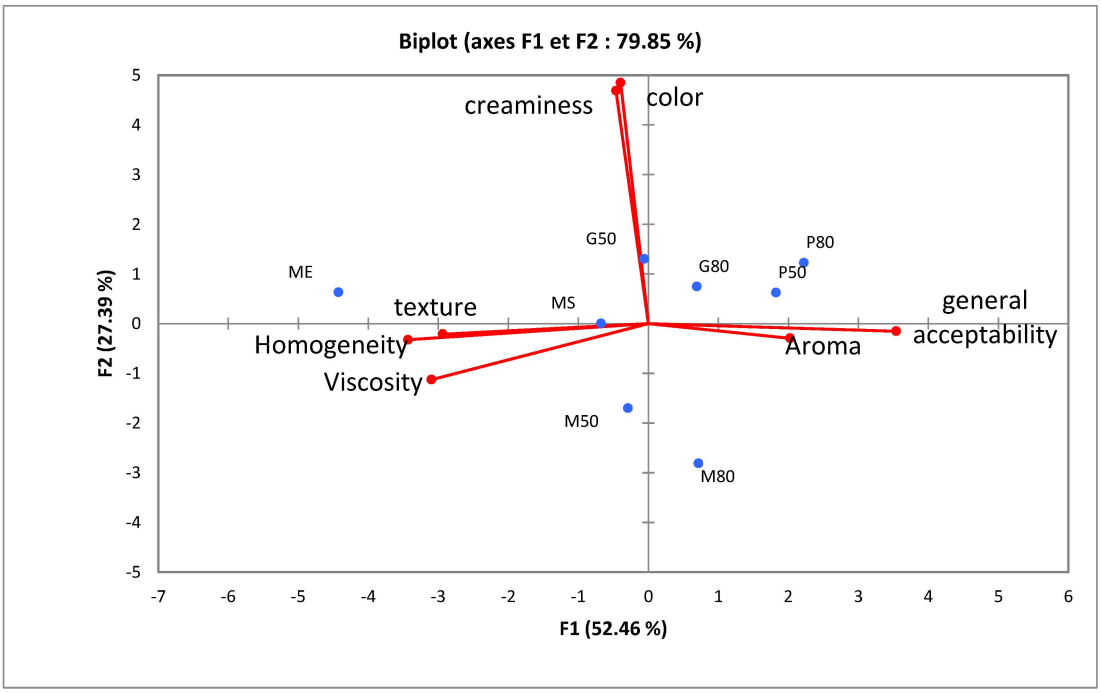


Figure 6. Influence of substitutions on sensory analysis of mayonnaises. Legend: MS: full-fat mayonnaise; ME: mayonnaise with 50% oil replacement + water; M50: mayonnaise with 50% oil replacement + modified maize starch; M80: mayonnaise with 80% oil replacement + modified maize starch; P50: mayonnaise with 50% oil replacement + modified sweet potato starch; P80: mayonnaise with 80% oil replacement + modified sweet potato starch; G50: mayonnaise with 50% oil replacement + modified ginger starch; G80: mayonnaise with 80% oil replacement + modified ginger starch.

4. Conclusions

The aim of the present study was to contribute to the valorization of local tubers and cereals through the formulation of mayonnaises made with modified starches. Low-calorie mayonnaise can be made from modified and unmodified sweet potato, ginger, and corn starches, but the properties depend on the percentage of oil reduction. Ginger and corn starches modified with stearin can produce low-calorie mayonnaise with 50% oil replacement, as physicochemical and rheological analyses revealed that corn cereals and ginger tubers had high amylose contents of 29.45% and 28.91%, respectively, consequently enabling better complexation of amylose with stearin. According to the sensory analysis, panelists preferred the mayonnaise with corn starch modified to replace 50% and 80% of the oil content, respectively. However, their viscosities were not as low as that of standard mayonnaise. Low-calorie mayonnaise made with no modified starch was more unstable and did not resemble a mayonnaise product compared with low-calorie mayonnaise made with modified starch.

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