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Design and Application of Hydrocolloids from Butternut Squash (*Cucurbita moschata*) Epidermis as a Food Additive in Mayonnaise-type Sauces

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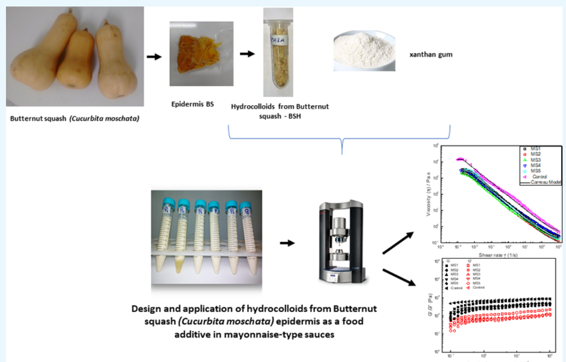
ABSTRACT: Hydrocolloids play a fundamental role in the design of new food products in their structure and functionality due to the interaction with the components of complex food matrices; for this reason, natural sources that are friendly to the environment must be sought for their extraction. A microstructure product such as mayonnaise is an oil-in-water-type emulsion design with the components of the complex varying from egg yolk, additives, spices, sugar, and other optional ingredients to improve its stabilities and organoleptic characteristics. The main objective of the study was to design and characterize the physicochemical, bromatological, and sensory analyses and rheological properties of the mayonnaise-type sauce formulated with hydrocolloids obtained from the epidermis of butternut squash (*Cucurbita moschata*) and xanthan gum. The rheological study allowed us to obtain a behavior of a non-Newtonian flow of the shear-thinning type for all the samples, and flow curves could be well described by the Carreau model ($R^2 \geq 0.993$). The samples exhibit a more elastic than viscous behavior, with a higher storage modulus than the loss modulus ($G' > G''$) in the evaluated frequency range. When performing the physicochemical analysis, pH values (4.02−4.28), titratable acidity (0.40−0.48), peroxide index (12.5−20 meq), and a stable behavior were achieved in all the formulations except for MS2, which showed instability. Regarding the sensory evaluation, the MS3 sample reflected the closest values to the control sample, with a higher level of satisfaction. On the other hand, the bromatological analysis of MS3 presented a humidity value of 55.3 ± 0.27; carbohydrates, 7.66 ± 0.42; protein, 0.87 ± 0.02; fiber, 0.94 ± 0.05; and ash, 0.54 ± 0.05. The development of this product contributes to the transformation and agro-industrial use of the butternut squash (*C. moschata*); likewise, it allows us to obtain a mayonnaise-type sauce with organoleptic and nutritional characteristics for human consumption.



■ INTRODUCTION

Hydrocolloids are a set of high-molecular-weight biopolymers and are one of the most commonly used ingredients in food formulations. They function as thickeners, gelling agents, emulsifiers, stabilizers, fat replacers, texture modifiers, clarifying agents, flocculating agents, clouding agents, and whipping agents; additionally, they have applications in the areas of edible coating/film and encapsulating.[1] Natural hydrocolloids, such as biological macromolecules, are widely used in food products since they have special benefits compared with synthetic and semi-synthetic hydrocolloids, such as being biocompatible, renewable, non-toxic, stable, biodegradable, environmentally friendly, cost-effective, easily accessible, and able to be chemically modified. Therefore, in the last ten years, the search for and characterization of new hydrocolloids from natural resources have increased enormously.[2] The choice of hydrocolloids in food products should be based on their functions. On many occasions, hydrocolloid mixtures are used as these impart special functional properties and/or modify the rheological properties of food products. The functional properties of hydrocolloid mixtures depend on not only the molecular parameters of each biopolymer but also the nature of their interactions. Therefore, in the specific design of new food formulations, it is necessary to control the interaction of biopolymers.[2]

The ingredients used play an important role on the rheological, physicochemical, sensory, and bromatological properties.[3−6] In this sense, emulsion-type foods are not thermodynamically stable systems and can phase separate through different physicochemical processes, such as gravitational separation, flocculation, coalescence, and Ostwald

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ripening.[7] A widely used method to improve the stability of the emulsion, that is, to make it kinetically stable, is the addition of hydrocolloids, specifically emulsifiers and stabilizers.[8] Emulsifiers are surfactant molecules that are readily adsorbed at the oil−water interface and can reduce the interfacial tension to promote emulsion formation and form a protective film.[9] Stabilizers are used to provide long-term emulsion stability. Some stabilizers adsorb at the interface, while others only change the viscosity of the continuous phase due to their non-adsorption properties.[10] Also, they contribute to the structural and textural properties of foods through their aggregation behavior and gelation.[11−13]

Since butternut squash (*Cucurbita moschata*) is considered as a promising raw material in the development of functional foods due to its high nutritional content including its dietary fiber, phenolic compounds (flavonoids and phenolic acids), minerals (especially potassium), vitamins (including β-carotene, vitamin A, vitamin B_2, α-tocopherol, vitamin C, and vitamin E), proteins, and carbohydrates; this vegetable is essential to provide benefits for human health.[14] The cultivation is simple and adaptable to organic farming, which allows in obtaining positive effects on both the environment and consumers.[15]

Many food products are emulsions in different forms such as milk, sauces, ice cream, desserts, mayonnaise, salad dressings, or butter. Most food-related oil-in-water (O/W) emulsions require long-term physical stability to maintain and adjust the desired product properties.[16] The size and distribution of the oil droplets determine the shelf life, color, and texture properties such as creaminess (McClements, 2005). For the food industry, obtaining and successfully stabilizing a certain droplet size remains a challenge. In this sense, mayonnaise is an oil-in-water-type emulsion and is a viscous type of sauce, manufactured by mixing vinegar, vegetable oil, salt, and egg yolk. Its emulsion strength is due to the microdroplets of fat in the interface with coalesced phospholipids and phosphoprotein.[17,18] Mayonnaise, due to the amount of emulsified oil, is susceptible to deterioration due to autoxidation, and its stability depends on the type of oil used. Therefore, the physical and chemical processes involved in the formation of emulsions has allowed the manufacture of mayonnaise which is much more stable during long-term storage and the development of products that contain a greater variety of new flavors.[19] Consequently, different ingredients, proteins with various emulsifiers and gums such as xanthan and guar gum, have been used to obtain a mayonnaise formulation with suitable emulsion properties and high stability.[20]

The novelty of this study should be written in the Introduction Section. In order to achieve a sauce-like microstructure product with adequate emulsion properties and high stability, several investigations have been carried out mainly using mixtures of new hydrocolloids such as Angum gum, Brea gum, and octenyl succinate starch with more common hydrocolloids such as xanthan gum (XG), guar gum, and gum arabic.[2,21−23] In the present study, hydrocolloids extracted from the butternut squash (*C. moschata*) epidermis (BSH) were used in combination with XG. Mandala et al.[24] reported that the addition of XG to O/W emulsions improves textural properties. Likewise, it is well known that produces a strong interaction with galactomannans, and this property is taken advantage of in food applications where it is desired to thicken, stabilize, or gel. The synergistic interaction between xanthan and galactomannans was pointed out for the first time by Rocks,[25] who reported that XG formed thermoreversible gels with locust bean gum but not with guar gum. The ability of xanthan gum to thicken and stabilize emulsion systems is attributed to a weak gel-like structure in the solution made up of XG molecules in the continuous phase of the emulsion, which prevents the oil droplets from emulsifying longer as the gravitational lift of the droplets is less than the yield stress of the xanthan weak gel.

Therefore, the main objective of the present study was to characterize the proximate composition and physicochemical, sensory, and rheological properties of the microstructure product mayonnaise-type sauce designed with BSH as the sole emulsifier, stabilizer, and/or thickener and in combination with XG.

RESULTS AND DISCUSSION

Rheological Analysis. *Viscous Flow Curves in Steady State.* The mayonnaise flow curves are shown in Figure 1 as a function of the deformation rate applied at 25 °C after 48 h of its design.

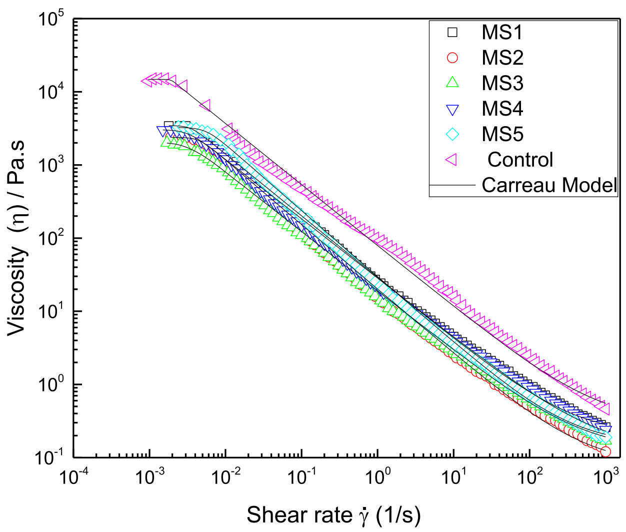

Figure 1. Viscosity (η) and shear rate (γ) for mayonnaise formulations at 25 °C.

The results obtained in all cases show the behavior of a non-Newtonian fluid of the shear-thinning type since the viscosity shows a potential decrease as the deformation or shear rate increases.[8] The same behavior has been observed in different mayonnaise formulations, such as commercial mayonnaise,[11,30] mayonnaise prepared from green banana pulp,[31] mayonnaise formulated without egg,[13] and low-fat mayonnaise.[31]

The non-Newtonian behavior, that is, the thinning of the flow, is possibly due to the flocculation−deflocculation of the oil droplets and the structural breakdown of the components mixed in the emulsion[32,33] since by increasing the speed of deformation, hydrodynamic forces cause aggregates that are deformed and then destroyed, causing a reduction in viscosity.[34] Therefore, the flow properties of the material are dominated by hydrodynamic forces and to a lesser extent by forces between particles and the Brownian motion; the continuous phase could also contribute to the pseudoplastic fluid. Because the mayonnaises presented a shear-thinning fluid behavior, different models can be used to adjust the experimental data of viscosity against the strain rate studied

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Table 1. Parameters Using the Carreau−Yasuda Model for Fitting the Flow Curves[a]

formulations	η_0 (Pa S)	η_∞ (Pa S)	λ_c (S)	a	n	R^2
MS1	3449.90 ±0.327	0.198 ± 0.078	289.15 ± 0.059	6.51 ± 0.045	0.155 ± 0.018	0.999
MS2	2380.28 ± 0.260	0.080 ± 0.135	233.37 ± 0195	6.10 ± 0.265	0.117 ± 0.011	0.998
MS3	2050.32 ± 0.298	0.125 ± 0.086	314.87 ± 0.280	3.26 ± 0.015	0.184 ± 0.019	0.999
MS4	3027.54 ± 0.047	0.125 ± 0.178	316.63 ± 0.167	4.43 ± 0.028	0.188 ± 0.014	0.999
MS5	3261.07 ± 0.154	0.151 ± 0.066	180.34 ± 0.398	4.60 ± 0.032	0.195 ± 0.027	0.998
control	14748.71 ± 0.045	0.306 ± 0.047	524.60 ± 0287	24.37 ± 0.049	0.164 ± 0.039	0.993

[a] η_0—zero shear rate viscosity; η_∞—infinite shear rate; λ_c—time constant of the Carreau model; α—> 0; n—behavior index of the power law; R^2—the correlation coefficient.

(0.001−1000 s^{-1}). In this case, it fitted the Carreau−Yasuda model very well, as shown in eq 1.[35]

$$\eta = \eta_\infty + (\eta_0 - \eta_\infty)[1 + (\lambda_c\dot{\gamma})^a]^{n-1/a} \qquad (1)$$

The Carreau−Yasuda model describes the flow of non-Newtonian fluids dependent on time, with zero shear viscosities η_0 and infinite η_∞. The time relaxation parameter λ_c defines the location of the transition from the shear-thickening and shear-thinning, where $1/\lambda_c$ is the critical shear rate at which the viscosity begins to decrease. The value n corresponds to the parameter of the power-law model; when n = 1, the model is reduced to the linear Newtonian model. For fluidizing liquids, $n < 1$, the viscosity decreases with the increase in the strain rate. The parameter a is dimensionless, sometimes called the Yasuda constant,[36] which describes the transition region between η_0 and the potential drop.

The parameters obtained through the adjustment to the Carreau−Yasuda model are presented in Table 1. The correlation coefficient values were $R^2 \geq 0.993$, which indicates a good fit of the experimental data. All the emulsions presented flow behavior index values (n) lower than 1, values consistent with those from the previous findings of Aslanzadeh et al.[37] and Yüceer et al.,[38] which confirms their shear-thinning behavior, which is a typical behavior in food emulsions.[39]

Apparent viscosity of dispersions in semi-dilute conditions is therefore related to the molecular structure that influences possibilities of interactions between BSH and XG. The five mayonnaise design with BSH−XG presented similar apparent viscosity (η_0) values that ranged from 2050.32−3449.90 Pa S; this value indicates the viscosity of the mayonnaise in situations of rest or slow movement. The commercial control sample presented a higher viscosity because it has a high content of xanthan gum in its formulation, which directly affects the increase in viscosity values, mainly due to the increase in molecular entanglements and the formation of interfacial films.[40] At low shear rates, the η values showed a Newtonian plateau followed by a zone of shear thinning. The carbohydrates and proteins molecules in the BSH tend to have a coiled structure; the relatively high η may contribute to the development of entanglement between the polymer chains composed of these coiled structures. Therefore, at high shear rates, the induced successive increasing force could result in an entangled deformation, bond breakage, and, consequently, a η drop.[41] All sample designs presented similarly behavior and results; MS3, with a mixture in equal parts of the two hydrocolloids used, was the one that presented the intermediary and the closest viscosity values with the other samples, which shows that the rheological parameters are influenced by the percentage of hydrocolloids used, also by the type of hydrocolloids, their concentration, and interaction with other hydrocolloids.[42,43] Based on these designs and rheological results, the use of BSH as an additive alone or with another gum as an alternative to formulate microstructure food matrices is highlighted.

Oscillatory Viscoelastic Tests. Frequency Sweeps. Stress sweep tests were performed at 25 °C to determine the linear viscoelastic region of the mayonnaise formulations. Figure 2 shows the profiles of the samples in terms of G' and G'' as a function of the angular frequency (rad/s) at 25 °C. The samples presented the linear viscoelastic region in a range of 1.0 to 10.0 Pa at a constant frequency of 1 Hz, where an effort of 5 Pa was established to be able to perform the frequency sweep tests from 0.1 to 100 Hz at 25 °C.

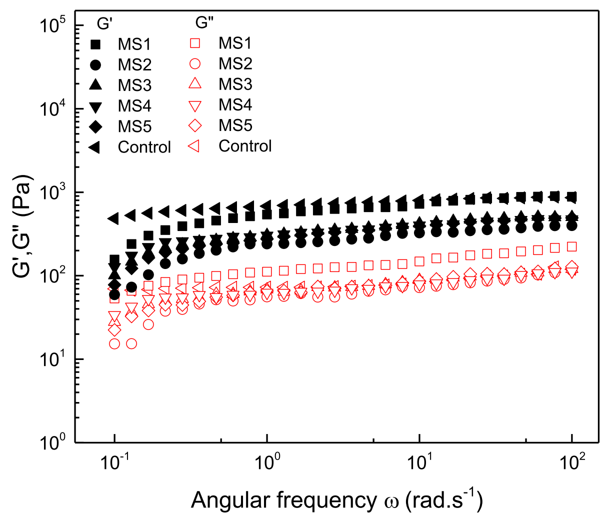

Figure 2. Elastic modulus (G') and viscous modulus (G'') of mayonnaise formulations versus angular frequency (rad/s) at 25 °C.

The results obtained show that the values of G' are greater than those of G'', in the entire frequency range, presenting an elastic behavior rather than a viscous behavior, that is, the material exhibits a behavior similar to that of a solid;[40,44] an equivalent behavior was found in mayonnaise formulations with variations of the proportion of oil and xanthan gum[45] and using modified starch and xanthan gum[26] as fatty substitutes. Furthermore, it was observed that the magnitude of the storage moduli in all cases was low in the order of 103 maximum, presented in the control sample, which suggests that the samples are weak gels and quickly decompose under shear stress.[45]

These results obtained show that a small difference was observed in the mechanical spectrum developed in the range of frequencies studied, depending on the type of hydrocolloids used; that is, in the control and the MS1 sample that contained a higher xanthan gum content, the storage modulus (G') was

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higher than that in the other cases where BSH were used as a total or partial substitute, which indicates that the samples presented a more compact structure due to the formation of large aggregates.[39] Therefore, it can be observed in Figure 2, that most of the viscoelastic behavior can be attributed to the interaction between BSH, xanthan gum, and the emulsion droplets.[46−48] In addition, the interactions of hydrocolloids with the other components that coexist in food, the matrices, allow greater flexibility for the development of food research. At the time of designing the structure and function of food that consumers need in the modern society, the stabilizers are important.

The phase angle tangent or loss tangent (tan δ) is used to describe the viscoelastic behavior; it is a dimensionless measure that compares the amount of energy lost during a test cycle with the amount of energy stored during this time. The loss tangent indicates whether elastic or viscous properties predominate in a sample, is obtained from the G''/G' relationship, and takes values from 0 to 1 when an elastic character predominates.[49] Figure 3 shows the comparison of the phase angle tangent for mayonnaise with different types of hydrocolloids in different concentrations.

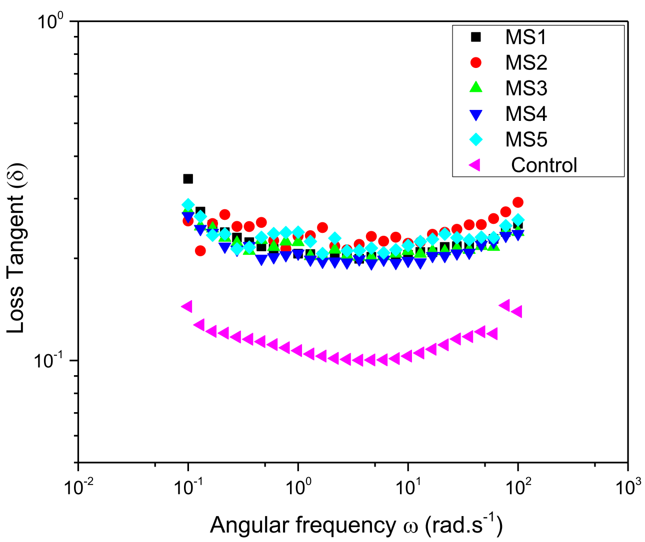

Figure 3. Phase angle tangent (tan δ) as a function of frequency at 25 °C of mayonnaise formulations.

Due to those facts mentioned above, all the values of the elastic modulus (G') were more significant than the values of the viscous modulus (G''), resulting that the values of the phase angle tangent were less than 1, which confirms that the elastic properties predominate. Similar behavior was obtained in mayonnaise prepared using a frozen−thawed egg yolk,[50] where all the samples showed a behavior similar to that of a solid. It is also observed that as a function of the frequency, the value of tan δ of the mayonnaise formulations shows a slight increase. However, the morphologies of the curves for all the formulations are similar, which shows that all the formulations of mayonnaise at different concentrations of BSH and XG exhibit similar viscoelastic properties, except for the control sample. In this sample, the values of the phase angle tangent are lower throughout the frequency range studied, because the two modules shown in Figure 3 maintained a distance from each other, as an indication of higher stability with values close to zero.[51]

Physicochemical Analysis. Table 2 shows the results achieved when performing the pH, acidity, and peroxide index analyses, which were performed on the five samples and the control sample. The results of three repetitions of each of the established methods were averaged, showing their standard deviation and their significant differences between each formulation.

In the first place, the results of the pH and titratable acidity analyses indicate that the mayonnaise-type sauces are considered acidic since the pH level found was in the range 4.02−4.28 and titratable acidity was between 0.40 and 0.48, and equally, the results of the peroxide index analysis were between (12.5−20) meq. These values are within the ranges allowed by the Colombian technical standard (NTC 1756) for these mayonnaise-type food products.[52] For MS1, a pH value of 4.21 ± 0.06, an acidity of 0.45 ± 0.2, and a peroxide value of 15 ± 5.0 meq were observed, with values similar to those of the control sample. This formulation obtained pH values of 4.02 ± 0.10, the acidity of 0.48 ± 0.01, and a higher peroxide index of 20 ± 0. On the other hand, MS2 (0.1% hydrocolloid) had the highest pH value of 4.28 ± 0.01, with a low acidity value of 0.40 ± 0.01, and a peroxide value of 12.5 ± 2.5 meq. According to the data previously exposed, the most effective ingredients on the formulations were xanthan gum and BSH with a pH of 10. The proportion of the gum and hydrocolloid is related directly to the acidity and pH since with a higher percentage of hydrocolloid, its pH increases. However, the higher the percentage of xanthan gum is, the lower the pH will be.[53] Regarding peroxide index values, a remarkable difference was observed between the control sample and the rest of the formulations due to the low percentage of oil that was obtained—used for them (65%). In this way, they presented low rancidity due to the low concentration of oil, unlike the control sample that obtained the maximum allowed value (20 meq).

Consequently, it is observed that there are no significant differences between the samples regarding the peroxide value, pH, and acidity. Similar results reported a pH of 3.79 in a mayonnaise sauce added with tucupi, also reported in studies using an acidified hibachi sauce based on low-fat mayonnaise with values between 3.51 and 4.35.[54,55] Due to its acidity and high fat content, mayonnaise is considered a microbially stable product and can be stored at room temperature.[56,57] However, there is a risk of quality loss due to the autoxidation of unsaturated fatty acids.[58−60]

Table 2. Analysis of pH, Acidity, and Peroxide Index of the Mayonnaise-type Sauce Formulated with BSH[a]

physicochemical parameters	MS1	MS2	MS3	MS4	MS5	Control
pH	4.21 ± 0.06^a	4.28 ± 0.01^a	4.23 ± 0.02^a	4.25 ± 0.04^a	4.24 ± 0.06^a	4.02 ± 0.10^b
peroxide index (meq O_2/kg)	15 ± 5.0^{ab}	12.5 ± 2.5^a	12.5 ± 2.5^a	15 ± 5.0^{ab}	12.5 ± 2.5^a	20 ± 0^b
acidity (% acetic acid)	0.45 ± 0.2^{ab}	0.40 ± 0.01^a	0.43 ± 0.03^a	0.42 ± 0.02^a	0.43 ± 0.02^a	0.48 ± 0.01^b

[a]Different letters in a row symbolize statistically significant difference ($p < 0.05$). Means ± standard deviation.

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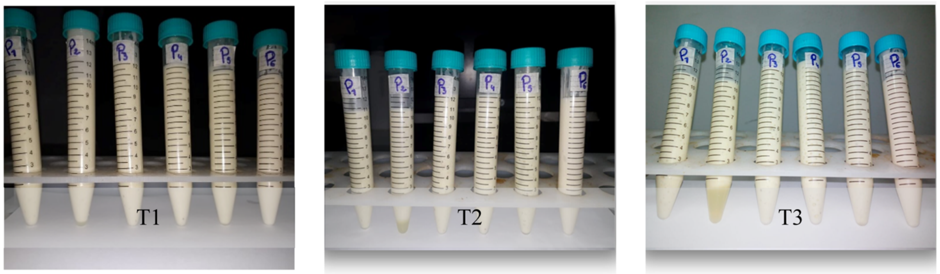

Figure 4. Stability test of the samples with observation times of 1 day (T1), 2 days (T2), and 8 days (T3). Source: authors.

Table 3. Sensorial Analysis of Mayonnaise-Type Sauce Formulations[a]

parameters	MS1	MS2	MS3	MS4	MS5	control
color	3.9 ± 0.9^{bc}	3.4 ± 1.1^{a}	3.9 ± 0.8^{bc}	3.6 ± 0.6^{ab}	3.6 ± 0.7^{ab}	4.2 ± 0.8^{c}
odor	3.6 ± 0.8^{c}	3.1 ± 0.9^{ab}	$3.9 \pm 0.^{c}$	3.4 ± 0.9^{bc}	3.4 ± 0.5^{bc}	2.8 ± 0.9^{a}
flavor	3.9 ± 0.8^{cd}	3.1 ± 1.0^{a}	3.75 ± 1.0^{bc}	3.7 ± 0^{bcd}	3.2 ± 0.9^{ab}	4.2 ± 0.8^{d}
consistency	3.1 ± 0.9^{bc}	2.3 ± 1.0^{a}	3.3 ± 0.7^{c}	3.54 ± 1.0^{c}	2.8 ± 0.8^{ab}	4.2 ± 0.8^{d}
general average	3.6 ± 0.4^{ab}	3.0 ± 0.4^{a}	3.7 ± 0.2^{b}	3.6 ± 0.2^{ab}	3.3 ± 0.3^{ab}	3.8 ± 0.7^{b}

[a]Different letters in a row symbolize statistically significant difference ($p < 0.05$). Means ± standard deviation.

Likewise, the determination of stability in the samples was analyzed. In Figure 4, 12 mL of the sauce samples can be seen photographed in test tubes after 1 day (T1), 2 days (T2), and 8 days (T3).

The stability of the emulsion generally involves the prevention of coalescence, flocculation, and cremation of the droplets.[40,61] Thus, in this case, the gum samples showed higher stability than the samples with the BSH. There was an increase in the viscosity of the aqueous phase due to the addition of xanthan gum, which decreased the movement of the oil droplets.[40]

In Figure 4, a separation was observed after 48 h in MS2, a sample that contained only BSH, reflecting in the lower part approximately 1 mL of oil. Those samples with xanthan gum showed higher stability. Likewise, after 8 days (T3) of the analysis, the MS2 sample showed more visible oil separation between the phases. From the above, it can be analyzed that the addition of XG in the samples improved their stability during the days of analysis, unlike the sample that only contained hydrocolloids, which was unstable. This fact indicates that the presence of hydrocolloids without the presence of XG does not have a significant effect on the stability of the emulsion compared with the presence of the hydrocolloid and xanthan gum.[62] Thus, the samples with XG show resistance to droplet coalescence, accelerating the creaming process.[63]

Sensorial Analysis. Table 3 shows the results of each of the parameters that were evaluated for the five formulations and the control sample with their statistically significant differences ($p < 0.05$).

Regarding sensorial analysis, the results obtained reflected a similar score for the five formulations in the different parameters classified as "neither I like it, nor I dislike it", in which no significant difference is observed in the scores between all the formulations and the sample control, taking into account that the control sample is the one that obtained the highest acceptability among the panelists. However, the samples that obtained the best evaluation were MS1, MS3, MS4, and the control sample. Besides, for the evaluation of the odor parameter, the control sample obtained a lower evaluation than the rest of the samples with a value of 2.8. This value is explained because the panelists commented that this sample had a characteristic odor of acetic acid; this is consistent with the physicochemical results, where the control sample presented the highest acidity and lowest pH values. Regarding the samples with the best scores (MS1, MS3, and MS4), they presented relatively close values in the flavor and consistency parameters because they contained a higher percentage of xanthan gum than the rest. Therefore, at the sensory level, the mayonnaise-type sauce with the best characteristics was the MS3 sample in similarity to the control sample, as can be seen in Figure 5.

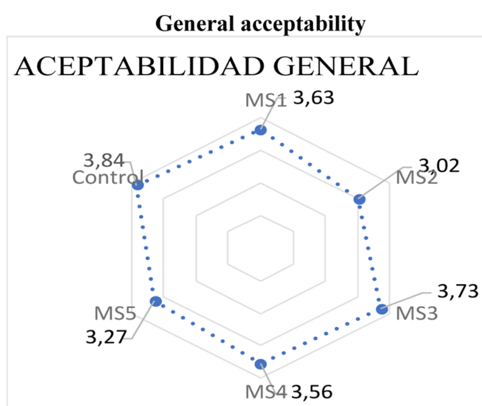

Figure 5. Average ratings for general acceptability of mayonnaise-type sauce formulations.

General Acceptability. Figure 5 shows the results obtained from the general acceptability of the parameters evaluated in the formulations, which were calculated by averaging the four sensory parameters of each of the formulations and the control sample. It is observed that all the samples obtained an acceptable level of satisfaction in general; it should be noted that the MS2 sample presented a lower percentage of acceptability; and a higher percentage of acceptability was observed for the MS3 and control sample. Consequently, the MS3 sample presents sensory characteristics similar to the mayonnaise that is marketed in the national

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Table 4. Bromatological Analysis of the Mayonnaise-Type Sauce Sample MS3 and Control

samples	carbohydrate (%)	humidity (%)	total fat (%)	total fiber (%)	protein (%)	ash (%)
MS3	7.7 ± 0.4	55.3 ± 0.3	35.6 ± 0.4	0.94 ± 0.05	0.87 ± 0.02	0.54 ± 0.05
sample control	6.7 ± 0.2	52.67 ± 0.5	40 ± 0.7	0	0	0.63 ± 0.04

market. This design (MS3) with the same percentage of BSH and XG presented the best sensory results and a similar viscous flow behavior in the dynamic modules close to that of the commercial control sample.

The formulations that obtained the lowest scores in the sensory evaluation were MS2 and MS5, with a higher percentage of BSH in their formulation, thus demonstrating that the high percentage of hydrocolloids affected the sensory parameters—evaluated, mainly the consistency and flavor, because these samples had a lower viscosity affecting the characteristic consistency of this type of sauces. The results obtained are similar, where little significant difference was found in the sensory evaluation between the different formulations of mayonnaise with corn flour in different percentages.[64] Similar results were reported in studies using xanthan gum in different treatments for a mayonnaise sauce with corn bran rice and sesame oil.[65]

Bromatological Analysis. Table 4 shows the data from the bromatological analysis of the MS3 mayonnaise-type sauce, considered to be the best sample due to the acceptability values in the sensory evaluation carried out in comparison with the control sample.

Means ± Standard Deviation. The bromatological results indicate that the selected mayonnaise-type sauce (MS3) presented carbohydrate values of 7.66 ± 0.42, the humidity value of 55.3 ± 0.27, a fat value of 35.6 ± 0.41, a fiber value of 0.94 ± 0.05, the protein value of 0.87 ± 0.02, and an ash value of 0.54 ± 0.05 with a statistically significant difference ($p < 0.05$). The increase in MS3 carbohydrates compared to that in the control sample is due to the presence of sugar in its formulation. Regarding the amount of fiber and protein, it is mainly due to the presence of BSH. Likewise, the protein percentage is related to the amount of egg used, in which both the yolk and the whites were used in combination. Total ash reflects the mineral content of food products; thus, the amount of ash in the sauce sample is due to the addition of spices such as pepper in the formulation and the incorporation of hydrocolloids.[66] The bromatological results are in accordance with those presented by the ICBF in its table of food composition (ICBF, 2018),[67] that is, the addition of BSH provided minimum values in fiber and proteins of hydrocolloids in the formulation. Similar studies report 0.29% protein; 0.58% carbohydrates; 15% fat, and 0.7% ash in the elaboration of a mayonnaise formulation reduced in fat cholesterol from bean protein and egg yolk.[68] In the same way, in a sauce mayonnaise dressing also with lutein as a natural coloring were found 0.5−2% of protein and a total fat content of 42.9−62.3%.[69] Likewise, in a mayonnaise sauce with added tucupi, values of 3.12% total sugars, 41.52% moisture, 43.95% lipids, 4.56% protein, and 2.06% ash were found.[54]

CONCLUSIONS

Hydrocolloids obtained from the epidermis of butternut squash (*C. moschata*) can be considered a good source for its use as an additive or ingredient for the design of food products, improving functionality and stabilities, in addition to being friendly with the environment. Stable mayonnaise-type sauces were designed using total and partial BSH as an additive, reducing the use and content of commercial gums such as xanthan. The rheological study of the different mayonnaise formulations allowed us to conclude that all the samples presented the behavior of a non-Newtonian flow of the shear-thinning type; it correctly adjusted to the Carreau−Yasuda rheological model with an average of $R^2 \geq 0.998$. The dynamic viscoelastic properties characterized by an oscillatory frequency sweep under small deformation conditions showed that these ingredients contributed to stability, evidenced as an increase in the elastic modulus predominating the solid-like behavior. The sample MS3 (0.05% XG and 0.05% BSH) design has the closest values to those of the commercial control sample in acceptance by the panelists, which was considered as the best mayonnaise-type sauce, according to the sensory analysis. The bromatological characterization was carried out on the MS3 sample; it indicates that the food product reached similar values to those of the commercial test, enriching it in fiber and protein. The interaction of BSH with other components in the design of food matrices allows increased flexibility for food research development. The stabilizers are indispensable in the design of the food structure and functionality that are demanded by the consumer in the modern society.

EXPERIMENTAL SECTION

Materials. Butternut squash (*C. moschata*) was harvested in the municipality of Santa Catalina, Department of Bolivar (Colombia), and transported to the laboratory of complex fluid engineering and food rheology (IFCRA) at Cartagena University (Cartagena de Indias, Colombia). Butternut squash (*C. moschata*) was selected according to the size, shape, and color uniformity. The xanthan gum was purchased from IPF (Medellin, Colombia) as an emulsifier. Additionally, commercial vegetable oil, spices, eggs, salt, and sugar were incorporated to enhance the flavor, and vinegar was used as the continuous phase of the emulsion. Similarly, a commercial brand mayonnaise sauce (Fruco) was obtained to make comparison with the standardized samples in this study, and it was called the control sample. All of these ingredients were purchased from a local commercial distributor (Cartagena, Colombia.) All other reagents were of analytical grade and used as received.

Methods. *Preparation of Hydrocolloids from Butternut Squash—BSH.* For the extraction of hydrocolloids from squash epidermis—BSH, the methodology proposed by Ibañez and Ferrero[26] was followed with some modifications. 2 kg butternut squash peel previously washed, disinfected, and without bruises was used. The shells were washed in the water at 80 °C for 10 min and ground. The oil extraction was carried throughout by pressing using felt bags with a capacity of 300 g each; the butternut squash shell was placed inside the bag, and then, the open end was cooked, placing it in a stainless-steel cylinder to be taken to a manual press (SILFRADENT PRESS 665) at 6000 bars. The pH was adjusted to 10 with sodium hydroxide (NaOH). This pH was used for the extraction because in previous studies carried out by the authors, it was

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Table 5. Design of Mayonnaise-type Sauce with Hydrocolloids

formulation	samples codes				
	MS1	MS2	MS3	MS4	MS5
oil	65%	65%	65%	65%	65%
egg	10%	10%	10%	10%	10%
vinegar	5.4%	5.4%	5.4%	5.4%	5.4%
salt	1.5%	1.5%	1.5%	1.5%	1.5%
sugar	1%	1%	1%	1%	1%
spices	1%	1%	1%	1%	1%
drinking water	16%	16%	16%	16%	16%
xanthan gum—XG	0.1%		0.05%	0.075%	0.025%
butternut squash hydrocolloids—BSH		0.1%	0.05%	0.025%	0.075%

shown that hydrocolloids obtained in a basic medium show higher yields and better functional properties than those extracted in acidic and neutral environments. Subsequently, a little amount of water was added to the flour obtained from the epidermis of butternut squash (*C. moschata*) to proceed with magnetic stirring for 4 h at 80 °C, followed by centrifugation at 4000 rpm, adding ethanol with a ratio of 1:1 concerning the supernatant. Consecutively, it was stirred by magnetic means for 2 h at 4 °C, and centrifugation were performed again under the same terms, subsequently removing the ethanol and, thus, leaving a precipitate. Finally, rapid lyophilization and grinding (MF 10 basic Microfine grinder drive couple with MF 0.5 Cutting-grinding head; IKA, Germany) were performed.

Design of the Mayonnaise Sauce with Hydrocolloids. The mayonnaise-type sauces were prepared in the laboratory according to the recipe described by Heggset et al.[27] with some modifications, which included 65% oil, 10% egg, 5.4% vinegar, 1.5% salt, 1% sugar, 1% spices, and 16% water. The five formulations were designed using variations of the ratio between BSH with a pH of 10 and XG used in the experimental design proposed by Matsuyama et al.[28] with some modifications, as detailed in Table 5.

First, for the continuous phase, the BSH−XG hydrocolloid mixture was dissolved in distilled water at 60 °C for 30 min with a magnetic stirrer (RCT basic S001, IKA, Germany) for its complete hydration. This solution was mixed with vinegar, salt, sugar, mustard, egg, and pepper in a high-speed mixer (Kitchen Aid, Benton Harbor-United States). For the dispersed phase, oil was added to the solution prepared previously, and it was homogenized in a rotor-stator system (Ultra-Turrax T25 basic, IKA, Germany) at 12,000 rpm for 5 min. The packaging was carried out in glass jars stored at a refrigeration temperature (25 °C) for 48 h for rheological, physicochemical, bromatological, and sensory analyses.

Rheological Analysis. The rheological properties of formulations were evaluated following the methodology described by Quintana et al.[29] using a controlled-stress rheometer Haake Mars 60 (Modular Advanced Rheometer System Thermo-Scientific, Germany), equipped with a Peltier temperature control and measuring system, using a rough plate geometry of 35 mm diameter and 1 mm gap. The viscous flow tests in the steady state were carried out at 25 °C, observing the variation of the viscosity in a stress range between 0.01 and 100 s^{-1}.

The oscillatory shear tests were carried out 48 h after the preparation process in order to obtain the viscoelastic responses by carrying out stress sweeps at a frequency of 1 Hz, applying an ascending series of stress values from 0.001 to 1000 Pa to determine the range of linear viscoelasticity. Then, frequency sweeps were performed to obtain the mechanical spectrum by applying a stress value, within the linear viscoelastic interval, in a frequency interval between 10^{-2} and 10^{2} rad/s. The tests were carried out at 30 °C. The viscoelastic parameters obtained were storage modulus (G'), loss modulus (G''), tangent of the phase angle (tan δ), and complex viscosity ($|\eta^*|$).

Physicochemical Analysis. The physicochemical parameters analyzed in the samples were pH with a Metter Toledo AG SG2 digital potentiometer, previously calibrated (AOAC 942.05/90.1995), and the peroxide index by the volumetric method using eq 2.

$$\text{IP} = \frac{\text{Vg(ts)} - \text{Vg(tsblank)} \times \text{Nts}}{P} \quad (2)$$

where IP: peroxide value, Vg (ts): volume spent of the sample, Vg (tsblank): volume spent of sodium thiosulfate in the blank, Nts: normality of sodium thiosulfate, and P: the weight of the sample expressed in grams.

Acidity was measured based on an alkalimetric titration with 0.1 N NaOH using phenolphthalein as an indicator and was calculated by eq 3.

$$\%\ \text{Acidity} = \frac{V \times N \times \text{Milieq} \times 100}{M} \quad (3)$$

where V: volume of the NaOH solution used for titration, N: normality of the titrant, and M: molarity of the solution.

On the other hand, the stability measurement was carried out by a qualitative method. Taking 12 mL of the samples in test tubes, which were analyzed at room temperature, the changes in the samples were visually evaluated after 1, 2, and 8 days.

Sensorial Analysis. Sensory analysis of mayonnaise-type sauce samples was subjected to sensory descriptive analysis, in order to provided valid and reliable information on the sensory characteristics of food products. Panelists (n = 30, 15 female, 15 males, aged 18−35 years) were recruited among staff and students at the University of Cartagena. Participants were instructed to evaluate each sample individually and not for relative rating. The samples were presented in individual booths illuminated with white light under controlled humidity and temperature (20 °C). In each session, the nine formulations with different percentages of gum and oil and a control sample obtained commercially were served at the same time, approximately 10 g of each paste conditioned at room temperature before testing. Sample evaluation was verified by repeating each session after resting for at least 2 h. To avoid carry-over effects and to neutralize sensory adaptation, tap water was offered ad libitum to cleanse the palate. The hedonic

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scale was used to evaluate the intensity and acceptability of color, flavor, taste, and texture. The evaluators were selected to determine changes in color, flavor, aroma, and texture, using a five-point hedonic scale, with the following descriptors: I dislike a lot = 1, I dislike a little = 2, I neither like nor dislike = 3, I like it = 4, and I like it a lot = 5. The samples were presented in a quantity of 2−3 g of the product, identified with random three-digit numbers, as described in the technical guide GTC 165 (18). The results were expressed as a percentage of the acceptability.

Bromatological Analysis. Moisture tests were performed by dehydration in an oven at 105 °C (AOAC 33.7.03 Method 926.08), and the ethereal extract (AOAC ethereal extract method 972.28), ash (AOAC 33.7.07 Method 935.42) fiber (AOAC, 2000), and proteins (Method Kjeldahl AOAC 33.7.12 Method 926.123) of the studied formulations were evaluated using techniques described by the Association of Official Analytical Chemists.

Statistical Analysis. The data were processed through the statistical software Statgraphics centurion XVI, using analysis of variance tests (ANOVA) with a confidence interval of 95%. All tests were carried out in triplicate.

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Notes

The authors declare no competing financial interest.

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