

PHYSICAL AND SENSORY PROPERTIES OF EGG YOLK AND EGG YOLK SUBSTITUTES IN A MODEL MAYONNAISE SYSTEM

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Accepted for Publication September 11, 2009

ABSTRACT

Physical and sensory properties of several commercially available egg alternatives in a mayonnaise formulation were compared with a control formulation using whole egg. The egg alternatives included modified corn starch (MCS), wheat protein (WP), whey protein concentrate (WPC), whey protein isolate (WPI), WPI-gum blend (WPI-GB) and WPC-fenugreek gum blend (WPC-FGB). These egg alternatives were evaluated at 100% and 50% replacement. At 100% replacement, all egg alternatives except WPI exhibited significantly higher emulsion stability compared with the control. WPI-GB, WPC-FGB and WP at 100% exhibited significantly higher viscosity than the control. When used at 50% replacement an antagonistic relationship with egg yolk was observed for viscosity and firmness. At 100% replacement, WPI exhibited significantly higher firmness value than the control. Descriptive and consumer panels reported that MCS and WPC-FGB exhibited attributes similar, if not better than, the control.

PRACTICAL APPLICATIONS

The egg alternatives were used to replace egg as a functional ingredient in a model mayonnaise system. These alternatives can deliver functionality at a

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lower cost and can be incorporated to produce a suitable mayonnaise system especially modified corn starch and blends of whey protein concentrate-fenugreek gum blend. These results may help producers in formulating a new mayonnaise type.

KEYWORDS

Egg yolk substitutes, mayonnaise, physical evaluation, sensory evaluation

INTRODUCTION

Eggs are considered a high-profile ingredient because of their high nutritional value and multifunctional properties, including emulsification, coagulation, foaming and flavor (Yang and Baldwin 1995). For these reasons, food designers have aspired to develop ingredients that emulate the egg's multifunctional properties. The desire to replace eggs in food systems was brought about by a multitude of concerns from consumers, and processors desire to have low-cholesterol foods, reduced allergens, less-expensive ingredients, increased shelf life, no refrigeration requirements and fewer microbial concerns (Lin *et al.* 2003; Swaran *et al.* 2003).

Food emulsions play a vital role in many food products. An emulsion is defined as a two-phase system consisting of immiscible liquids that differ in stability; mayonnaise (Yang and Baldwin 1995; Garti *et al.* 1997; Chouard 2004). Egg yolk is an excellent emulsifier for food systems. Egg yolk contains surface-active fractions (i.e., lipovitellin, livetin and lipovitellenin) that are absorbed at the oil-in-water (o/w) interface and form a film around the oil droplets and prevent coalescing (Yang and Baldwin 1995; Breeding and Beyer 2000). Thus, whole egg and egg yolk are key ingredients in the production of many food emulsions, such as mayonnaise.

Several protein products have been evaluated as emulsifying agents in o/w emulsions. Whey protein (Daugaard 1993a,b; Turgeon *et al.* 1996; Zayas 1997; Srinivasan *et al.* 2001; Takeda *et al.* 2001), wheat gluten (Aoki *et al.* 1980; Yao *et al.* 1990) and soy protein (Rir *et al.* 1994; Takeda *et al.* 2001) can be used as emulsifying agents to replace egg yolk in o/w emulsions (Aryana *et al.* 2002). Carbohydrates, including starches and gums, are often used in food emulsions; they are not typically classified as emulsifiers however, because they do not have hydrophilic and hydrophobic sections that are absorbed at the interface (Garti *et al.* 1997; Chouard 2004). Garti *et al.* (1997) evaluated fenugreek gum (FG) individually in o/w emulsions. Chiralt *et al.*

(1994) found that, when processing emulsions containing egg yolk and locust bean gums, an increase in gum from 0.5 to 1% led to an increase in the apparent viscosity of the samples. A shelf-stable mayonnaise can be formulated by using iota-carrageenan (IC) and wheat protein (WP) to partially replace egg yolk in mayonnaise production (Samhouri *et al.* 2007; Abu Ghoush *et al.* 2008). With the advent of new technologies, many new food ingredients are being advertised, but there is very little literature that compares new ingredients with eggs in a scientific study. The hypothesis of this study states that new egg alternatives may replace egg as a functional ingredient in emulsion-like systems such as mayonnaise. The objective was to evaluate the physical and sensory properties of the mayonnaise systems formulated with either egg or egg alternatives.

MATERIALS AND METHODS

The ingredients used in all mayonnaise formulations included iodized salt (Kroger Co., Cincinnati, OH), pure cane sugar (C&H Sugar Co., Crockett, CA), apple cider distilled vinegar (H.J. Hentz Co., Pittsburgh, PA), ground dry mustard (Kroger Co.), and corn oil (Kroger Co.).

The egg and egg substitutes evaluated in the mayonnaise formula were either donated or purchased. They included: pasteurized liquid egg yolk (Cutler Egg Products, Abbeville, AL); wheat protein isolate (WP) (MGP Ingredients, Atchison, KS); whey protein concentrate (WPC) (Parmalat Ingredients, Ontario, Canada); modified corn starch (MCS) (National Starch and Chemical, Bridgewater, NJ); FG (Emerald Seeds, El Centro, CA); propylene glycol alginate, locust bean and guar gum (PB-S-GSP) (TIC Gum, Belcamp, MD); and whey protein isolate (WPI) (Davisco International, Eden Prairie, MN).

Mayonnaise Preparation

The mayonnaise was prepared according to a modified procedure of Yang and Cotterill (1989). The salt, sugar, dry mustard and 24 mL (44%) of the vinegar were mixed with a rubber spatula in a mixing bowl of a kitchen mixer (Kitchen Aid Inc., St. Joseph, MI). The egg yolk or egg substitute was added and mixed with a rubber spatula. A 90-mL aliquot of corn oil was added dropwise from a 100-mL burette at a rate of 3 mL/min while continuously being blended at speed 8 with the Kitchen Aid mixer using a whisk attachment. The mixer was stopped and the bowl scraped. The mayonnaise was mixed at speed 8 for 3 min. An additional 90 mL of corn oil was added dropwise over 20 min while blending at speed 8. The mixer was stopped and the bowl

scraped. The mayonnaise was mixed on high speed for 3 min. The remaining 30 mL of cider vinegar was added and the mayonnaise was mixed on speed 4 for 30 s. Mixing was resumed at speed 8 and the remaining 234-mL of corn oil was added dropwise over 50 min. The bowl was scraped a final time, and the mayonnaise was mixed at speed 8 for 3 min. The mayonnaise was placed into three 150-mL glass sample cups and placed at 4C for 24 h. The wattage being sent to the mixer was monitored with an electric current monitor ECM 1200 (Brultech, Ontario, Canada), and ranged between 65 and 100 W.

Egg Substitute Preparation

Egg substitutes were prepared based on recommendations from the suppliers and preliminary research. The egg substitutes were combined with water to form solutions that were used to replace the egg yolk in the mayonnaise formulation at 100% (100:0) and 50% (50:50) replacement.

WP. A mixture of 12.5% WP and 87.5% distilled water was prepared. The pH was adjusted by mixing 52.5 mL water with a 24-mL aliquot of vinegar in a 150-mL beaker. The water and vinegar solution was stirred continuously at a vortex over a medium heat setting. The WP was slowly added to the water solution until fully dispersed. The solution was heated to 70C. To prevent protein precipitation, salt was excluded from the formulations containing WPI. The solution was used to replace the egg yolk in the basic mayonnaise formulation, and the standard procedure was followed.

WPC. A mixture of 35% WPC and 65% distilled water was prepared. The water was placed in a 150-mL beaker and stirred continuously at a vortex on a magnetic hot plate. The WPC was added slowly to the water until completely dispersed. The standard mayonnaise procedure was followed.

WPI. A mixture of 31.5% WPI and 68.5% distilled water was used to replace the egg yolk in the mayonnaise formulation. The water was placed in a 150-mL beaker and stirred continuously at a vortex on a magnetic hot plate. The WPI was added slowly to the water until completely dispersed. The standard mayonnaise procedure was followed.

MCS. A mixture of 15% MCS and 85% distilled water was prepared. The water was placed in a 150-mL beaker and stirred continuously at a vortex over medium heat (level 4) on a magnetic hot plate. The MCS was added slowly to the water until completely dispersed. The solution was heated to 70C while stirred continuously at a vortex. The standard mayonnaise procedure was followed.

WPC and FG (WPC-FGB). A combination of 22.5% WPC, 0.4% FG, and 77% distilled water replaced the egg yolk in the formulation. The WPC was mixed with the dry ingredients. In a separate beaker, the FG and water were continuously mixed at a vortex, and the solution was heated over medium setting heat on a magnetic stir plate until the solution reached 70C. The standard mayonnaise procedure was followed.

WPC and Gum Blend (WPC-GB). A combination of 22.5% WPC, 0.4% PB-S-GSP, and 77% distilled water was used to replace the egg yolk in the formulation. The whey protein concentration was mixed with the dry ingredients. In a separate beaker, the PB-S-GSP and water were continuously mixed at a vortex and the solution heated over medium setting heat until the solution reached 70C. The standard mayonnaise procedure was followed.

Mayonnaise Evaluation

Physical Measurements. A modified procedure of Harrison and Cunningham (1986) was used to evaluate the emulsion stability of mayonnaise samples. One hundred grams of mayonnaise were placed in a 250-mL beaker at 24C, and checked every 4 h until the emulsion broke. A broken emulsion was defined as the time when oil becomes visible on the surface of the mayonnaise.

The pH of the mayonnaise was measured with a Fisher Scientific (Saint Louis, MO) pH meter AP63 calibrated with buffer solutions of pH 4 and 7.

Mayonnaise samples were measured with a Hunter Lab Miniscan MS/S 4000S Spectrocolorimeter (HunterLab Inc., Reston, VA) calibrated with a white tile and light trap. The mayonnaise was measured according to the procedure described for translucent semisolid foods (Hunter Associates Laboratory, Inc. 2004). The sample was placed into a 6.25-cm glass sample cup with a 10-mm black ring and white ceramic disk. Values of lightness (L^*), redness (a^*) and yellowness (b^*) were determined by using illuminant C and a 10° viewing angle. Hue angle was calculated with the formula $\tan^{-1}(b/a)$.

Viscosity Measurement. Apparent viscosity of the mayonnaise was determined with a Bohlin VOR rheometer (Bohlin Rheology, AB Lund, Sweden). The samples were removed from refrigerated (4C) temperatures and placed between a cone and plate geometry with a 30 mm diameter, 5° cone angle, and a torque element of 91.1 g-cm. The gap between the cone and plate was set at 0.15 mm. The rheometer was cooled to 4C before to the sample being placed onto the lower plate to simulate refrigeration temperatures. Samples were removed from 4C storage and were allowed to rest between the

cone and plate for 60 s to allow the samples to relax. The apparent viscosity was calculated within shear rates 0.925/s to 92.5/s. A shear rate of 9.26/s was used for statistical analysis because Morris and Taylor (1982) found that viscosity measured at 10/s shows a high correlation ($R^2 = 95$) with trained panel scores.

Texture Measurement. A texture analyzer, TAXT2 (Texture Technologies, Scarsdale, NY), was used to evaluate the firmness (spreadability) of the mayonnaise samples. The samples were removed from 4C storage and placed directly under a 25-mm cylinder probe (TAXT2, Scarsdale, NY). The probe speed was set at 1.0 mm/s, penetrate to 10 mm into the sample with a post speed of 10 mm/s. The firmness value for each sample was measured.

Sensory Test

Trained Sensory Panel. A panel consisting of five men and five women was assembled to evaluate the descriptive characteristics of the mayonnaise samples. The panel received 4 h of training using commercial mayonnaise and salad dressings. The training focused on the products, surface shine, spreadability, firmness in the mouth, mouth coating and sour flavor. Appropriate references and characteristic definitions were presented during the training sessions. The panelists were given the 0 and 10 anchor references, along with samples that had values between the anchors. The panel discussed and agreed upon these samples' reference values.

To avoid sensory fatigue, the panelists only evaluated the descriptive characteristics of five mayonnaise treatments: control, MCS, WP, WPC and WPC-FGB. Only one whey protein treatment (WPC) and one blend (WPC-FGB) were evaluated. These treatments were chosen based on the results of the physiochemical evaluations. Substitute treatments were colored to have the same yellow appearance as the control. The panelist used a ballot to evaluate the sensory attributes of the mayonnaise formulations.

For the firmness in the mouth, mouth coating and sour flavor evaluation, the panelists were given samples of the references and mayonnaise samples in 75-mL paper cups. The panelists used spoons to sample the products. Panelists were provided with salting crackers and water to help cleanse their palates between samples. For the evaluation of the mayonnaise spreadability, the panelists used plastic knives to spread the references and mayonnaise samples on pieces of white sandwich bread. The panelists evaluated the force required to spread the sample across the bread and how uniform the sample spread. The panelists used these characteristics to determine the spreadability score of the mayonnaise samples. To evaluate surface shine, the references and the may-

onnaise samples were placed on a white Styrofoam plate for viewing. The panelists determined the amount of shine/light reflected off the surface of each sample.

Consumer Sensory Test. One hundred and ten panelists participated in the study. Panelists representing a university population were recruited based on availability and health (no food allergies). The majority of panelists (74%) were between the ages of 18 and 30 years, and 64% of the panelists were female. Sixty-six percent of the panelists reported that they consume mayonnaise at least once per week.

The panelists used a ballot to evaluate the appearance, odor, mouth feel/texture, flavor and overall acceptability of the mayonnaise formulations. A 9-point hedonic scale was used (1 = dislike extremely 5 = neither like nor dislike and 9 = like extremely) to evaluate the products attributes. The panelists were asked about their intent to purchase the product and were given space to indicate what specifically they liked or disliked about the products attributes.

Three mayonnaise formulations were chosen for evaluation: control; MCS; and WPC-FGB. These formulations were selected based on their performance in the physiochemical and trained-panel sensory evaluations. Consumers will typically experience sensory fatigue and decreased concentration when more than three samples are presented to them. The egg-substitute treatments were colored to have the same yellow appearance as the control. Each formulation was randomly assigned a three-digit code, and the samples were randomly distributed to the panelists. The samples were placed into marked, clear, 40 mL plastic cups. The panelists were given spoons to sample the mayonnaise. Distilled drinking water and crackers were used to cleanse the palate between samples. Data were collected during one session over 4 h. Consumer data between panelists were expected to be variable, but consistent within panelists.

Statistical Analysis

The physical measurements were evaluated in a modified in complete-block design. The experiment was conducted over 12 days (blocks). The control was done each day, for a total of 12 replications. Three replications were made for each egg substitute, distributed over the 12 blocks; duplicate pairing was avoided. Three subsamples of each replication were taken, and measurements were made on each sub-sample. Analysis was done by using SAS GLMMIX (SAS 2003). When treatment effects were found significantly different, the least squares means with Tukey–Kramer groupings were used to differentiate treatment means. The trained-panel results were evaluated in a

randomized block design where blocking was based on panelists, $n = 10$. The consumer test results were evaluated in a randomized complete-block design where blocking was based on consumers, $n = 110$. Consumer data was expected to be variable, between panelist but consistent within panelists. The panelists' answers to the intent to purchase question were converted to numerical values, yes = 1 and no = 2. A level of significance was observed at $\alpha = 0.05$ for all statistical calculations.

RESULTS AND DISCUSSION

Physical Measurements

WPI and the control exhibited emulsion stability values that were not significantly different at 100% replacement (100:0). All other 100:0 samples had emulsion stability values that were significantly higher than that of the control (Table 1). Takeda *et al.* (2001) found similar success when evaluating wheat gluten in o/w emulsions. They reported that gluten was an excellent emulsifying agent at acidic pH. They attributed these results to the glutenin and gliadin fractions forming a viscoelastic protein film around the oil droplets preventing coalescing. Garti *et al.* (1997) evaluated FG individually in o/w

TABLE 1.
COMPARISON OF EMULSION STABILITY VALUES* OF
MAYONNAISE SAMPLES PREPARED WITH EITHER EGG
YOLK OR EGG SUBSTITUTE AT TWO REPLACEMENT
LEVELS AT AMBIENT TEMPERATURES

Treatments	Emulsion stability (h)		pH	
	100:0	50:50	100:0	50:50
Control	25.50 ^e	NA	3.78 ^b	NA
WP	54.33 ^{cd}	35.33 ^{de}	3.52 ^c	3.73 ^{bc}
WPC	74.67 ^b	22.67 ^e	4.17 ^a	3.98 ^{ab}
WPI	31.33 ^e	17.33 ^e	4.17 ^a	4.03 ^{ab}
MCS	90.67 ^{ab}	20.00 ^e	3.04 ^d	3.52 ^c
WPC-FGB	96.00 ^a	20.00 ^e	3.88 ^{ab}	3.95 ^{ab}
WPI-GB	72.33 ^{bc}	18.33 ^e	3.94 ^{ab}	3.90 ^{ab}

* Means with different superscripts indicate significant differences among all treatments ($P \geq 0.05$).

WP, wheat protein isolate; WPC, whey protein concentrate; WPI, whey protein isolate; MCS, modified corn starch; FG, fenugreek gum; GB, gum blend; PB-S-GSP, propylene glycol alginate, locust bean and guar gum; NA, not applicable.

emulsions. They reported that FG had the ability to significantly reduce the interfacial tension of oil and water and form a thick interfacial film on oil droplets, which creates a stable emulsion having small oil droplets.

Despite the 12.5% decrease in whey concentrate, the whey concentrate blends produced mayonnaise with stability values that were comparable with that of the WPC treatment. The thickening properties of gums may have caused an increase in viscosity, which slowed down the migration rate of oil droplets (Chouard 2004). Although the two blends were used at the same level, the mayonnaise containing FG exhibited higher emulsion stability than the sample containing the TIC gum blend. This corresponds with data reported by Garti *et al.* (1997), who found that FG had superior emulsification properties, compared with those of locust bean and guar gums.

The emulsion stability of all treatments at 50% replacement (50:50) was not significantly different from that of the control. The MCS, WPI-GB, WPC and WPC-FGB treatments had significantly lower emulsion stability values than their respective 100:0 samples (Table 1). Emulsion stability often decreases with a decrease in viscosity, which allows the movement of oil droplets through the aqueous phase (Ramachandra-Rao and Hemantha-Kumar 1998; Chouard 2004). Most of the 50:50 treatments exhibited lower viscosity values than the 100:0 samples, which may lead to their decreased stability.

Commercial mayonnaise is shelf stable and can remain at refrigerated temperatures for up to six months. The extended stability of commercial mayonnaise is caused by a homogenization step during production. Homogenization is the use of intense shearing to increase the number and reduce the size of the oil droplets in the dispersed phase. The droplet size is an important factor in emulsion stability, and an emulsion containing a large number of small droplets is more stable. In the current work, no homogenization step was performed, resulting in lower stability values, compared with those of a commercial mayonnaise.

Microbial growth and sour flavor notes are influenced by pH. The control mayonnaise had a pH value of 3.78 (Table 1), which is similar to the pH of average commercial mayonnaise samples studied by Gomez and Fernandez (1992), Chirife *et al.* (1989), 3.88 and 3.84, respectively. Commercial mayonnaise typically has a pH between 3.5 and 4.2. The MCS was the only egg substitute that produced mayonnaise with a pH below this range. The protein-based treatments with 100% substitution made mayonnaise with significantly higher pH values compared with the pH of MCS. The control's pH was significantly lower than the two whey treatments, but was not significantly different from either of the whey concentrate blends. The pH values of the 50:50 treatments were between the control and their respective 100:0 samples. All 50:50 treatments, except MCS, had pH values that were not significantly different, from the control.

TABLE 2.
L AND HUE VALUES* OF MAYONNAISE SAMPLES
PREPARED WITH EITHER EGG YOLK OR EGG
SUBSTITUTE AT TWO REPLACEMENT LEVELS,
MEASURED BY USING A HUNTER LAB MINISCAN

Treatments	L value		Hue value	
	100:0	50:50	100:0	50:50
Control	79.74 ^a	NA	91.00 ^d	NA
WP	82.72 ^a	82.29 ^a	96.80 ^b	92.97 ^c
WPC	80.32 ^a	80.35 ^a	97.89 ^{ab}	93.24 ^c
WPI	81.85 ^a	80.01 ^a	99.18 ^a	93.21 ^c
MCS	84.47 ^a	83.42 ^a	98.12 ^{ab}	92.94 ^c
WPC-FGB	82.00 ^a	81.76 ^a	97.57 ^{ab}	93.06 ^c
WPI-GB	81.61 ^a	80.83 ^a	98.11 ^{ab}	93.73 ^c

* Means with different superscripts indicate significant differences among all treatments ($P \geq 0.05$).

WP, wheat protein isolate; WPC, whey protein concentrate; WPI, whey protein isolate; MCS, modified corn starch; FG, fenugreek gum; GB, gum blend; PB-S-GSP, propylene glycol alginate, locust bean and guar gum; NA, not applicable.

The emulsion stability (i.e., shelf life) of different mayonnaise formulations is presented in Table 1. The emulsion stability increased significantly (about fourfold) for the mayonnaise formulated with WPC-FGB and for the mayonnaise formulated with MCS alone (more than threefold) compared with the control treatment. This result suggests that these treatments may possess better polysaccharides-protein interaction in stabilizing mayonnaise formulation and can have variable effect on stability and rheological properties. Also, this result confirms the previous finding that addition of IC and WP as an emulsifier alternative to egg yolk in a model mayonnaise system can efficiently stabilize the o/w emulsion (Abu Ghoush *et al.* 2008). Thus, the oil droplets were kept apart by the particulate WPC-FGB and coalescence became less likely than that of the 100% egg yolk during storage. Also, 50:50 WPC-FGB and the other treatments exhibited a less stability compared with 100:0.

All treatments exhibited L^* values (Table 2) that were not significantly different and ranged from 79.74 to 84.47. The control exhibited a significantly lower hue value (more color) than did all other treatments (Table 2). This may be because the egg substitute treatments did not contain the yellow pigments that egg yolk does (i.e., xanthophylls, lutein, carotene and cryptoxanthin). Vulink (2000) observed similar results when comparing whey protein emulsions with those made with egg yolk. The 50:50 treatments all had hue values that were between the control and their respective 100:0 samples. All 50:50 treatments exhibited hue values that were not significantly different.

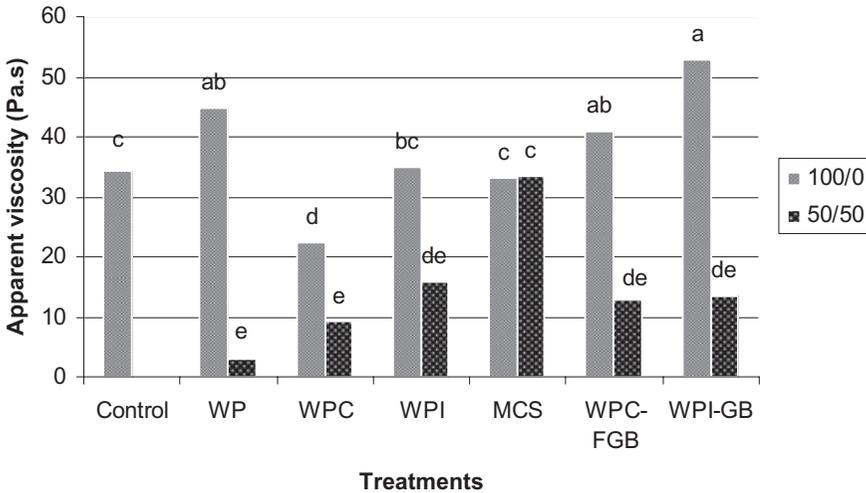


FIG. 1. COMPARISON OF APPARENT VISCOSITIES OF MAYONNAISE SAMPLES PREPARED WITH EITHER EGG YOLK OR EGG SUBSTITUTE AT TWO REPLACEMENT LEVELS, AT 4C AND SHEAR RATE 9.25/S

Means with different superscripts indicate significant differences among all treatments ($P \geq 0.05$).

WP, wheat protein isolate; WPC, whey protein concentrate; WPI, whey protein isolate; MCS, modified corn starch; FG, fenugreek gum; GB, gum blend; PB-S-GSP, propylene glycol alginate, locust bean and guar gum.

The control exhibited an apparent viscosity value that was not significantly different from viscosities of MCS and WPI at 100% replacement (Fig. 1). WPC 100:0 had a significantly lower viscosity than did the control, whereas the viscosity value of whey concentrate blends 100:0 and wheat protein 100:0 were significantly higher. These results indicate that the egg substitute treatments at 100% replacement are capable of forming emulsions similar to those made by egg yolk. Whey protein has been evaluated and has shown success as an emulsifier for mayonnaise-like products (Morris and Taylor 1982; Jost *et al.* 1989; Daugaard 1993a,b; Turgeon *et al.* 1996). Daugaard (1993a,b) found that several whey protein products produced emulsions with similar organoleptic, viscosity and creaminess values as those of the egg control. Turgeon *et al.* (1996) reported that several whey protein fractions produced emulsions with complex viscosity measurements comparable with a commercial mayonnaise.

The whey concentrate blends had apparent viscosities significantly higher than that of the whey concentrate treatment, despite the 12.5% decrease in whey concentrate. This is caused by the gelling/thickening and emulsifying effects of the gums. The TIC gum blend contains alginate, locust bean, and guar gums.

Locust bean gum can produce a heat-irreversible gel, whereas guar gum is an excellent emulsifier and thickening agent; alginate has emulsifying, gelling and shear-thinning thickening properties. Chiralt *et al.* (1994) found that when processing emulsions containing egg yolk and locust bean gums, an increase in gum from 0.5 to 1% increased the apparent viscosity of the samples.

All protein-based treatments at 50% replacement had apparent viscosity values that were significantly lower than that of the control (Fig. 1). The 50:50 protein-based treatments had significantly lower viscosities than those of their respective 100:00 samples. These data may suggest an antagonistic effect between egg yolk protein and either whey or wheat proteins. This is contradictory to what Daugaard (1993a,b) reported. Their studies found there were no synergistic or antagonistic effects between egg yolk and whey protein when cold processing was used. There was an antagonistic effect however, when the process involved the heating of the proteins (Daugaard 1993a,b). There was no significant difference between MCS at 100 and 50% replacement, indicating that was no antagonistic or synergistic relationship between egg yolk and the MCS.

MCS at 100% replacement exhibited a significantly lower firmness value compared with that of the control (Fig. 2), but the MCS and control had similar apparent viscosity values, approximately 35 Pa·s. These results would indicate that apparent viscosities are the same. The force required to start the flow of the sample is much less for MCS than the control, as less force was required to penetrate the sample.

WPI and blends had a firmness value significantly higher than that of the control. The remaining 100:0 treatments (WP, WPC, WPC-FGB) had firmness values that were not significantly different from that of the control. This indicated that the egg substitutes were able to produce mayonnaise-like emulsions at 100% replacement.

As seen with viscosity, all 50:50 protein-based treatments had significantly lower firmness values than did their 100:0 samples, suggesting an antagonistic relationship between egg protein and either whey or wheat proteins. The MCS 50:50 and 100:0 treatments had firmness values that were not significantly different, suggesting that no antagonistic relationship existed between egg protein and the MCS. All 50:50 treatments had significantly lower than that of the control.

Trained Sensory Panel

The control and wheat isolate exhibited surface shine scores that were not significantly different, but both these treatments had significantly higher scores than the other treatments did (Fig. 3). WPC, MCS, and WPC-FGB all had Surface shine values that did not differ significantly. The surface shine seems

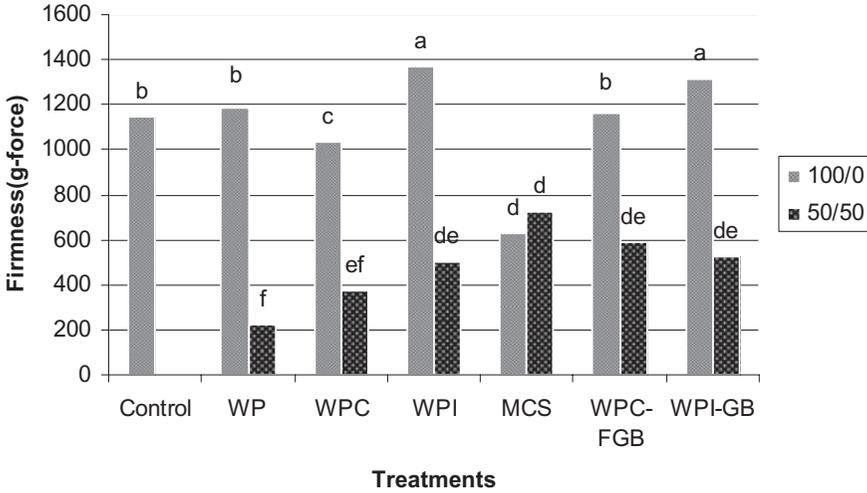


FIG. 2. COMPARISON OF FIRMNESS OF MAYONNAISE SAMPLES PREPARED WITH EITHER EGG YOLK OR EGG SUBSTITUTE AT TWO REPLACEMENT LEVELS, AT 4C AND SHEAR RATE 9.25/S

Means with different superscripts indicate significant differences among all treatments ($P \geq 0.05$).

WP, wheat protein isolate; WPC, whey protein concentrate; WPI, whey protein isolate; MCS, modified corn starch; FG, fenugreek gum; GB, gum blend; PB-S-GSP, propylene glycol alginate, locust bean and guar gum.

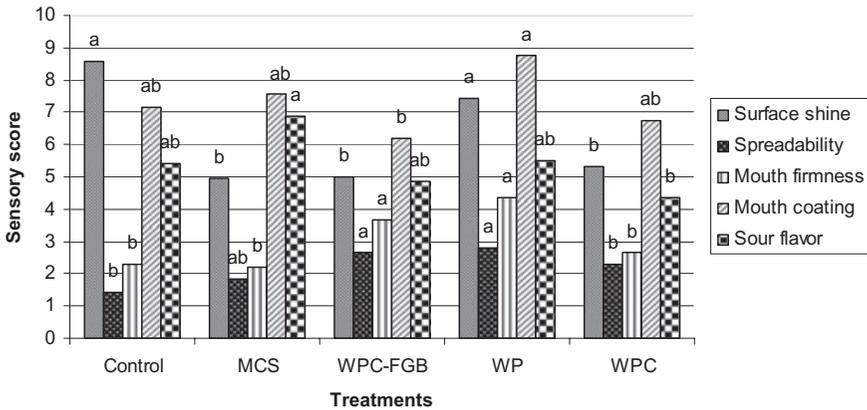


FIG. 3. ATTRIBUTES SCORES FOR MAYONNAISE MADE WITH THE EGG YOLK AND SELECTED EGG SUBSTITUTES, AS MEASURED WITH A TRAINED SENSORY PANEL

Means with different superscripts indicate significant differences among all treatments ($P \geq 0.05$).

WP, wheat protein isolate; WPC, whey protein concentrate; MCS, modified corn starch; FG, fenugreek gum; GB, gum blend.

to be correlated with the emulsion stability values. The control and wheat isolate 100:0 had lower emulsion stability values than those of the other treatments evaluated by the panel, which may have caused them to have a shiny appearance as the emulsion started to break down.

Wheat isolate and WPC-FGB exhibited significantly higher spreadability values than that of the control. This does not follow the physical measurements of mayonnaise firmness, for which wheat isolate and WPC-FGB were not significantly higher than the control. Both WPC and MCS had spreadability values that were not significantly different from those of the control.

Wheat isolate and WPC-FGB had significantly higher firmness values than those of the remaining treatments, including the control. These values corresponded with the spreadability values.

All the egg-substitute treatments had mouth-coating scores that were not significantly different from that of the control. Wheat isolate and FG/ whey concentrate were the only treatments that exhibited significantly different mouth coating scores.

All the egg-alternatives treatments had sour flavor scores that were not significantly different from that of the control. The MCS and WPC were the only treatments that had significantly different sour flavor scores, with MCS having a higher value. This corresponds to the pH of the samples; MCS exhibited a significantly lower pH value than that of WPC.

Consumer Panel

MCS and fenugreeek/whey concentrate had higher appearance scores than that of the control, with MCS having the highest score (Fig. 4). Several consumers commented that the control had an oily/greasy appearance and that MCS had a smooth creamy appearance. This corresponds to the trained panel's evaluation of the surface shine, finding that the control had a higher shine than that of MCS and WPC-FGB. Consumers commented that all three samples had more yellow pigment than typical mayonnaise.

All three treatments exhibited odor values that were not significantly different. Consumers' comments were divided between no odor and vinegar/acetic acid odor for all treatments.

MCS had the highest mouthfeel score. Consumers commented that the sample was very smooth in texture. The control and WPC-FGB had mouthfeel scores that were not significantly different. Several consumers commented that the control had a greasy mouth feel and that WPC-FGB felt too thick.

WPC-FGB had a higher flavor score than that of the control, but the score was not significantly higher than the score for MCS. The control and MCS had multiple consumer comments about the high acid/sour flavors.

The control had a lower acceptability score than the egg substitute treatments had acceptability scores for MCS and WPC-FGB was not significantly

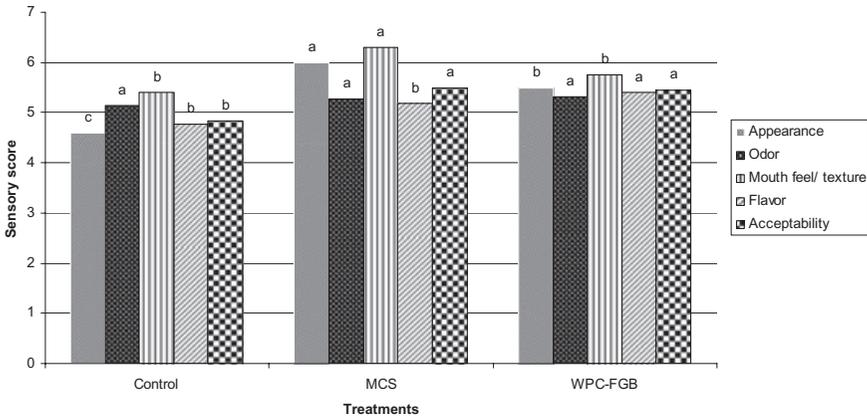


FIG. 4. ACCEPTABILITY SCORES FOR MAYONNAISE SAMPLES MADE WITH THE CONTROL AND SELECTED EGG SUBSTITUTES AS MEASURED BY A CONSUMER PANEL ($n = 110$)

Means with different superscripts indicate significant differences among all treatments ($P \geq 0.05$). WPC, whey protein concentrate; WPI, whey protein isolate; MCS, modified corn starch; FG, fenugreek gum; GB, gum blend.

TABLE 3.
CONSUMER'S INTENT TO PURCHASE MAYONNAISE SAMPLES MADE WITH THE CONTROL AND SELECTED EGG SUBSTITUTES AS MEASURED BY A CONSUMER PANEL, $n = 110$

	%		
	Control	MCS	WPC-FGB
Yes	38.7	45.7	43.8
No	61.3	54.3	56.2

WPC, whey protein concentrate; MCS, modified corn starch; FGB, fenugreek gum blend.

different. All three treatments had intent-to-purchase scores that were not significantly different. Table 3 has the percentage breakdown of the consumers' intent to purchase answers.

CONCLUSION

The present study demonstrated that several commercially available ingredients can successfully replace 100% of the egg yolk in a mayonnaise

formulation. All four whey based treatments exhibited texture properties that were similar to those of the control and emulsion stability values that exceeded the stability score of the control. The sensory evaluations indicated that the whey-based treatments exhibited attributes similar to the control, and consumers preferred the appearance and flavor of the whey-based treatment. These results demonstrate the ability of whey proteins to successfully replace egg yolk in a mayonnaise formulation. The addition of gums to the WPC treatment produced mayonnaise similar to that of the control and WPC treatments, but the amount of WPC used was decreased by 12.5%, which could be advantageous when evaluating the cost of ingredients. Wheat protein showed similar success in the mayonnaise formulation. When used at 50% replacement, both the whey and wheat proteins exhibited an antagonistic relationship with egg yolk. MCS had a viscosity value that was similar to viscosity score of the control and had higher emulsion stability. The texture values of MCS were significantly lower than the control, but the trained panel did not detect this difference. The pH of the MCS was not typical for mayonnaise. The consumers overall acceptance score was higher for the cornstarch than for the control.

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