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RESEARCH ARTICLE

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Pasta quality as impacted by the type of flour and starch and the level of egg addition

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Abstract

This study investigated the effects of substituting wheat flour with fractions of different starch types and egg levels on pasta quality. First order mixture response surface model was used where the effects of various starch types and egg levels on pasta quality were evaluated. Coefficients of estimation were determined and fractional contribution of wheat, starch type and egg levels were evaluated. Egg levels negatively ($p < .05$) impacted treatments pasting viscosities, except in potato starch and rice flour. Stabilized rice bran peak viscosity increased from 215.0 to 3420.0 cP with decrease in egg level from 33 to 0%. Flow behavior index of treatments solution with various fractions of starch types and egg level ranged from 0.34 to 1.42 and was significantly ($p < .05$) lower than control (i.e., 2.15) indicating a better fit as a shear thinning model. Water holding capacity values of acorn starch and lupine flour were the greatest among treatment ranging from 86.8% to 176.0% and from 83.3% to 152.0%, respectively. Results also showed a possible modification of cooked pasta quality including firmness, stickiness, cooking loss, and water uptake, keeping with consumer acceptability through varying starch type and egg level.

Practical applications

Results show that flour and starch type and egg level interaction play significant role in pasta blends formulation. Moreover, substitution of wheat flour with acorn, native or modified corn and potato starches fractions, as well as with lupine, rice, tapioca, and stabilized rice bran flours would have significant effects on the physical properties and acceptability of various cereal products. For instance, the use of rice bran in potentially developed products would enhance the consumption of whole grain foods, resulting in improved intake of fiber and other healthy components.

KEYWORDS
egg level, flour type, pasta quality, starch type

1 | INTRODUCTION

Pasta is one of the most commonly consumed cereal products due to the convenience of preparation, palatability, and nutritional quality. It contains about 77% carbohydrates and 11–15% proteins (Bashir, Aeri, & Masoodi, 2012). Firmness of pasta dough and stickiness of cooked pasta are probably the primary quality parameters of pasta (D'egidio, Mariani, Nardi, Novaro, & Cubadda, 1990). Hydration of the protein fraction before starch gelatinization also appears to play a critical role in constructing the final pasta quality. The ability of proteins to form a continuous and interconnected protein phase that is able to entrap starch granules can provide the necessary cohesion of pasta. In contrast to bread dough, where the native endosperm proteins are usually fully hydrated forming a gluten polymeric three-dimensional network, protein network formation is limited in the case of pasta dough (Dexter & Matsuo, 1978). Proteins are known to provide a support network for starch granules through the formation of starch–proteins network providing strength for starch granules (Hamaker, Griffin, & Moldenhauer, 1991).

Several studies have investigated the supplementation of pasta flour with various legumes. For example, Zhao, Manthey, Chang, Hou, and Yuan (2005) studied the effect of incorporating green and yellow peas, lentils, and chickpea flours on the quality characteristics of spaghetti. The authors reported a general increase in trimness and

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color intensity but a decrease in the overall quality of cooked spaghetti when substituting wheat flour with the legume flours. Sabanis, Makri, and Doxastakis (2006) also investigated the effect of 5–50% durum flour replacement using untreated chickpeas flour on the physical properties of lasagna dough. The authors reported improved physical properties of lasagna dough, but a deterioration of processing, handling and cooking characteristics with the increased substitution levels was also reported. Others indicated that functional properties of pasta dough as well as cooked pasta are affected by changes in flour chemical composition, protein quality, and water absorption kinetics during cooking (Debbouz & Doetkott, 1996 and D'egidio et al., 1990).

Starch substitution can be used to modify the performance of a given wheat flour for pasta. In this regard, Hen, Chols, and Voragen (2006) investigated that effect of, substituting part of wheat flour with fractions of potato and sweet potato starches and their derivatives on white salted noodles. The authors reported a decrease in cooking loss and significant increase in softness, stretchability, and slipperiness when replacing up to 20% wheat by acetylated potato starch or acetylated sweet potato starches. Rho, Chung, and Seib (1989) also reported that addition of 10% modified wheat or waxy maize starches decreased surface firmness of cooked noodles. The use of navy pinto bean starches, conversely, was reported to significantly increase hardness of cooked starchy noodles (Kim, Wiesenborn, Lorenzen, & Berglund, 1996). Payas-Duarte, Mock, and Satterlee (1996) substituted durum wheat with lupine, light, and dark buckwheat and amaranth flours (i.e., at 5, 15, 25, and 30%) and produced multigrain pastas. The authors indicated that the use of lupine did not affect pasta characteristics; however, the use of dark buckwheat and amaranth significantly decreased firmness and increased cooking loss and color values compared to the control durum-flour significantly. Perez and Perez (2009) reported that the use of 20% of cassava flour in making fettuccines has no impacts on cooking loss and sensorial color, taste, texture, and appearance of produced fettuccines. However, the authors reported a decrease in protein content when replacing 20% of wheat with cassava flour. Additionally, the use of acorn for human consumption has increased due to its nutritional value (Ozcan 2007; Ozcan & Gulriz 2005; Rababah et al., 2008).

Durum wheat sometimes lacks some of pasta functional characteristics including cooked weight loose and firmness due to inconsistent seasonal variations of wheat quality. Therefore, supplementation of pasta with starches is of great interest to account for such variations and keeping pasta functionality without the necessity of using dough improvers. Lupine flour, for instance, has gained great interest as food ingredient supplementing different food products due to its protein (i.e., 40–45%) and fiber (i.e., 25–30%) contents (Abdelrahman, 2014; Lopez, 2014). The high lysine, low methionine content of lupine complements that of wheat flour proteins which are poor in lysine and relatively higher in the sulphur containing amino acids. Lupine flour was largely used in cakes, pancakes and has been added to spaghetti, bread as well as gluten free products (Dervas, Doxastakis, Hadjisavva-Zinoviadi, & Triantafillakos, 1999; Tronc, 1999).

Limited information are available on the effects of cereal and other plant starches/flours products including acorn starch, lupine flour, corn and modified corn starches, potatoes, and tapioca flour on pasta quality. The use of such products is expected to influence pasta quality. Therefore, the objective of the current work is to provide detailed information on the effects of replacing wheat flour with fractions of various starch/flour on pasta quality characteristics.

2 | MATERIALS AND METHODS

2.1 | Materials

Commercial all-purpose wheat (Al-Arabia Wheat Flour, Co.), Rice flour and stabilized rice bran (Gulf Rice Milling Co., Inc. Houston, TX), native corn starch (Alalali, Basamh Marketing Co., Ltd., Saudi Arabia), modified waxy corn starch (Penford Food Ingredient, Centennial, Co.), tapioca flour (Monity and Totoco Co., Ltd., Bangkok Thailand), potato starch (Barry farm, Wapakoneta, OH) lupine flour (Irwin Valley Milling Pty Ltd., Western, Australia), acorn starch (i.e., locally harvested and extracted as described below), and whole egg powder (Honeyville Food Products, Inc., Brigham City, UT) was used in this study.

Acorn starch was produced using sodium hydroxide alkaline solution according to the method described by Sosulski and McCurdy (1987) with minor modification of soaking durations. In summary, acorn flour was defatted by soaking in hexane (1:10 w/v) for 24 hr after which hexane was drained. Defatted acorn flour was soaked in a 0.02 N sodium hydroxide solution (1:10 ratio w/v) for 2 hr at 25C with continues stirring. The soaked sample was then wet-milled in an Osterizer blender for 3 min (i.e., speed setting at 6) and filtered twice though U. S. standard test sieves number 100 and then 400, respectively. The slurry was then centrifuged at 4,000 rpm for 30 min at 4C in a 5810R centrifuge, (Eppendorf, Germany) and the supernatant was discarded. The sediment was washed five times with 0.02 N sodium hydroxide (1:10 flour to sodium hydroxide) and the slurry was then centrifuged again at 4,000 rpm for 30 min. The dark tailings layer atop the starch sediment was carefully scraped away and discarded. The sediment was washed three times using distilled water, centrifuged at 4,000 rpm for 30 min and again the dark tailings layer atop the starch was carefully scraped away and discarded. After washing and centrifugation, the resulting sediment was suspended in distilled water and adjusted to pH of 7.0 (pH meter: HANNA Instrument, UK) with 0.1 N hydrochloric acid (HCl) before a final centrifugation at 4,000 rpm for 30 min. The resulting starch was then air dried for 48 hr at 40C to a moisture content of 12% before grinding and passing through a sieve number 100.

2.2 | Design of the experiment

A three factors first order mixture response surface design was used as described by Scheffé (1965) to conduct the study where wheat (x_1), starch or flour type (x_2), and whole egg powder (x_3) were considered as the main factors (Table 1). The proportions of each factor used in the model were expressed as a fraction of the mixture and for each

TABLE 1 Mixture response surface model of starch/flour type, wheat, and whole egg powder used in this study

Treatments	Wheat, starch/flour, and egg fractions		
	X_1 (%)	X_2 (%)	X_3 (%)
66% X_1, 17% X_2, 17% X_3	66.0	17.0	17.0
50% X_1, 50% X_2, 0% X_3	50.0	50.0	0.0
33% X_1, 34% X_2, 33% X_3	33.0	34.0	33.0
17% X_1, 66% X_2, 17% X_3	17.0	66.0	17.0
0% X_1, 50% X_2, 50% X_3	0.0	50.0	50.0

Note. Fractions represent percentage of a total of 100 g treatment.
X_1 = wheat %; X_2 = Starch or flour %; X_3 = Egg %.

treatment combination, the sum of the component proportions will be equal to one (Equation 1), where:

$$X_i = x_1 + x_2 + x_3 = 1 \tag{1}$$

A full factorial combination of the three factors was used in this study. In this design, the number of points (*n*) necessary to run a mixture experiment is: $n = 2_q - 1$ where *q* is equal to the number of components being studied (3). JMP release 10.0 (SAS institute, Cary, NC) was used to build up the model parameters. Table 1 also presents the percentages of each of the three variables (i.e., wheat, starch or flour type and egg level) used in the model. Fractions represent percentage of a total of 100 g of starch/flour type, wheat, and egg powder used in each treatment. Control sample (i.e., 100% wheat) was included in the study.

2.3 | Pasting measurement

Pasting profile and viscosities (i.e., peak, trough, setback, breakdown, and final) and pasting temperature of treatments were assessed and recorded with a Rapid Visco Analyzer (RVA-4 Rapid Visco Analyzer, Foss North America, Eden-Prairie, MN) according to the AACCI approved method 76-21 (AACC, 2000). Approximately 3 g of each treatment was mixed with 25 ml of distilled water. The slurry was then mixed at 50C for 1 min at 160 rpm before being heated from 50 to 95C at a heating rate of 12C/min. The hot paste was then held at 95C for 2.5 min and then cooled down to 50C at a cooling rate of 12C/min. Data obtained from the RVA were processed by Thermocline version 1.2 software (Newport Scientific Inc., Warriewood, Australia). All samples were measured in triplicate.

2.4 | Rheological measurements

A mixture of 5.0 g of each treatment and 95 ml distilled water was prepared for rheological property measurements. Homogenization of treatments was performed using a homogenizer (×120, Igenieurbuero CAT, Stufen, Germany) before rheological property measurements. Treatments were held at the room temperature (23.2C) for 1 hr before rheological measurement. Apparent viscosity of treatments was measured during shear rate of 6–60/s at 23.2C. A rotational viscometer (SNB-AI Digital Viscometer, Shandong, China) was used for viscosity measurements where samples were kept constant in a holding cup during the entire rheological measurement duration. Flow behaviors of treatment described in terms of consistency coefficient and flow behavior index was evaluated in this study using Herschel–Bulkley model (Equation 2) and was used to describe the experimental data for flow curves of all samples

$$\tau = \tau_o + {}_m\gamma^{\dot{n}} \tag{2}$$

where τ is shear stress (mPa), τ_o is yield stress (mPa), *m* is the consistency coefficient (mPa·s^n), $\dot{\gamma}$ is shear rate (s^{-1}), and *n* is the flow behavior index (dimensionless). Herschel–Bulkley model was used to describe the rheological behavior of treatments functional properties. Flow behavior index (*n*) is typically used to characterize fluid and semi-fluid behavior with *n* value of (1) describing a Newtonian fluid, *n* value of less than (1) describing a shear thinning, and *n* value of greater than (1) describing a shear thickening fluid behavior.

2.5 | Water holding capacity

Water holding capacity (%) of each treatment was determined by the method described by Abu-Salem and Abou-Arab (2011) with modifying the centrifuge speed and the holding temperatures. In summary, flour treatments were dispersed in distilled water and the dispersions was allowed to stand for 1 hr at 25, 35, 45, and 55C before centrifuging (Eppendorf, 5810R, Hamburg, Germany) at 3800 RPM for 30 min at 4C. Sediment weights were recorded and used to calculate water holding capacity [WHC (%)] as the following equation.

$$\text{WHC }(\%) = (\text{Weight of sediment/weight of dry solids}) * 100\% \tag{3}$$

2.6 | Pasta making and cooked pasta quality

Prepared flour treatments (wheat, various starch/flour ratio, and egg level) were mixed with 30% by weight water containing 2% salt. Treatments were mixed thoroughly using a household kitchen Aid mixer (Model KSM150PSER) at speed of 4 for 5 min to distribute water uniformly throughout the flour particles. The produced pasta dough was then placed in pasta making machine fitted with an adjustable sheet thickness cutter.

Pasta was cooked in excess boiling water with 1 teaspoon of salt and 1 tablespoon of olive oil for 6 min (i.e., optimum cooking time as determined according to AACC method 66-50.01, 2000). Immediately after cooking, pasta was drained into a sieve, transferred to a bowl, and cooled to room temperature (23.2C) before quality measurements. All subsequent analyses on cooked pasta were made on pasta cooked at the optimum cooking time ±1 min.

2.7 | Water uptake of cooked pasta

Moisture content of pasta was measured before and after cooking and cooked moisture uptake was calculated using the following equation:

$$\text{Water uptake (\% db)} = \left(\frac{\text{water content (cooked pasta)}}{\text{water content (dry pasta)}} - 1\right) \times 100 \qquad (4)$$

2.8 | Cooking loss of pasta during cooking

The loss of dry matter of pasta after cooking was determined by a two-stage drying procedure. Cooking loss was calculated using the following equation:

$$\text{Cooking loss (\% db)} = \left(\frac{\text{dry matter (cooked pasta)}}{\text{dry matter (dry pasta)}} - 1\right) \times 100 \qquad (5)$$

2.9 | Cooked pasta texture

Texture measurements were evaluated using a texture analyzer (Mecmesin Ltd., West Sussex, RH1306Z, UK). A single compression test measurements of cooked pasta was performed using a 35 mm cylindrical probe compressing a single dough ring strand at a constant deformation rate of (1 mm/s) to 80% of the initial strand thickness. Hardness (i.e., the maximal peak force attained during the first compression) and stickiness (i.e., the negative area under the first compression curve) were recorded.

2.10 | Sensory attributes for cooked pasta

Sensory attributes of cooked pasta were assessed in a sensory evaluation laboratory, Department of Nutrition and Food Technology, Faculty of Agriculture, The University of Jordan. A total of 50 consumers were recruited to perform the consumer evaluation testing. For the consumer testing, each consumer was assigned a log number, given a brief explanation of the test objectives and seated at a separate testing booth. Randomized samples across treatment were served at 25C in Styrofoam food cups and identified by a three-digit code and consumers were instructed to complete their evaluations. Samples were presented one at a time to each of the consumers. Unsalted crackers and water were provided for panelists to rinse their palates between samples. Consumers evaluated each sample in duplicate on separate testing days. A ballot consisting of five questions was designed to evaluate consumers' acceptance of various aspects of the sample to be tested. A 9-point hedonic scale according to Meilgaard, Civille, and Carr (1999) was used. Consumers were asked to express their overall acceptance of the product and their acceptance and texture. Consumers were also asked to intensify the overall product firmness, stickiness, flavor, and color of each sample using the 9-point hedonic scale.

2.11 | Statistical analysis

Analysis of variance (ANOVA) was carried out on physical treatments data using JMP release 10.0 (SAS institute, Cary, NC). Least significant differences (LSD), at a 5% level of probability, were determined between treatments. A first order mixture response surface model was fitted using three factors starch/flour type, wheat, and whole egg powder as the model factors. The model search was started with the special cubic equation (Equation 6):

$$Y = \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_{12} x_1 x_2 + \beta_{13} x_1 x_3 + \beta_{23} x_2 x_3 \qquad (6)$$

where Y is the predicted response, β's are the parameter estimates for each linear and cross product term for the prediction model, x_1, x_2, x_3, x_1x_2, x_1x_3, and x_2x_3 are the linear terms of the factors used and the cross product terms, respectively. The model chosen was based on its significance ($p < .05$), the insignificance of the lack of fit and the highest R^2 according to Cornell (1986).

3 | RESULTS AND DISCUSSION

Table 2 presents the effect of starch/flour type and egg level on the pasting properties of wheat flour treatments. Stabilized rice bran had the lowest ($p < .05$) peak viscosity of 72.5 cP compared to 6767.5 cP for waxy corn starch. Regardless to the egg level used, the increase in wheat proportions in treatments resulted in an increase in peak viscosity of stabilized rice bran treatments and in a decrease in waxy corn starch peak viscosity. For instance, the increase in wheat contribution from 17 to 34, 50, and 66% resulted in an increase in peak viscosity of stabilized rice bran treatment from 72.5 to 215.0, 3420.0, and 1484.0 cP, respectively. A similar trend was reported for lupine treatments. Conversely, peak viscosity of waxy corn starch treatment decreased from 6767.5 to 2279.5 cP as the wheat proportion increased from 17% to 66%, respectively. Similarly, peak viscosity of acorn starch treatments increased from 549.5 cP to 691.5, 3713.0, and 1115.0 cP with the increase in wheat proportion from 17 to 34, 50 and 66%, respectively.

Results also indicated a significant contribution of egg level in affecting treatments peak viscosity. For example, peak viscosity of stabilized rice bran treatment decreased from 3420.0 to 215.0 cP as the egg level in samples increased from 0% to 33%. Native corn and acorn starch and tapioca flour treatments showed similar trends with peak viscosity decreased from 4921.0 to 1513.0 cP for corn and from 3713.0 to 691.5 cP for acorn and from 3423.5 to 1940.0 cP for tapioca flour with the increase in egg level from 0% to 33%, respectively. Rice flour, on the other hand, showed a decrease in peak viscosity from 1350.0 cP to 548.5 with the decrease in egg level from 33% to 0% in treatments. Similar trends were reported for trough, breakdown, final, and setback viscosities of starch/flour types and egg levels. A 100% wheat flour control had pasting viscosities of peak, trough, breakdown, final, and setback viscosities of 1873.2, 1520.3, 352.9, 1950.5, and 430.2, respectively.

These results demonstrated that pasting properties of wheat are greatly affected by the starch/flour composition (i.e., protein and fiber types and contents). Sliwinski, Kolster, Prins, and Van Vliet (2004) and Chiang, Chen, and Chang (2006) demonstrated that greater protein resulted in higher extensibility, greater bread loaf volume height and expansion. This was further supported by the fact that the greater protein content of treatments due to the increased lupine flour, for example, resulted in low pasting properties. Starch was long reported to play the principal role in pasting formation. Proteins and lipids were also reported to promote the formation of a protective insoluble polymeric matrix conferring rigidity to the starch granules and also provide

TABLE 2 Pasting viscosities [peak, trough, breakdown, final, and setback (cp)] and pasting temperature [Pasting T. (C)] of wheat flour [17, 34, 50, and 66%] substituted with fractions [66, 33, 50, and 17%] of starch/flour types and egg levels

Starch/Flour type	Peak	Trough	Breakdown	Final	Setback	Pasting T.
Wheat = 17%, Starch type = 66% Egg = 17%						
Acorn Starch	549.5^{f}	535.0^{f}	14.5^{f}	956.0^{e}	416.0^{e}	81.3^{c}
Native Corn Starch	2,700.5^{d}	1,481.0^{d}	1,219.5^{d}	2,998.5^{c}	1,517.5^{c}	74.3^{d}
Lupine Flour	214.5^{g}	160.0^{g}	54.5^{e}	284.5^{f}	124.5^{f}	84.4^{b}
Potato Starch	6,321.5^{b}	2,230.5^{a}	4,091.0^{b}	3,266.5^{c}	1,036.0^{d}	65.3^{f}
Stabilized Rice Bran	72.5^{h}	60.5^{h}	12.0^{f}	175.5^{g}	115.0^{f}	95.0^{a}
Rice Flour	1,766.0^{e}	1,661.5^{c}	54.5^{e}	3,575.5^{b}	1,864.0^{b}	81.6^{c}
Tapioca Flour	3,816.0^{c}	1,263.5^{e}	2,552.5^{c}	2,409.5^{d}	1,146.0^{d}	71.4^{e}
Waxy Corn Starch	6,767.5^{a}	1,986.0^{b}	4,781.5^{a}	4,679.5^{a}	2,693.5^{a}	66.3^{f}
Wheat = 34%, Starch type = 33% Egg = 33%						
Acorn Starch	691.5^{f}	646.5^{e}	45.0^{f}	1,196.5^{e}	550.0^{f}	81.8^{b}
Native Corn Starch	1,513.0^{d}	1,214.0^{c}	299.0^{d}	2,327.5^{c}	1,113.5^{c}	77.1^{c}
Lupine Flour	559.0^{g}	508.5^{f}	50.5^{f}	826.0^{f}	317.5^{g}	81.2^{b}
Potato Starch	2,611.5^{b}	1,386.0^{b}	1,225.5^{b}	2,330.0^{c}	944.0^{d}	67.0^{e}
Stabilized Rice Bran	215.0^{h}	183.5^{g}	31.5^{g}	551.5^{g}	368.0^{g}	94.9^{a}
Rice Flour	1,350.0^{e}	1,226.5^{c}	123.5^{e}	2,840.5^{b}	1,614.0^{b}	81.9^{b}
Tapioca Flour	1,940.0^{c}	1,099.0^{d}	841.0^{c}	1,762.0^{d}	663.0^{e}	73.5^{d}
Waxy Corn Starch	3,613.0^{a}	1,921.5^{a}	1,716.5^{a}	5,051.0^{a}	3,129.5^{a}	67.0^{e}
Wheat = 50%, Starch type = 50% Egg=0%						
Acorn Starch	3,713.0^{c}	1,559.0^{c}	2,154.0^{b}	2,802.5^{d}	1,243.5^{c}	71.8^{f}
Native Corn Starch	4,921.0^{a}	2,033.5^{a}	2,887.5^{a}	3,241.5^{cd}	1,208.0^{c}	66.2^{g}
Lupine Flour	1,550.5^{e}	997.0^{d}	553.5^{e}	1,882.0^{e}	885.0^{d}	77.9^{d}
Potato Starch	543.0^{f}	408.5^{e}	134.5^{g}	948.0^{f}	539.5^{e}	87.3^{a}
Stabilized Rice Bran	3,420.0^{d}	1,864.0^{ab}	1,556.0^{d}	3,688.5^{ab}	1,824.5^{b}	80.3^{c}
Rice Flour	548.5^{f}	340.0^{e}	208.5^{f}	650.0^{f}	310.0^{e}	84.3^{b}
Tapioca Flour	3,423.5^{d}	1,679.0^{bc}	1,744.5^{c}	3,503.0^{bc}	1,824.0^{b}	73.4^{e}
Waxy Corn Starch	4,048.0^{b}	1,873.5^{ab}	2,174.5^{b}	4,004.5^{a}	2,131.0^{a}	66.2^{g}
Wheat = 66%, Starch type = 17% Egg = 17%						
Acorn Starch	1,115.0^{h}	885.5^{f}	229.5^{f}	1,870.5^{f}	985.0^{d}	78.7^{ab}
Native Corn Starch	2,441.5^{c}	1,283.0^{b}	1,163.5^{b}	2,770.0^{b}	1,492.0^{b}	74.2^{c}
Lupine Flour	1,839.0^{f}	972.0^{e}	867.0^{d}	2,087.5^{e}	1,115.5^{c}	77.8^{b}
Potato Starch	2,550.5^{b}	1,343.0^{a}	1,207.5^{b}	2,459.0^{c}	1,116.0^{c}	67.4^{d}
Stabilized Rice Bran	1,484.0^{g}	736.5^{g}	747.5^{e}	1,444.5^{g}	708.0^{e}	79.1^{ab}
Rice Flour	2,814.0^{a}	1,349.5^{a}	1,464.5^{a}	3,383.0^{a}	2,033.5^{a}	67.4^{d}
Tapioca Flour	1,995.0^{e}	1,245.5^{c}	749.5^{e}	2,744.5^{b}	1,499.0^{b}	79.9^{a}
Waxy Corn Starch	2,279.5^{d}	1,202.5^{d}	1,077.0^{c}	2,296.5^{d}	1,094.0^{c}	5.1^{b}

Note. For the same wheat fraction used, pasting viscosity [peak, trough, breakdown, final and setback (cp)] and pasting temperature (°C) for treatments within the same set (i.e., same column) having different letter(s) are significantly ($p < .05$) different according to the LSD.

protection to the starch granules integrity (Saleh & Meullenet 2013). Fractional replacement of various starch/flour types and egg level apparently influenced protein–starch interaction during pasting, which may show that protein and lipid molecules promoted the formation of insoluble polymeric matrix conferring rigidity to the starch granules and also providing protection to starch granule integrity (Grinberg & Tolstoguzov 1997). Marshal, Goynes, and Normand (1990) also indicated that the structure of proteins play a key role in affecting cereals functional properties. The decrease in pasting properties was attributed to the lack of protein's ability to form appropriate bonding necessary for protecting swollen starch granules integrity from rupture as well as the decrease in contribution of total starch available for swelling (Saleh & Meullenet 2007).

Table 3 presents flow behavior index, consistency coefficient, and water holding capacity of various treatments. Wheat flour had flow behavior index and consistency coefficient values of 1.207 and 5.00, respectively, that are greater than that of treatments containing various proportions of starch or flour and egg levels. Flow behavior index (*n*) for treatments [except acorn starch (66%), wheat (17%) and egg (17%)] were less than 1 indicating best fit of batter dough using Herschel–Bulkley Model. Since batter behavior acquired a yield stress, having a flow behavior index of close to 1; data was fitted with Herschel–Bulkley Model. The flow behavior index of treatments ranged from 0.35 to 1.42 irrespective of wheat–starch–egg variation. ANOVA analyses indicated significant differences in flow behavior index and in consistency coefficient across treatments. Acron flow behavior index and consistency coefficient varied with the egg and wheat starch contribution in each treatment. Previous study on the effect of hydrocolloids on the physical properties of acorn starch by Saleh, Ajo, Al-Ismail, and Ondier (2016) suggested that acorn starch viscoelastic behavior is influenced by the variation in treatments chemical composition and water availability. The authors further indicated that the magnitude of change in flow behavior index and consistency coefficient for acorn starch is a function of acorn starch–hydrocolloids interaction.

TABLE 3 Flow behavior index (*n*), consistency coefficient (*m*), and water holding capacity (WHC) of wheat flour [17, 34, 50, and 66%] substituted with fractions [66, 33, 50, and 17%] of starch/flour types and egg levels

Starch/Flour type	Flow behavior index (*n*)	Consistency coefficient (*m*)	Water holding capacity (WHC)
Wheat =17%, Starch type = 66% Egg = 17%			
Acorn Starch	1.42 ± 0.019^{a}	0.46 ± 0.004^{d}	176.0 ± 1.36^{a}
Native Corn Starch	0.94 ± 0.006^{b}	0.44 ± 0.049^{d}	80.2 ± 1.33^{e}
Lupine Flour	0.34 ± 0.003^{g}	0.85 ± 0.002^{b}	152.0 ± 1.44^{b}
Potato Starch	0.72 ± 0.025^{c}	0.48 ± 0.015^{cd}	87.5 ± 1.38^{d}
Stabilized Rice Bran	0.43 ± 0.007^{f}	0.98 ± 0.013^{a}	107.6 ± 0.56^{c}
Rice Flour	0.65 ± 0.019^{d}	0.96 ± 0.034^{a}	89.7 ± 0.44^{d}
Tapioca Flour	0.97 ± 0.005^{b}	0.53 ± 0.004^{c}	81.5 ± 1.53^{e}
Waxy Corn Starch	0.59 ± 0.015^{e}	0.49 ± 0.017^{cd}	80.4 ± 2.78^{e}
Wheat = 34%, Starch type = 33% Egg = 33%			
Acorn Starch	0.85 ± 0.005^{c}	0.89 ± 0.006^{ef}	141.9 ± 0.57^{a}
Native Corn Starch	0.93 ± 0.023^{cd}	1.08 ± 0.011^{c}	76.0 ± 1.36^{d}
Lupine Flour	0.94 ± 0.005^{cd}	0.97 ± 0.024^{d}	121.2 ± 1.13^{b}
Potato Starch	1.09 ± 0.033^{ab}	0.87 ± 0.021^{f}	64.4 ± 0.50^{e}
Stabilized Rice Bran	1.00 ± 0.160^{abc}	1.22 ± 0.011^{b}	81.4 ± 0.87^{c}
Rice Flour	0.99 ± 0.008^{bc}	0.98 ± 0.003^{d}	77.6 ± 1.54^{d}
Tapioca Flour	1.13 ± 0.013^{a}	0.94 ± 0.016^{de}	62.7 ± 0.10^{e}
Waxy Corn Starch	1.02 ± 0.032^{abc}	2.36 ± 0.049^{a}	64.7 ± 0.98^{e}
Wheat = 50%, Starch type = 50% Egg = 0%			
Acorn Starch	0.80 ± 0.008^{d}	0.98 ± 0.014^{a}	149.5 ± 2.11^{a}
Native Corn Starch	0.98 ± 0.025^{a}	1.02 ± 0.029^{a}	79.2 ± 0.01^{f}
Lupine Flour	0.84 ± 0.030^{c}	0.97 ± 0.030^{a}	136.3 ± 1.77^{b}
Potato Starch	0.38 ± 0.006^{g}	0.91 ± 0.181^{a}	85.5 ± 2.07^{e}
Stabilized Rice Bran	0.42 ± 0.013^{f}	0.98 ± 0.039^{a}	108.7 ± 2.07^{c}
Rice Flour	0.98 ± 0.001^{a}	0.86 ± 0.000^{a}	95.1 ± 1.50^{d}
Tapioca Flour	0.59 ± 0.007^{e}	1.05 ± 0.382^{a}	74.5 ± 4.00^{g}
Waxy Corn Starch	0.93 ± 0.010^{b}	1.16 ± 0.003^{a}	85.3 ± 0.71^{e}
Wheat= 66%, Starch type= 17% Egg=17%			
Acorn Starch	0.98 ± 0.000^{c}	1.07 ± 0.070^{a}	86.8 ± 0.57^{a}
Native Corn Starch	0.98 ± 0.003^{c}	1.07 ± 0.071^{a}	75.6 ± 0.71^{ab}
Lupine Flour	0.44 ± 0.005^{d}	0.36 ± 0.009^{d}	83.3 ± 0.82^{a}
Potato Starch	1.00 ± 0.009^{c}	1.06 ± 0.045^{a}	64.7 ± 0.92^{b}
Stabilized Rice Bran	1.22 ± 0.007^{a}	0.50 ± 0.015^{c}	86.7 ± 1.48^{a}
Rice Flour	0.35 ± 0.013^{e}	0.97 ± 0.034^{a}	68.6 ± 0.87^{b}
Tapioca Flour	1.01 ± 0.014^{c}	0.74 ± 0.008^{b}	75.8 ± 0.22^{ab}
Waxy Corn Starch	1.05 ± 0.050^{b}	0.65 ± 0.031^{b}	68.8 ± 0.57^{b}

Note. Flow behavior index (*n*), consistency coefficient (*m*), and water holding capacity (%) ± standard deviation within the same treatment (i.e., same column) having different letter(s) are significantly ($p < .05$) different according to the LSD. Wheat flour (100%) had a WHC of 66.8%.

Response surface model coefficients were calculated and presented in Table 4 to further illustrate the effects of starch type and egg level on the rheological properties of treatments. Flow behavior indices of wheat/starch type interactions and wheat/egg level ranged from 1.18 to 8.49 and 2.23 to 10.80, respectively. Similarly, consistency coefficient of wheat/starch and wheat/egg interactions ranged from 1.92 to 21.22 for wheat/starch and 3.08 to 15.94 for wheat/egg interactions. The shear-thinning behavior of treatments were attributed to structural interactions of wheat/starch and wheat/egg as well as to the changes in composition of batter where the greater starch and egg substituted wheat flour significantly affected batter rheological properties. The results of this study correspond to those from Xue and Ngadi (2006) who reports that changes in viscoelastic properties of gluten are affected by the structural properties of the gliadin and glutenin subfractions and the interactions between them and other components namely lipids and starch. Similarly, Marco and Rosell (2008) showed that changes in viscoelastic properties of batter as a result of increasing water absorption, produced by the addition of protein isolate. Gluten fractions were also reported to be responsible for differences in network matrix formation of noodle resulting in internal firmness (Oh, Seib, Ward, & Deyoe, 1985). Free fatty acids and their esters were also reported to interact with starch resulting in changed noodles quality (Mohri, 1980).

Furthermore, Ashwini, Jyotsns, and Indrani (2009) reported that egg proteins play a key role in the formation of batter rheological behavior of food materials. The authors indicated that as a result of heating; egg yolk coagulation usually determines the final product texture. Egg white was also reported to affect products gelling, foaming, and emulsifying characteristics that controls batter structural formation (Sozer, 2009).

TABLE 4 Coefficient of estimates of flow behavior index (*n*), consistency coefficient (*m*), water holding capacity, cooked pasta water uptake, and cooking loss of wheat flour substituted with fractions of starch/flour types and egg levels

Starch/Flour type	AS	NCS	LF	PS	SRB	RF	TF	WCS
Flow behavior index (n)								
Wheat	0.42	0.18	−1.57	−0.27	0.70	−1.97	−0.36	0.12
Starch Type	3.00	1.20	−0.99	0.87	0.29	−0.31	1.41	0.10
Egg Level	−2.99	−1.18	0.99	−0.85	−0.27	0.32	−1.38	−0.07
Wheat*Starch	3.62	1.18	8.47	3.32	7.27	8.49	5.28	3.28
Wheat*Egg	9.87	6.48	4.62	8.17	7.06	2.23	10.8	5.37
Consistency coefficient (m)								
Wheat	0.57	−0.03	−1.90	0.60	−2.24	−0.03	−0.60	−5.34
Starch Type	−0.14	−0.56	0.37	0.03	0.47	1.29	−0.34	−2.96
Egg Level	0.15	0.58	−0.36	−0.01	−0.45	−1.27	0.36	2.98
Wheat*Starch	3.05	5.28	6.95	2.38	7.46	1.92	6.10	21.22
Wheat*Egg	3.08	4.38	7.45	3.45	8.08	7.89	4.03	15.94
Water holding capacity (%)								
Wheat	−6.8	107.8	2.6	52.4	116.2	53.5	104.7	64.1
Starch Type	36.5	50.7	170.2	86.8	133.8	88.5	118.9	99.0
Egg Level	294.7	68.4	72.0	16.2	65.3	75.0	8.5	3.3
Wheat*Starch	538.6	0.0	199.4	163.5	−64.9	96.5	−149.2	125.2
Wheat*Egg	−227.4	0.0	160.5	148.5	−147.2	−47.6	160.4	166.6
Cooked pasta water uptake (%)								
Wheat	48.3	53.5	70.1	73.3	66.7	66.6	61.5	84.1
Starch Type	194.4	−4.8	55.8	60.0	114.7	53.4	79.6	124.6
Egg Level	0.0	160.0	14.0	16.2	6.9	47.1	−42.7	32.6
Wheat*Starch	0.0	0.0	0.0	106.5	0.0	45.4	0.0	−131.5
Wheat*Egg	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cooking loss (%)								
Wheat	0.85	1.53	3.18	2.11	2.80	2.21	1.85	3.04
Starch Type	16.70	6.33	8.62	9.50	10.80	12.00	6.05	0.79
Egg Level	0.00	−8.13	−3.68	4.60	−3.50	−3.35	−2.65	−0.03
Wheat*Starch	0.00	0.00	0.00	6.00	0.00	6.98	0.00	9.94
Wheat*Egg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

AS = acorn starch; NCS = native corn starch; LF = lupine flour; PS = potato starch; SRB = stabilized rice bran; RF = rice flour; TF = tapioca flour; WCS = waxy corn starch.

Table 3 also presents the WHC of wheat substituted with fractions of starch/flour types and egg levels. Acorn starch (66%), wheat (17%), and egg level (17%) treatment had the greatest (176%) WHC and tapioca flour (33%), wheat (34%), and egg (33) sample had the lowest (i.e., 62.7) WHC. WHC for 100% wheat (i.e., 66.8% not shown) was not included in Table 3. Results indicated an increase in WHC with the increase in starch/flour contribution in treatments, Figure 1, with some exceptions. Lupine flour treatments showed a greater water holding capacity (i.e., 152.0, 121.2, 136.3, and 83.3%) with the decrease in flour percentage in each treatment and irrespective of egg level used. The increased WHC of lupine flour was attributed to lupine protein (i.e., 37.6–52.6%) and fiber (16.2%) contents (Kohajdova, Karovicova, & Schmidt, 2011).

Results further supported a significant three model theory (i.e., starch–protein–lipid) interaction in the formation of WHC. This was clearly demonstrated in Table 4 where wheat/starch and wheat egg interaction showed greater coefficient of estimation than wheat, starch, or egg contribution alone. The increase in lipid content in treatments (i.e., with the increase in egg level in treatments) played a role in

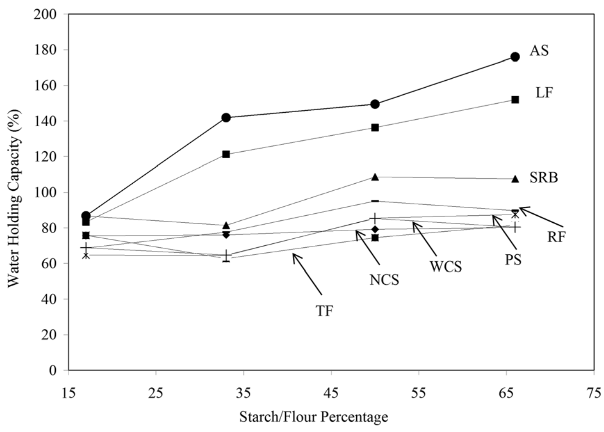

FIGURE 1 Effect of starch/flour types [AS = acorn starch; LF = lupine flour; SRB = stabilized rice bran; RF = rice flour; PS = potato starch; WCS = waxy corn starch; NCS = native corn starch; and TF = tapioca flour] percentage [17, 33, 50, and 66%] on the changes in water holding capacity of wheat flour treatment irrespective to egg level used

TABLE 5 Firmness, stickiness, water uptake, and cooking loss of cooked pasta made using various fractions of wheat and starch/flour types and egg levels

Starch/Flour type	Firmness (N)	Stickiness (N.s)	Water uptake (%)	Cooking loss (%)
Wheat = 17%, Starch type = 66% Egg = 17%				
Acorn Starch	76.4 ± 0.94^{f}	44.7 ± 1.25^{f}	78.5 ± 0.31^{b}	3.2 ± 0.15^{b}
Native Corn Starch	197.0 ± 2.74^{d}	125.8 ± 4.46^{d}	66.5 ± 0.25^{c}	3.1 ± 0.09^{b}
Lupine Flour	258.7 ± 1.04^{a}	176.2 ± 2.18^{a}	42.6 ± 0.05^{e}	3.0 ± 0.20^{b}
Potato Starch	51.9 ± 1.62^{h}	46.2 ± 1.83^{f}	66.8 ± 0.16^{c}	2.8 ± 0.13^{b}
Stabilized Rice Bran	199.7 ± 1.42^{c}	131.2 ± 2.32^{c}	59.5 ± 0.11^{d}	4.2 ± 0.19^{a}
Rice Flour	219.5 ± 3.17^{b}	136.5 ± 2.54^{b}	59.7 ± 0.13^{d}	3.0 ± 0.18^{b}
Tapioca Flour	108.1 ± 1.09^{e}	84.4 ± 0.78^{e}	30.2 ± 0.51^{f}	1.6 ± 0.28^{c}
Waxy Corn Starch	57.0 ± 1.32^{g}	44.3 ± 1.44^{f}	87.3 ± 0.69^{a}	2.2 ± 0.76^{bc}
Wheat = 34%, Starch type = 33% Egg = 33%				
Acorn Starch	264.7 ± 2.63^{c}	187.7 ± 2.28^{b}	80.5 ± 1.99^{a}	5.8 ± 0.29^{a}
Native Corn Starch	273.5 ± 1.62^{b}	224.1 ± 1.69^{a}	69.6 ± 1.61^{b}	5.9 ± 3.43^{a}
Lupine Flour	279.1 ± 2.15^{a}	188.5 ± 2.52^{b}	46.9 ± 0.96^{e}	3.7 ± 0.02^{ab}
Potato Starch	166.4 ± 0.70^{f}	102.6 ± 2.77^{f}	62.0 ± 0.75^{d}	3.4 ± 0.67^{ab}
Stabilized Rice Bran	255.9 ± 1.90^{d}	124.9 ± 2.77^{e}	62.8 ± 0.25^{cd}	4.4 ± 0.20^{ab}
Rice Flour	253.2 ± 1.77^{e}	161.7 ± 2.02^{c}	60.9 ± 0.77^{d}	3.3 ± 0.002^{a}
Tapioca Flour	146.1 ± 2.24^{h}	224.1 ± 2.23^{a}	33.1 ± 1.40^{f}	1.9 ± 0.36^{b}
Waxy Corn Starch	157.3 ± 2.12^{g}	142.3 ± 1.07^{d}	65.7 ± 1.24^{c}	2.4 ± 0.58^{b}
Wheat = 50%, Starch type = 50% Egg = 0%				
Acorn Starch	38.1 ± 1.44^{d}	29.5 ± 0.28^{d}	ND	ND
Native Corn Starch	37.2 ± 1.05^{d}	37.0 ± 1.08^{c}	24.3 ± 0.64^{e}	2.4 ± 0.08^{d}
Lupine Flour	76.7 ± 0.94^{b}	52.7 ± 2.70^{b}	63.0 ± 1.19^{d}	5.9 ± 0.57^{ab}
Potato Starch	17.0 ± 0.29^{f}	18.3 ± 0.56^{e}	93.3 ± 0.18^{a}	3.3 ± 0.47^{cd}
Stabilized Rice Bran	105.9 ± 3.02^{a}	59.6 ± 0.92^{a}	90.7 ± 1.30^{b}	6.8 ± 0.98^{a}
Rice Flour	54.0 ± 1.08^{c}	38.1 ± 1.93^{c}	71.4 ± 1.00^{c}	3.9 ± 0.15^{cd}
Tapioca Flour	19.5 ± 0.93 e	12.0 ± 1.06^{f}	70.5 ± 0.49^{c}	2.4 ± 0.33^{d}
Waxy Corn Starch	16.1 ± 0.13^{f}	12.4 ± 0.67^{f}	71.4 ± 0.09^{c}	4.4 ± 1.09^{bc}
Wheat = 66%, Starch type = 17% Egg = 17%				
Acorn Starch	153.2 ± 1.70^{e}	62.2 ± 0.47^{h}	64.9 ± 0.73^{c}	3.4 ± 0.167^{a}
Native Corn Starch	223.4 ± 2.34^{a}	157.7 ± 0.83^{a}	61.8 ± 1.00^{d}	2.3 ± 0.176^{b}
Lupine Flour	184.9 ± 0.45^{c}	151.2 ± 1.01^{b}	58.1 ± 1.28^{e}	3.4 ± 0.40^{a}
Potato Starch	171.0 ± 3.40^{d}	134.4 ± 2.43^{c}	73.2 ± 0.39^{a}	3.1 ± 0.18^{a}
Stabilized Rice Bran	206.5 ± 3.80^{b}	98.3 ± 1.90^{e}	64.7 ± 1.70^{c}	3.6 ± 0.32^{a}
Rice Flour	109.0 ± 3.76^{g}	75.6 ± 1.66^{g}	66.1 ± 1.03^{bc}	3.2 ± 0.26^{a}
Tapioca Flour	169.1 ± 1.68^{d}	126.0 ± 2.39^{d}	46.8 ± 1.07^{f}	1.9 ± 0.36^{b}
Waxy Corn Starch	117.9 ± 1.07^{f}	92.7 ± 1.72^{f}	67.5 ± 0.45^{b}	3.2 ± 0.10^{a}

Note. Firmness (N), stickiness (N.s), water uptake (%), and cooked pasta loss (%) ± standard deviation for treatments within the same set (i.e., same column) having different letter(s) are significantly ($p < .05$) different according to the LSD. ND = Not determined.

changing WHC of treatments with coefficients of estimation ranging from −164.9 to 538.6. Protein–starch interaction manifested by wheat–starch interaction showed a positive contribution of WHC for acorn starch, lupine flour, potato starch, rice flour, and waxy corn starch and a negative effect for stabilized rice bran and tapioca flour. Conversely, wheat–egg interaction negatively affected WHC of acorn starch, stabilized rice bran, and rice flour treatments (Table 4). Our results are in agreement with Dzudie, Scher, and Hardy (2002) who reported an increase in WHC of food products including meats as a result of adding fiber.

Table 5 presents cooked pasta quality characteristics including water uptake, cooking loss, and instrumental textural attributes (i.e., firmness and stickiness). For the same wheat, starch/flour, and egg level, except when 0 egg level used, lupine flour samples had the greatest cooked pasta firmness having values ranging from 184.9 to 279.1 N whereas waxy corn starch produced the softest firmness value of 57.0 N. Results further indicated that eggs significantly affected cooked pasta firmness. For instance, the increase of egg from 0 to 17 and 33%; resulted in increasing waxy corn starch firmness from 16.1, to 57.0 and 157.3 N, respectively. Similarly, acorn samples firmness increased from 38.1 to 76.4 and 264.7 N, respectively. Cooked pasta stickiness showed similar trends; a result in consistent with the significant correlations between firmness and stickiness of cooked pasta products.

Results confirm that the formation of starch–protein–lipids networks in a food system provide mechanical support for the mixture and protect the formed structure against rupture (Derycke et al., 2005); these networks in turn are responsible for the rigid nature of cooked pasta. Our results are also in accordance with Fitzgerald, Martin, Ward, Park, and Shead (2003) report that protein disruption of rice proteins by protease treatment decreased the formation of a protein network. It thus weakened the strength of the starch granules allowing

TABLE 6 Sensory attributes of cooked pasta made using wheat flour [17, 34, 50, and 66%] substituted with fractions [66, 33, 50, and 17%] of starch/flour types and egg levels

Starch/Flour type	Overall liking	Firmness	Stickiness	Flavor	Color
Wheat = 17%, Starch type = 66% Egg = 17%					
Acorn Starch	ND	ND	ND	ND	ND
Native Corn Starch	ND	ND	ND	ND	ND
Lupine Flour	ND	ND	ND	ND	ND
Potato Starch	6.0 ± 0.05^{b}	7.4 ± 0.22^{b}	7.0 ± 0.15^{a}	6.3 ± 0.13^{a}	8.3 ± 0.33^{a}
Stabilized Rice Bran	ND	ND	ND	ND	ND
Rice Flour	7.0 ± 0.27^{a}	8.3 ± 0.03^{a}	7.2 ± 0.08^{a}	4.5 ± 0.05^{b}	8.5 ± 0.20^{a}
Tapioca Flour	ND	ND	ND	ND	ND
Waxy Corn Starch	7.1 ± 0.12^{a}	8.2 ± 0.24^{a}	6.2 ± 0.24^{b}	6.3 ± 0.08^{a}	8.5 ± 0.04^{a}
Wheat = 34%, Starch type = 33% Egg = 33%					
Acorn Starch	6.5 ± 0.10^{bc}	7.4 ± 0.14^{ab}	7.0 ± 0.19^{b}	6.4 ± 0.19 ^{b}	7.4 ± 0.05^{b}
Native Corn Starch	5.0 ± 0.19^{d}	5.0 ± 0.19^{c}	7.1 ± 0.20^{b}	5.3 ± 0.25^{c}	5.9 ± 0.9^{e}
Lupine Flour	7.3 ± 0.12^{a}	7.3 ± 0.05^{ab}	7.8 ± 0.04^{a}	7.9 ± 0.21^{a}	8.3 ± 0.12^{a}
Potato Starch	6.5 ± 0.05^{bc}	5.7 ± 0.19^{c}	6.5 ± 0.09^{c}	5.2 ± 0.24^{cd}	6.8 ± 0.24^{c}
Stabilized Rice Bran	6.7 ± 0.21^{b}	7.7 ± 0.28^{a}	8.0 ± 0.01^{a}	6.3 ± 0.04^{b}	6.4 ± 0.12^{d}
Rice Flour	6.4 ± 0.25^{bc}	6.5 ± 0.25^{b}	4.0 ± 0.08^{d}	6.4 ± 0.15^{b}	8.2 ± 0.20^{a}
Tapioca Flour	4.4 ± 0.15^{e}	5.4 ± 0.07^{c}	6.9 ± 0.11^{b}	4.5 ± 0.05^{d}	5.1 ± 0.12^{f}
Waxy Corn Starch	6.3 ± 0.03^{c}	6.6 ± 0.81^{b}	7.1 ± 0.10^{b}	5.4 ± 0.61^{c}	6.5 ± 0.21^{cd}
Wheat = 50%, Starch type = 50% Egg = 0%					
Acorn Starch	6.1 ± 0.25^{bc}	6.0 ± 0.15^{d}	6.4 ± 0.11^{cd}	8.1 ± 0.12^{ab}	7.1 ± 0.30^{b}
Native Corn Starch	6.9 ± 0.08^{a}	8.4 ± 0.20^{a}	7.5 ± 0.24^{bc}	7.3 ± 0.19^{b}	7.9 ± 0.16^{a}
Lupine Flour	6.0 ± 0.17^{bc}	5.8 ± 0.19^{d}	8.4 ± 0.12^{ab}	6.3 ± 0.14^{c}	7.1 ± 0.25^{b}
Potato Starch	7.1 ± 0.24^{a}	6.7 ± 0.28^{c}	6.5 ± 0.19^{cd}	8.0 ± 0.24^{a}	6.8 ± 0.26^{bc}
Stabilized Rice Bran	6.5 ± 0.39^{ab}	8.4 ± 0.14^{a}	7.1 ± 0.14^{c}	7.9 ± 0.09^{a}	6.0 ± 0.32^{e}
Rice Flour	7.4 ± 0.07^{a}	8.3 ± 0.03^{a}	8.2 ± 0.14^{a}	7.6 ± 0.37^{ab}	6.5 ± 0.27^{cd}
Tapioca Flour	5.8 ± 0.14^{bc}	7.2 ± 0.14^{b}	6.7 ± 0.25^{cd}	7.9 ± 0.20^{ab}	5.9 ± 0.10^{e}
Waxy Corn Starch	5.3 ± 0.84^{c}	6.2 ± 0.24^{d}	5.7 ± 1.16 ^{d}	5.4 ± 0.39^{d}	6.1 ± 0.10 ^{de}
Wheat = 66%, Starch type = 17% Egg = 17%					
Acorn Starch	7.6 ± 0.33^{ab}	7.1 ± 0.19^{cde}	7.5 ± 0.28^{bc}	7.6 ± 0.05^{c}	7.3 ± 0.28^{bcd}
Native Corn Starch	5.6 ± 0.20^{e}	6.3 ± 0.03^{f}	7.4 ± 0.15^{c}	5.7 ± 0.08^{f}	6.5 ± 0.27^{cde}
Lupine Flour	7.7 ± 0.28^{a}	8.8 ± 0.35^{a}	8.5 ± 0.17^{a}	8.6 ± 0.09^{a}	8.5 ± 1.00^{a}
Potato Starch	6.3 ± 0.09^{d}	6.9 ± 0.19^{de}	7.8 ± 0.33^{d}	5.7 ± 0.09^{f}	7.5 ± 0.42^{bc}
Stabilized Rice Bran	7.3 ± 0.35^{abc}	8.0 ± 0.23^{b}	8.0 ± 0.39^{b}	8.2 ± 0.11^{b}	6.3 ± 0.18^{e}
Rice Flour	6.9 ± 0.10^{c}	7.5 ± 0.17^{bc}	8.5 ± 0.02^{a}	6.1 ± 0.20^{e}	7.7 ± 0.03^{b}
Tapioca Flour	7.1 ± 0.12^{bc}	6.9 ± 0.20^{ef}	7.2 ± 0.24^{cd}	5.2 ± 0.17^{g}	6.4 ± 0.29^{de}
Waxy Corn Starch	7.5 ± 0.05^{ab}	7.5 ± 0.49^{bcd}	7.5 ± 0.05^{bc}	6.5 ± 0.17^{d}	8.0 ± 0.20^{ab}

Note. For the same wheat fraction used, sensory attributed of cooked pasta ± standard deviation within the same treatment (i.e., same column) having different letter(s) are significantly ($p < .05$) different according to the LSD. About 100% wheat treatment had overall, firmness, stickiness, flavor, and color scores of 8.8, 7.6, 6.4, 6.5, and 8.2, respectively.

them to absorb more moisture, swell faster, and to a greater degree thereby increasing their susceptibility to disruption through shear force.

Yang and Chang (1999) showed that proteins are tightly bound starch granules prevented starch from exhibiting its crystalline and pasting property. Rao (1999) also reported that although proteins and starch are thermodynamically different polymers; their presence together can lead to significant starch–protein interactions which affect texture significantly. The authors further demonstrated that if starch gelatinization takes place earlier than proteins gel formation, the formed networks can act independently with the net strength and texture of products dependent on both networks.

Cooked pasta water uptake and cooking loss are presented in Table 5. Pasta water uptake of various treatments ranged from 32.2% for tapioca flour to 87.3% for waxy corn starch (i.e., wheat = 17%, starch type = 66%, and egg = 17%). Variation in starch type percentage and egg level resulted in inconsistent pasta water uptake trends. Results were supported by the estimated response surface model coefficients (Table 4) indicating a significant rule of starch type, egg level, and wheat percentage in water uptake. Cooked pasta water uptake was positively influenced by wheat and starch or flour type used. For instance, potato starch and rice flour influenced pasta water uptake having coefficients of 106.5 and 45.4, respectively. Similar trends were reported for pasta cooking loss where wheat and starch types played a key role in affecting cooking loss. Egg level, conversely, almost exclusively has a negative impact on pasta cooking loss regardless of starch/flour types used. Results further showed that wheat/starch, wheat/egg and starch/egg interactions had no effect on pasta cooking loss (Table 4).

Cooking loss of pasta and noodles is considered an important factor in evaluating product quality. Several studies have shown the significant influence of starch structure in the formation and maintaining three-dimensional starch–protein–lipid network pasta structure that is usually interlinked by starch–protein–lipid network (Derycke et al., 2005). Kim et al. (1996) reported a strong correlation between amylose content of potato starch and cooking loss. The authors related the increase in cooking loss to the swell of potato starch during boiling in water, hydration of amorphous regions, and subsequent degradation of formed amylose networks with increased cooking time, resulting in increasing the amylose content of the cooking water. Noodles made of navy and pinto bean starches, on the other had had limited cooking loss due to the lipid and protein content in the navy and pinto beans (Gujska, Reinhard, & Khan, 1994). The results of this study correspond to those from Das and Chattoraj (1989) who reported a significant influence of egg level on the cooking time of noodles. The authors indicated a critical role of added egg on the consumer acceptability of cooked pasta texture. Walsh and Gills (1971) also stated that high protein content is related with high cooking loss. The presence of proteins and lipids are believed to aid in the formation of starch–protein–lipids networks (i.e., amylose–lipid and amylose–protein networks) providing mechanical support for the mixture and protect the formed rigid nature of cooked pasta limiting its cooking loss. This theory is supported by findings from Savita, Arshwinder, Gurkirat, and Vikas (2013) who reported an increase in solid loss in cooked water of pasta with the increase in whole egg and egg albumen level when used with in semolina wheat flour. Fibers, conversely, were reported to negatively impact the end-use properties of pasta. Fibers was indicated to play a role in disrupting starch–protein matrix of the dough during pasta preparation, often swell faster than starch and compete for water during dough development (Rakhesh, Fellows, & Sissons, 2015).

Sensory attributes (i.e., overall liking, firmness, stickiness, flavor, and color) of substituted starch/flour types and egg levels are presented in Table 6. Overall liking scores for the 100% control wheat samples was 8.8 compared to 7.7 for lupine (i.e., 17% lupine, 66% wheat, and 17% egg); the greatest overall liking among treatments. Results indicated acceptable overall liking scores for all treatments except for treatment of 34% wheat, 33% tapioca, and 33% egg and that having 50% wheat and 50% of each waxy corn starch and tapioca treatments having overall scores of 4.4, 5.3, and 5.8, respectively. Hardness, stickiness, flavor, and color results did not reveal a consistent trend in affecting treatments sensory scores. Starch pasta products were reported to have a great transparency scores that usually affects consumer overall and appearance rating (Kim & Wiesenborn, 1995). Since most treatments reflected fractions of starch/flour; produced pasta had an acceptable appearance compared to the control. Cooked pasta texture was acceptable as indicated by consumer scores. Results are in line with Galvez and Resurreccion (1992) indications that cooked starch noodles should be neither too firm nor too soft. Texture scores of treatments could be a result of starch chemical composition variation. For instance, high-amylose starches are known to be too firm, resulting from a rigid and tight structure that inhibits water absorption (Toyokawa, Rubenthaler, Powers, & Schanus, 1989). Savita et al. (2013) studied the influence of different protein sources on cooking and sensory quality of pasta. The authors reported that incorporation of milk proteins increased the time taken by the starch to gelatinize as a result of the increased water absorption. A 9.9% increase in water absorption was reported in casein-supplemented pasta. The authors further indicated no significant variation in the acceptability score of pasta with the addition of casein and whey protein concentrate but significant improvement with added skim milk powder. Niturkar, Doke, Joglekar, and Rotte (1992) also reported an improvement of 4% milk protein fortified vermicelli including color and texture compared to nonfortified treatments. The authors further reported an improvement in sensory score of cooked noodles in terms of better color, texture, and flavor than a control sample.

4 | CONCLUSION

Fractional replacement of various starch/flour types and egg level significantly impacted treatments functionality through influencing protein–starch interaction. Proteins and lipids also promote a formation of an insoluble polymeric matrix; providing protection to the starch granules integrity and thus functionality during processing. Findings of this study provide valuable information for the potential use of types and levels of starch and egg level to enhance pasta quality including, water loss, adhesion, and WHC. Flow curves of batters containing flour blends of substituted starches/flour types and egg levels showed shear thinning behavior and significantly impacted treatments physical properties thus pasta quality.

ETHICAL STATEMENTS

Conflict of Interest: The authors declare that they do not have any conflict of interest.

Ethical Review: This study does not involve any human or animal testing.

Informed Consent: Written informed consent was obtained from all study participants.

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