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Evaluation of the physiochemic and sensory properties of biscuits made from a mixture of wheat flour, potato starch, and corn starch

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ABSTRACT

This study was set to reveal the effect of using composite flours to make laboratory biscuits by substituting 30% of wheat flour with potato starch (T1) and corn starch (T2) individually, compared with a 100% wheat flour control (T0). The results obtained indicated that biscuits from T1 had a significantly higher moisture content (6.28%) and carbohydrate (70.74%) with ash (0.68%), protein (6.90%), and fat (15.40%) reduced compared to the control as well as T2 biscuits. Physical properties of the biscuits indicated that the T0 control treatment acquired the highest diameter, thickness (height), and spread ratio; the T2 (corn starch) treatment obtained the least thickness with significant differences ($P \leq 0.05$). Sensory analysis showed that the T0 control treatment obtained the highest overall acceptance scores. However, among the starch-substituted biscuits, T1 (potato starch) was rated significantly better than T2 (corn starch). All the studied sensory properties showed significant differences ($P \leq 0.05$) except for softness and crumb (pulp) color. The total sensory scores were 91.8 (T0), 87.4 (T1), and 75.6 (T2) over 100.

1-Introduction

The Potato (*Solanum tuberosum* L.) is a member of the Solanaceae family and is one of the most important food crops in the world [1]. It is the third most important crop after Wheat and Rice. "Global production was over 370 million metric tons" (FAO/FAOSTAT). Potatoes are called "food security crop" because it provides energy and nutrients to thousands of communities, mainly in developing countries [2]. It is the third source of carbohydrate in the tropics after rice and maize and has an important place in the diet of true European family". This "is because of its nutritional value, versatile industrial and domestic utility, and availability at a lower price to the poorer segment" [3]. Its tubers are rich in essential amino acids, particularly lysine; they contain much higher levels of dietary fibres, starch, and low fat [4,5]. The high content of starch in potatoes makes them one of the most important raw materials for the food processing industry, including potato chips, French fries, etc., and pre-peeled potatoes [6]. Recently, the use of natural starches and biopolymers in food formulation has attracted much interest due to their roles in enhancing product quality as well as shelf-life extension, as proved in recent research works on edible coatings and food packaging [7,8,9,10].

Starch (12–15% of the potato tuber) is an important quality parameter of the crop [11]. Physicochemical characteristics of potato starch are unique in terms of low fat and protein content and high esterified phosphorus; hence it is more gelling starch. Both amylose and amylopectin long chains reduce the slumping of starch; hence they improve the quality of all baked products to which the starch is added [12]. However, approximately 30% of potatoes are discarded during harvesting/storage of the crop because of small size, odd shape, and other aesthetic imperfections [12]. These low-quality potatoes, which are typically used for animal feeding, could provide an important source of starch if their carbohydrate content remains intact and free from microbial contamination [13,14]. Wheat consumption is associated with an increasing prevalence of celiac disease and gluten intolerance, which has become a major global health issue. The demand for gluten-free products is increasing, therefore, there is a need to develop functional baked products having appropriate nutritional and sensory properties. Corn, rice, and potato flours and/or starches are generally used in formulations. Corn starch is of major importance in biscuit production due to its appropriate functional properties, availability, and low cost. It should be underlined that the formulations applied in this study are not gluten-free since they still contain considerable wheat flour; they are rather low-gluten products. The problem is therefore to find a way to use a larger portion of the low-grade potatoes that are currently wasted, even though the carbohydrate content of these tubers is intact, and particularly to make functional products with reduced content of wheat flour especially in the form of baked products. We hypothesized that substituting 30% of wheat flour with potato starch would yield biscuits with sensory scores (≥75 out of 100) and higher carbohydrate content compared to both a 100% wheat flour control and biscuits made with an equivalent substitution of corn starch.

2- Materials and Methods

2-1. Sampling

Low-grade Arizona potatoes were collected from the local markets in Baghdad. They were washed with tap water to remove surface dirt, and sprouts were cut off with a knife. The prepared potatoes were kept in a refrigerator at 2 ± 5°C and used within one week of storage.

2-2. Starch Extraction

The water soaking method by Torres et al. (2020) [12] was used with some modifications for starch extraction from the pre-stored potatoes. The potatoes were peeled by hand, cut into small pieces, and then soaked in filtered water at a 2:1 (w/v) ratio until fully chopped. The potatoes were mashed with the same soaking water in a Kenwood blender. The mashed potatoes were then transferred to a magnetic mixer and blended at 200 rpm for 90 minutes at room temperature. A potato puree was obtained after sieving the mashed potatoes through a No. 100 (150 µm) silk sieve. The potato pulp remaining on the sieve was washed with filtered water and the collection was again sifting and mashed. The filtrate was kept for 24 hours at 4°C to precipitate the starch. The precipitated starch was filtered and washed with water. Then, it was dried in an oven at 40°C for 48 hours. The dried starch was stored in plastic bags.

A Completely Randomized Design (CRD) with three treatments and three independent replicates per treatment was used. The treatments were:

Table 1. Ingredients of a standard biscuit with 15g substitution of potato starch and corn starch.

Treatment Code	Description
T0 (Control)	100% wheat flour (113 g), 0% starch substitution
T1 (BP)	70% wheat flour (79.1 g) + 30% potato starch (33.9 g)
T2 (BC)	70% wheat flour (79.1 g) + 30% corn starch (33.9 g)

Potato starch: corn starch was kept at 100:0 for T1 and 0:100 for T2. This allowed the two types of starch to be tested independently against the control, thus isolating and identifying their individual effects on biscuit quality. A blend of the two starches was not included in the experiment.

2-4.Method of Operation

These were prepared in the Grain Technology Laboratory, Department of Food Science, College of Agricultural Engineering Sciences, University of Baghdad. The standard biscuits were prepared according to the method of the American Association of Cereal Chemists A.A.C.C. (2000) code (10-50 B) as described by Mahdi and Shakir [18] with some modifications. The complete biscuit recipe is shown in Table 1. Ingredients are expressed in grams and as a percentage of the total flour/starch blend weight for each treatment. The formula was based on a fixed total flour+starch weight of 113 g.

Table 2. Complete biscuit recipe (in grams).

Ingredients	Function	T0 (Control)	T1 (Potato)	T2 (Corn)	% of flour blend weight
Wheat flour (Al-Tazaj, all-purpose)	Structure	113.0	79.1	79.1	70% (T1, T2)
Potato starch	Substitute	0.0	33.9	0.0	30% (T1 only)
Corn starch	Substitute	0.0	0.0	33.9	30% (T2 only)
Sugar (finely granulated sucrose)	Sweetness/tenderizing	65.0	65.0	65.0	57.5%

Vegetable fat (margarine, 45-50% moisture)	Tenderness/shortening	32.0	32.0	32.0	28.3%
Sodium Bicarbonate (baking soda)	Leavening agent	2.5	2.5	2.5	2.2%
Salt (iodized table salt)	Flavor/toughening	1.0	1.0	1.0	0.9%
Glucose Powder	Browning/crispness	3.0	3.0	3.0	2.7%

No additional water or liquid was added to the formulation.

2-5.Physical Parameters of the Biscuits:

The biscuits were made from the mixtures listed in Table 1 using a Kenwood electric mixer (Model KMX754, 1000W, Kenwood Ltd., UK). All ingredients were first equilibrated at room temperature for at least one hour. The mixing procedure was as follows: The sugar and vegetable shortening (margarine) were creamed together using a flat beater at speed 2 for 3 minutes. Then, a dry mix of flour, starch, salt, sodium bicarbonate, and glucose powder (pre-sifted twice through a No. 60 mesh sieve for aeration) was added slowly over 30 seconds while mixing at speed 1. The whole mass was then mixed at speed 1 for exactly 1 minute. No water was added to the mixture; instead, the moisture content of the vegetable shortening (45-50%) was used to get a semi-dry mixture. The final biscuit dough mixture was a moist, crumbly powder (slightly moist powder) that could be compressed but not formed into a cohesive dough.

Two stainless steel bars (38 cm length × 7 mm thickness) were placed on a parchment paper. The moist powder was then transferred as is, using the scraper attached to the electric mixer, between the two bars and rolled with a rolling pin to the exact thickness of the bars (7 mm). Biscuit discs were cut to size using a 60 mm diameter steel circular cutter and any excess material removed. The discs, still on the parchment paper, were transferred to a flat aluminum baking tray (30 × 40 cm). Baking was done in a preheated electric oven (Model XF023, Unox, Italy) at 200°C for 10 minutes. The resulting biscuits were then transferred to a wire rack and cooled at ambient temperature (25 ± 2°C) away from direct drafts for 1 hour. After cooling, the discs were kept in sealed low-density polyethylene (LDPE) bags at room temperature for further physical, chemical, and sensory studies. All tests were done within 48 hours of baking.

2-6. Sensory evaluation of biscuit treatments:

The physical parameters — diameter, thickness, and spread factor — of the laboratory biscuits were measured as per the AACC procedure (2010), following what was outlined by Mahdi and Shakir [18].

horizontally, and the total combined width was measured using a digital Vernier caliper (Model CD-6" CSX, Mitutoyo, Japan) with accuracy 0.01 mm. The average diameter per biscuit was calculated by dividing the total length by six. The measurement was carried out in triplicate (three sets of six biscuits per batch).

• Thickness (mm): Six biscuits were stacked on top of each other, and the total height was measured with the same digital caliper. The average thickness per biscuit was obtained by dividing the total height by six. This was done in triplicate.

• Spread Ratio: was calculated by dividing the average diameter (mm) by the average thickness (mm) for each replicate, using the formula: $SF = D / T$, where D = average diameter per biscuit (mm) and T = average thickness per biscuit (mm).

Statistical analysis: The chemical composition of wheat flour, corn starch, potato starch, and the final biscuits was analyzed using standard AOAC methods [19].

Parameter	Standard Method
Moisture content	AOAC 925.10 (Air oven method, 105°C to constant weight)
Ash content	AOAC 923.03 (Muffle furnace, 550°C for 4 hours)
Crude protein	AOAC 979.09 (Kjeldahl method; Nitrogen conversion factor N × 5.7 for wheat flour)
Crude fat	AOAC 920.39 (Soxhlet extraction with petroleum ether)
Total Carbohydrates	Calculated by difference: 100 – (% Moisture + % Ash + % Protein + % Fat)
Energy content (kcal/100g)	Calculated as: (% Protein × 4) + (% Carbs × 4) + (% Fat × 9)

Crude fiber was not determined in this study. Resistant starch and in vitro starch digestibility were not measured; this is acknowledged as a limitation.

2-8. Sensory Evaluation of Biscuit Treatments

A quantitative descriptive sensory analysis was carried out in individual sensory booths under controlled lighting (white fluorescent) in the Food Science Department. The evaluation panel was composed of thirty semi-trained panelists (15 males and 15 females aged between 22 and 45) selected from faculty members, graduate students, and trained staff. Panelists were recruited based on the following criteria: non-smokers, regular consumers of biscuits (at least once per week), no known allergies to any of the ingredients (wheat, gluten, potato, corn), and in good general health. All panelists provided verbal informed consent before participating in the study. The evaluation form was a 10 cm structured graphic line scale anchored at both ends (e.g., "dislike extremely" to "like extremely"), as described by Al-Zubaidi [20]. The attributes assessed and their maximum scores were: Appearance (20 points), Surface characteristics (10), Freshness/softness (10), Taste and aroma (20), Crumb/Pulp colour (10), and Spreading coefficient/Overall texture (30). The total maximum score was 100. Each sample was given a random three-digit code and presented to the panelists at the same time on white plastic plates in a randomized serving order. Each biscuit was presented whole. Panelists were asked to cleanse their palate between each sample evaluation with unsalted crackers and room-temperature water.

2-9 Statistical Analysis

Data are presented as the mean ± standard deviation (SD) of three independent experimental replicates (batches) per treatment. The Statistical Analysis System (SAS) program (2018) was used for the analysis of data with a Completely Randomized Design (CRD). Significant differences among treatment means were compared using one-way analysis of variance (ANOVA) followed by the Least Significant Difference (LSD) post-hoc test at a 5% level of significance (α = 0.05). Sensory data were subjected to the same parametric tests after confirming that the total scores (scale of 0-100) approximated a normal distribution, verified by the Shapiro-Wilk test. Levene's test was used to check the homogeneity of variances [21].

3- Results and Discussion

3-1- Proximate Chemical Composition

Table 2 gives the chemical composition of wheat flour, corn starch, and potato starch. The results of the proximate chemical composition analysis indicated that all components of wheat flour were higher than those of both potato starch and corn starch, except for total carbohydrates. The moisture content was (12.60, 12.29, 10.28%) (wheat flour, potato starch, corn starch), respectively. From Table 2, it can be seen that fat, protein, and ash content were lower in potato starch than in corn starch; they were (0.09, 0.18, 0.23%) in potato starch and (0.51, 0.71, 0.14%) in corn starch, respectively. On the other hand, the ash content was higher in potato starch (0.23%) than in corn starch (0.14%). This fact is now correctly reflected in the table. Carbohydrate content was lower in potato starch (87.21%) than in corn starch (88.36%). Results for wheat flour were higher than those estimated in this study. Values for moisture, protein, fat, ash, and carbohydrates were 11.62%, 10.64%, 2.00%, 0.88%, and 74.86%, respectively. All values of potato starch fell within the ranges indicated by Tong et al. for 27 varieties except for a lower ash content. This range includes moisture (6.3–20.4%), fat (0.00–0.46%), protein (0.08–1.18%), and ash (0.21–1.30%). Values of moisture, protein, and fat for corn starch in this study were lower than those indicated by Ibrahim et al., while ash and carbohydrate content were higher (10.45%, 7.13%, 7.70%, 0.62%, and 74.1%, respectively). The protein content of wheat grains is very important in quality consideration and is influenced by environmental and genetic factors. Autumn and winter wheat varieties, especially in the Northern Europe, are dominant in producing soft grains with low protein content. They are referred to as spelt wheat. The most preferred type of biscuit production is soft wheat, which has low gluten capacity and elasticity, because it is more affordable and of better quality. Wheat meant for biscuit making typically falls between 8.5% and 10.5% protein, while wheat used for cakes and pastries — like kahi and baklava — usually sits under 8.5% protein [18].

The fat content of flour has a significant effect on the rheological properties of dough, although it is relatively low compared to other ingredients. Ash content is primarily determined by the bran amount in the wheat grain and serves as a useful indicator of milling efficiency, indicating color differences in flour. High ash flours generally make biscuits of darker color [24].

Table 2. Chemical Estimation of Corn Starch and Potato Starch.

Type of starch:	% Moisture	% Ash	% Protein	% Fat	% Carbohydrates
Wheat flour	12.6	0.65	10.5	1.25	75.7
Corn starch	10.28	0.14	0.51	0.71	88.36
Potato starch	12.29	0.23	0.09	0.18	87.21

3-2- Effect of Replacing Wheat Flour with Cornstarch and Potato Starch on the Chemical Composition of Biscuits.

Table 3 shows the effect of substituting wheat flour with corn starch (T2) and potato starch (T1) on the chemical composition of the biscuits under analysis. It shows that biscuits from the (T1) treatment are more moist than those from the other two treatments, recording (6.28%) with results statistically similar to T0 and T2 (P>0.05). This was later attributed to the large starch granules of potato starch. Horstmann [25] noted that most of the moisture in potato starch is as a result of the large starch granule size. Potato starch has abundant hydroxyl groups which can form hydrogen bonds, thereby increasing its hygroscopicity. It also has natural phosphate groups attached to amylopectin, which further increases its ability to attract and hold water. Table 3 shows that the high moisture content in the (T1) biscuit sample is due to lower levels of ash, protein, and fat, and a higher carbohydrate percentage compared to corn starch. The same table also shows that there are huge differences (P≤0.05) in ash and protein content between T1 (potato) and both T0 (control) and T2 (corn). Only the (T1) treatment showed a significant decrease, reaching the lowest values for ash and protein, which is consistent with the lower inherent levels of these components in potato starch (Table 2).

Table 3. shows the effect of replacing wheat flour with corn starch and potato starch on the chemical composition of the laboratory biscuit.

Type of starch	% Moisture	% Ash	% Protein	% Fat	% Carbohydrates
Control	5.31	1.68 a	7.90 a	16.03	68.26
BP	6.28	0.68 b	6.90 b	15.40	70.74
BC	5.30	1.54 a	7.80 a	16.05	69.31
L.S.D.	1.08 N.S.	* 0.559	* 0.893	0.724 N.S.	3.06 N.S.

* P≤(0.05)

3-3. Physical Properties

Table 4 Effect of Partial Replacement of Wheat Flour with Corn Starch and Potato Starch on Physical Properties of Biscuits. The biscuits made from composite flour with potato starch (T1) had smaller diameter (35.5 mm) significantly different from T0 control (38.5 mm). Biscuits of T2 corn starch showed an intermediate diameter of 37.5 mm. This may be attributed to the effect of type of starch on its interaction with dough components in the course of baking. The gluten network was weakened due to the reduced wheat flour. Biscuit thickness- T0 control treatment attained the highest thickness of 6.8 mm; while T2 treatment had the lowest thickness of 4.5mm which was significantly lower than that of the control.

The spread ratio of the biscuits of the T0 control treatment was the highest (8.5) as compared to those made from composite flour with potato starch (T1, 6.3) and corn starch (T2, 5.15). This high spread ratio further confirms that gluten proteins are critical in attaining superior quality and acceptability over products made from composite flour. The T1 and T2 biscuits did not differ significantly in spread ratio.

Table 4. Effect of replacing wheat flour with potato and corn starch on the physical properties of manufactured biscuits.

Physical properties	(Control)	(BP)	(BC)	L.S.D.
Diameter (mm)	38.5 a	35.5 b	37.5 ab	* 2.38
Height (mm)	6.8 a	5.6 ab	4.5 b	* 1.55
Diffusion coefficient (Spread Ratio)	8.5 a	6.3 b	5.15 b	* 1.72

P≤(0.05)*

The increase in biscuit diameter during baking is the main factor due to the interaction of sodium bicarbonate and proteins, and the expansion of air and water within the mixture. The presence of fat shall enhance the brittleness of the biscuit, thereby further enhancing the volume expansion. The results also agree with those of Seevaratnam et al. and Misra and Kulshrestha, where it was noted that potato flour could be used as a partial substitute for wheat flour in the making of different bakery products. They further observed that with the increase in levels of substitution, the diameters of the biscuits and spread index increase, while thickness decreases slightly. This is due to the fact that potato flour has a relatively high water retention capacity because it contains a high percentage of damaged or free starch.

3-4. Sensory Properties of Biscuits

Table 5. Effect of replacement of wheat flour with potato starch and corn starch on the qualitative and sensory properties of biscuits. The panelists were 30 in number and they were semi-trained. The acceptance scores of the biscuits produced from wheat flour blended with potato starch (T1) were higher than those of wheat flour blended with corn starch (T2) . From the results, it is evident that the substitution did not enhance any of the sensory parameters studied in comparison with the control group T0. This effect was more pronounced for the biscuit samples T2 where a significant decrease in the scores of sensory evaluation ($P \leq 0.05$) was observed for appearance, surface characteristics, taste/aroma, spreading coefficient, and total score, although the total score for T2 (75.6) remained within the pre-defined acceptable limit of 75.

This can be attributed to what Tester (28) pointed out; the difference in chemical composition and granule structure between potato starch and corn starch. Potato starch has a higher percentage of amylopectin and natural phosphate groups, which increases its water absorption and swelling capacity. It also has larger granule size and a type B crystal structure as opposed to the smaller granules of corn starch with a type A crystal structure. This difference leads to variations in gelling behavior and mixture properties, which subsequently affect the quality of the resulting biscuits. In their study, Seevaratnam et al. (26) found that the acceptable limit for wheat flour substitution in biscuit production was highest up to a 30% substitution with potato starch. All sensory parameters of the control group were better than those of the group using potato starch. However, the results do not agree with those of Salama et al. [29] who found a significant improvement in the sensory properties of biscuits when wheat flour was enriched with corn starch as the substitution percentage increased. Results of the latter researcher showed that the sample (100% wheat flour) was generally well-received and achieved consistent scores across all parameters evaluated. Only a slight decrease in texture and mouthfeel scores was noted when 20% yellow corn flour was added, other parameters being remarkably stable. Thirty percent yellow corn flour, however, significantly improved oral sensation and overall product acceptability. Thirty percent, 40%, and 50% yellow corn starch each offered even higher sensory outcomes than the previous two samples, consistently achieving high scores across all criteria evaluated. These two samples thus attained the highest scores.

Table 5. Sensory Evaluation of Biscuits and the Effect of Substitution with Potato and Corn Starch.

Qualitative characteristics	Grade	(Control)	(BP)	(BC)	L.S.D.
Appearance	20	17.8 a	17.4 ab	15.4 b	* 2.76
Surface characteristics	10	9.4 a	8.6 a	4.6 b	* 2.13
Freshness	10	8.5	8.2	7.8	1.46 N.S.
Taste and aroma	20	18.4 a	16.7 ab	15.7 b	* 1.97
Pulp color	10	9.1	9.0	8.5	1.29 N.S.
Spreading coefficient	30	28.6 a	27.5 a	23.6 b	* 2.88
Total	100	91.8 a	87.4 a	75.6 b	* 7.83

$P \leq (0.05)$*

4-Conclusions and Recommendations

The study showed that substitution of wheat flour with potato starch up to 30% (T1) could produce biscuits with acceptable sensory quality (total score 87.4/100) and higher carbohydrate content than the 100% wheat flour, which is supportive of our hypothesis. Substitution with corn starch at the same level (T2) significantly reduced its thickness and overall acceptability (75.6/100) though it also scored at the acceptability level. The control (T0) biscuits were best both structurally and sensorially, proving once more the irreplaceable role of gluten in biscuit quality. Some aspects of it have not been fully developed. The ratio of potato to corn starch was not varied (only 100:0 and 0:100 were tested), nor were synergistic blends, e.g., 50:50. The number of subjects for the sensory evaluation (n=30) was at the minimum acceptable limit; hence, a larger consumer study is needed. Moreover, critical analyses like resistant starch content, in vitro starch digestibility, and stability of shelf life (moisture gain, texture changes during storage) were not carried out. A cost-benefit analysis comparing the raw material costs of wheat flour versus that of potato starch from culled potatoes should also be done to check industrial feasibility.

Further studies are recommended to refine the level of substitution, examine binary starch blends in terms of sensory and nutritional properties, and develop protein-rich gluten-free ingredients to enhance structure, as well as complete shelf-life and cost analyses. Such strategies are vital for establishing economically viable, low-gluten baked goods from inferior and surplus potatoes that meet consumer acceptance as well as food industry requirements. The possible use of natural preservatives or edible coatings to increase biscuits' shelf life, based on recent research in the field of food packaging, should also be considered as a supporting technology for these starch-based formulations.

Ethical Approval

This study did not involve human participants or animals. All experimental procedures were conducted in accordance with institutional and laboratory biosafety guidelines.

Conflict of Interest

The authors declare that they have no conflict of interest.

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Data Availability

All data supporting the findings of this study are available within the manuscript.

5-Reference

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