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THE PRODUCTION OF HIGH-PROTEIN EXTRUDED CORN SNACKS FORMULATED WITH QUINOA SEED AND MORINGA LEAF POWDER

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ABSTRACT: Three corn snack blends formulated with substitutions of 15, 30, and 45% of both quinoa seed flour QSF (12.5, 25, and 37.5%) and treated moringa leaf powder TMLP (2.5, 5, and 7.5%) with and without cheese flavor were prepared. The chemical composition, amino acid patterns, and sensory attributes of the extrudates were determined. Also, the effect of storage for 3 months at ambient temperature (25±2ºC) on thiobarbituric acid (TBA), water activity (a_w), and sensory properties was investigated. The obtained results showed that protein, ash, and fat contents of the extrudates increased ($p \leq 0.05$) with increasing substitution levels of QSF and TMLP, the mean value of protein content increased ($p \leq 0.05$) from 10.35% for control to 21.01% for B3 (37.5% QSF, 7.5% TMLP, and 49% corn), while carbohydrate decreased. The flavored extrudates had the highest ($p \leq 0.05$) values of ash and fat contents and the lowest ($p \leq 0.05$) values of fiber and carbohydrate. The amino acids (especially glutamic acid) of the non-flavor extrudates were improved with increasing levels of QSF and TMLP. The values of TBA decreased from 0.565 for control to 0.503 for blend 3 and increased from 0.304 at zero time to 0.781 after 3 months of storage. Generally, the mean values of a_w for all extrudates increased ($p \leq 0.05$) from 0.32 to 0.51 during storage, while they decreased ($p \leq 0.05$) from 0.43 to 0.37 with increasing levels of QSF and TMLP. The extrudates had acceptable sensory attributes during storage. In conclusion, the substitution of both QSF and TMLP to corn up to 30% achieved the best results in TBA values, water activity, sensory properties, and nutritive values.

Keywords Extrudates, Quinoa seed, Moringa leaf, Amino acid, Storage, TBA, Water activity, Sensory properties.

INTRODUCTION

Ready-to-eat snacks are among the most popular foods and are accepted by many consumers due to their convenience, appeal, and texture, but these snacks do not satisfy the needs of consumers' health. Most conventional snacks are usually high in fat and calories. It can be sweet (Ngqangashe *et al.*, 2021), salted (Oddo *et al.*, 2021), fried (Patel *et al.*, 2018), baked (Langston *et al.*, 2023), and extruded (Grasso, 2020) depending on the formulation and processing methods. According to a survey, the average number of times children in North America eat snacks is six times per day (Iqbal *et al.*, 2021).

Extrusion cooking is thus one of the most preferred food-processing techniques due to its continuous process with high productivity, high temperature, and short cooking period that destroys harmful microbial organisms, anti-nutrients, and enzymes, resulting in significant nutrient-retention products with a longer shelf life (Abilmazhinov *et al.*, 2023). However, the nutritional advantages of extruded foods range from increased protein and starch digestibility to the retention of various micronutrients (Egal and Oldewage-Theron, 2020).

Snack foods based on cereals and grains are low in nutrient density, high in calories and fat content, and lack some essential amino acids like threonine, tryptophan, and lysine (Ahmad *et al.*,

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2017). The combination of moisture, sheer, temperature, and pressure causes rapid cooking during the extrusion process, and resulting in gelatinization of starch, denaturation of protein, inactivation of many native enzymes that cause food deterioration during storage, destruction of naturally occurring toxic substances, and diminishing microbial counts in the final product (Choton *et al*., 2020; Abedi and Pourmohammadi, 2021).

Several studies have been conducted on extrusion to improve the protein content of barley flour, tomato, and grape pomace (Altan *et al*., 2009). Novel grains such as amaranth, quinoa, and kaniwa, as well as nutritious foods such as fruits, vegetables, herbs, and by-products, are used to develop acceptable snacks (Ramos-Diaz *et al*., 2015; Wani and Kumar, 2019), who are produced from rice flour, chickpea flour, and corn flour (60:30:10). Buckwheat (*Fagopyrum spp*.), amaranth (*Amaranthus L*.), and quinoa (*Chenopodium quinoa*) are common pseudo-cereal species (Sinkovic, 2016). Extruded products from wheat supplemented with lentils, green peas, yellow peas, and chickpeas showed increasing protein content and improved protein digestibility (Patil *et al*., 2016). Extruded products were produced from apple pomace levels with corn flour and sorghum flour (Lohani and Muthukumarappan, 2016). Quinoa incorporation in quinoa:corn:rice and quinoa:oats:rice to obtain acceptable extrudates, which combine the nutritional benefits of quinoa and oats, resulting in higher protein and soluble dietary fiber (Alajil *et al*., 2018).

Quinoa (*Chenopodium quinoa Willd*) has high nutritional value and is rich in proteins with an extraordinary balance of essential amino acids (Filho *et al*., 2017). Angeli *et al*. (2020) reported that quinoa contained 11.1 to 18.1% protein, 4.0 to 7.9% fat, 2.3 to 4.8% ash, 1.2 to 19.5% fiber, and 48.6 to 68.1% carbohydrate.

Moringa leaf *(Moringa oleifera*) contained 6.2 to 8.2% moisture, 22.8 to 44.05% protein, 3.3 to 15.3% fat, 9.1 to 20.6% ash, 3.6 to 30.97% crude fiber, and 27.05 to 53.6% carbohydrate (Chan, 2018). Alkali pre-treatment of moringa leaf led to a reduction in the content of antinutrients and improved the functional properties of ready-to-eat puffed snacks, which also exhibited high protein (21.6 g/ 100 g) and dietary fiber (14.8 g/100 g) contents. It is possible to develop a ready-to-eat convenience food product with good functional and nutritional properties using TMLP (Devisetti *et al*., 2016).

Yadav *et al*. (2018) evaluated changes in the chemical and sensory properties of a low-fat, high-protein, and fiber-enriched extruded snack during storage, which recorded increases in moisture content, $a_{w,}$ and TBA values with decreases in sensory evaluations.

Therefore, the main goal of the current study is to produce protein-rich corn snack formulas by substituting corn grits with different levels of QSF and TMLP and evaluating their nutritional value, chemical, physical, sensory, and amino acid contents, as well as their storage stability.

MATERIALS AND METHODS

1. Materials

Quinoa seed (*Chenopodium quinoa*) was obtained from the Agriculture Research Center, Giza, Egypt, and the Ministry of Agriculture (in May 2020). Moringa leaf (*Moringa oleifera*) was obtained from the Faculty of Agriculture Farm of Menoufia University, Shibin El-Kom city, Egypt. Yellow corn grits were purchased from El-Suez Co., El-Sadat city, Menoufia governorate, Egypt. Cheese flavor was obtained from the New First Taste Company for flavors and fragrances, Egypt.

2. Technological Methods.

2.1. Preparation of quinoa seed flour

Quinoa seeds were cleaned from foreign materials, washed, and dried on the oven (vacuum oven, Zhicheng, Model ZKD-5055, China) at 45ºC then milled by an electric mill (Retsch mill, 5657 HAAN, Germany) into flour and stored in the White Whale Chest Freezer, 273 Liters, Black, WCF345XAB, at -18ºC in polyethylene bags until used.

2.2. Pre-treatment of moringa leaf with calcium oxide

Moringa leaf was rinsed with tap water for 2 min, and then heated with 0.5% (W/V) calcium oxide solutions (at 60ºC) for 25 minutes. They were washed with distilled water, followed by drying at 45°C for 24 hours. The dried leaf was ground into a fine powder. The obtained leaf powder was packaged in polyethylene bags and stored below 4°C until used (Devisetti *et al*., 2016).

2.3. Preparation of Snack Blends

Three blends as well as a control (100% corn) have been prepared by mixing the recommended proportion of raw materials and corn (Table 1). The previous blends were manually conditioned to 16% moisture by spraying with a calculated amount of water. The blends were put in polyethylene bags and stored at 4°C overnight.

3. Analytical Methods.

3.1. Proximate composition.

Proximate composition (moisture, ash, protein, fat, and fiber) was carried out according to AOAC (2012), and total carbohydrate was calculated by difference.

3.2. Amino Acids pattern.

To evaluate the amino acid pattern, a high-performance Amino Acid analyzer (Biochrom 30) and EZChrom (software used for data collection and processing) were used (AOAC, 2012).

3.3. Thiobarbituric acid (TBA) value.

Thiobarbituric acid (TBA) was determined by the method of Strange *et al*. (1977).

3.4. Water activity.

Water activity (a_w) was measured at 25ºC using a Decagon Aqualah Meter Series 3TE (Pullman, WA, USA). All stored samples of snack blends were broken into small pieces immediately before water activity measurements. The measurements were performed in triplicate (Shahidi *et al*., 2008).

4. Sensory evaluation of processed snack.

Sensory evaluations were carried out after snacks were processed at zero time. Ten panelists assisted in obtaining the acceptable values of appearance, color, flavor, crispiness, taste, and overall acceptability with 0 to 20 scores, where 0 is no response and 20 is a strong response, as described by Kramer and Twigg (1970).

5. Statistical analysis.

All data will be shown as the mean ± SD (standard deviation). All statistical analyses were performed using CoStat version 6.311 (Copyright 1998–2005, CoHort Software). Analyses of variance one-way ANOVA were carried out for chemical composition of raw materials, a two-way ANOVA for chemical composition of snack extrudates after processing, and a three-way ANOVA for storage treatment effects on TBA, water activity, and sensory properties of all extrudates. While a factorial experiment was used to analyze the data on sensory attributes. Differences between treatments were considered significant at the 5% probability ($P \leq 0.05$) level.

Table 1. Formulas composition of snack blends.

Blends	Raw materials (%)				
	Corn	Quinoa seed Flour	Moringa leaf powder	Maize starch	Salt
Control	99	-	-	-	1
B1	79	12.5	2.5	5	1
B2	64	25	5	5	1
B3	49	37.5	7.5	5	1

RESULTS AND DISCUSSION

1. Proximate composition of raw materials.

The data in Table 2 illustrate the chemical composition of raw materials (corn grits, quinoa seed flour, and treated moringa leaf powder) on a dry weight basis. The evaluation of the chemical composition of raw materials plays an important role in the estimation of the nutritional value of processed snack blends. The moisture content of corn flour, QSF, and TMLP was 11.76, 11.44, and 7.89%, respectively.

Treated moringa leaf powder had the highest ($P \leq 0.05$) protein content (33.37%), followed by QSF (16.22%), while corn flour had the lowest content (11.06%). It was also noticed that the highest ($P \leq 0.05$) crude fat content was recorded for QSF and TMLP (7.52 and 7.75%, respectively), while the lowest ($P \leq 0.05$) content (5.03%) was recorded in corn flour.

It was also observed that the highest ($P \leq 0.05$) ash and crude fiber content was recorded for TMLP (11.05 and 10.73%, respectively), while the lowest ($P \leq 0.05$) content (1.92 and 1.91%) was recorded for corn flour. Corn flour had the highest carbohydrate content (80.08%), followed by QSF (65.43%) and TMLP (37.1%). These results are in agreement with those reported by Gudeta (2018) for corn flour, Vega-Gálvez *et al*. (2010), González Martín *et al.* (2014), Barakat *et al*. (2017), Angeli *et al.* (2020) for QSF, Devisetti *et al.* (2016), and Chan (2018) for TMLP.

2. Proximate composition of the extrudates

The proximate composition of flavored and non-flavored corn snacks formulated with both QSF and TMLP is presented in Table 3. Protein, ash, fat, and fiber contents significantly increased ($p \leq 0.05$) with increasing substitution levels of QSF and TMLP up to 45%, while carbohydrate content decreased ($p \leq 0.05$) to 55.62% for B3 compared to control (77.94%). This may be due to the decrease in corn grit proportion, which had higher starch content and thus led to a decrease in the starch content of the formulated blends.

The mean values of snack formulas of protein, ash, fat, and fiber increased ($p \leq 0.05$) from 10.35 to 21.01%, 1.43 to 3.42%, 9.24 to 15.92%, and 1.04 to 4.03%, respectively. This may be due to the high content of protein, ash, and fat in QSF and TMLP (Table 2). These results are in accordance with the results of Devisetti *et al*. (2016), who reported that snacks produced from TMLP, black gram, and corn flour in the proportion of 20:60:20 contained 21.6% protein, which is higher compared to the extruded snack prepared from a blend of oats and moringa leaf flour.

Table 2. Chemical composition of corn, quinoa seed flour, and treated moringa leaf powder (g/100 g dry weight).

Chemical composition	Raw materials			LSD
	Corn	Quinoa seed Flour	Treated moringa leaf powder	
Moisture	11.76 ± 0.21^{a}	11.44 ± 0.13^{b}	7.89 ± 0.09^{c}	0.304
Protein	11.06 ± 0.08^{c}	16.22 ± 0.29^{b}	33.37 ± 0.37^{a}	0.550
Ash	1.92 ± 0.09^{c}	3.25 ± 0.14^{b}	11.05 ± 0.09^{a}	0.223
Fat	5.03 ± 0.09^{b}	7.52 ± 0.34^{a}	7.75 ± 0.04^{a}	0.407
Fiber	1.91 ± 0.08^{c}	7.58 ± 0.34^{b}	10.73 ± 0.09^{a}	0.421
Carbohydrate	80.08 ± 0.05^{a}	65.43 ± 0.36^{b}	37.1 ± 0.26^{c}	0.510

Means in the same row with the different letters are significantly ($p \leq 0.05$) different.

Table 3. Chemical composition of high-protein snack extrudates of quinoa seed and treated moringa leaf (g/100 g dry weight).

Chemical composition	Treatments	Blends				Means 1	LSD
		Control	B1	B2	B3		
Moisture	Non-flavored	3.13±0.06	2.18±0.09	2.42±0.12	2.98±0.07	2.68^{b}	0.088
	Flavored	3.39±0.16	2.29±0.05	3.06±0.16	3.27±0.04	3.00^{a}	
Means 2		3.26^{a}	2.23^{d}	2.74^{c}	3.13^{b}		0.124
Protein	Non-flavored	10.17±0.38	14.53±0.40	16.96±0.39	20.82±0.40	15.62^{a}	0.389
	Flavored	10.53±0.26	14.72±0.40	16.66±0.79	21.21±0.41	15.56^{a}	
Means 2		10.35^{d}	14.63^{c}	16.37^{b}	21.01^{a}		0.551
Ash	Non-flavored	1.25±0.02	2.34±0.05	2.45±0.08	2.97±0.11	2.25^{b}	0.059
	Flavored	1.62±0.05	2.83±0.02	3.12±0.07	3.87±0.1	2.86^{a}	
Means 2		1.43^{d}	2.59^{c}	2.79^{b}	3.42^{a}		0.084
Fat	Non-flavored	2.22±0.23	4.52±0.38	5.37±0.02	6.86±0.07	4.74^{b}	0.285
	Flavored	16.26±0.07	21.69±0.81	24.25±0.03	24.97±0.09	21.79^{a}	
Means 2		9.24^{d}	13.10^{c}	14.81^{b}	15.92^{a}		0.403
Fiber	Non-flavored	1.07±0.08	2.42±0.01	3.39±0.02	4.43±0.26	2.83^{a}	0.111
	Flavored	1.01±0.03	2.08±0.06	3.34±0.15	3.62±0.18	2.51^{b}	
Means 2		1.04^{d}	2.25^{c}	3.37^{b}	4.03^{a}		0.157
Carbohydrate	Non-flavored	85.30±0.27	76.19±0.79	71.83±0.40	64.92±0.24	74.56^{a}	0.782
	Flavored	70.58±0.18	58.68±0.59	53.50±2.26	46.33±0.39	57.27^{b}	
Means 2		77.94^{a}	67.43^{b}	62.67^{c}	55.62^{d}		1.12

[1] Mean (flavored) in the same column with different superscript letters is different significantly ($p \leq 0.05$).
[2] Mean (blends) in the same row with different superscript letters are different significantly ($p \leq 0.05$).
Interaction between blends × flavored is significant ($p \leq 0.05$).

The protein content of the produced snack formulas ranged from 14.63 for B1 to 21.01 for B3, while the control samples had 10.35%, which is lower than the recommendation of FAO (2001), which recommends that non-fried snacks contain at least 12% crude protein. The increase in fiber content is a positive effect, whereas fiber protects against the development of colorectal cancer and a range of other diseases, including obesity, cardiovascular ailments, and diabetes (Liu *et al*., 2011).

Generally, the addition of cheese flavor significantly ($p \leq 0.05$) affects the chemical composition of extrudate blends. Fat content increased from 4.74 to 21.79%, while fiber and carbohydrate content decreased with the addition of cheese flavor. The increase in fat content of all flavored blends is mainly due to the fact that the flavor was dissolved in the oil phase. The flavored blends had the highest value of moisture (3.00%), which could be a result of gaining moisture during their passing through the drying oven for loading with the flavored agent due to the hygroscopic nature and porous structure of the extrudates. However, all values are within the allowed limits mentioned in the Egyptian standard specifications (EES 1525/2005), which recommend that moisture content should not exceed 5% because food with low moisture content would limit microbial growth and extend the storage period, as recorded by Okiki *et al*. (2015).

The increase in protein content is due to the 45% incorporation of QSF and TMLP, and developed extrudates can improve protein digestibility through the inactivation of enzyme inhibitors and denaturation of proteins in the raw material, which makes them more susceptible to enzyme attack and enhances the bioavailability of protein (Beigh *et al*., 2020).

3. Amino acid pattern of the snack blends

The nutritive quality of protein depends on its content of essential amino acids. Nine amino acids are strictly essential for humans: phenylalanine, isoleucine, leucine, lysine, methionine, threonine, tryptophan, valine, and histidine (essential in childhood) (WHO, 2007).

The amino acid content (g/100 g protein) of the extrudates is illustrated in Table 4. Glutamic acid was the highest amino acid content in the control sample, and its value increased by increasing the substitution level compared with Hen's egg (FAO, 1970), as Barakat *et al*. (2019) and Barakat *et al*. (2017) mentioned that glutamic acid in quinoa is more than 2-fold higher than in the referenced egg protein.

Table 4. Amino acid pattern of formulated extrudates (g/100 g protein) compared with hen's egg standard.

Amino acids %	Control	Blend 1	Blend 2	Blend 3	Hen's egg (FAO 1970)
Essential amino acids (EAA)					
Methionine	0.04	0.02	0.03	0.03	0.210
Theronine (THR)	0.29	0.35	0.42	0.48	0.320
Cystine (CYS)	0.14	0.09	0.11	0.11	0.110
Total sulfur amino acids	**0.47**	**0.46**	**0.56**	**0.62**	
Tyrosine (TYR)	0.33	0.30	0.41	0.48	0.260
Phenylalanine (PHE)	0.31	0.32	0.42	0.50	0.358
Total aromatic amino acids	**0.640**	**0.620**	**0.830**	**0.980**	
Hisitidine (HIS)	0.17	0.18	0.23	0.26	0.152
Valine (VAL)	0.25	0.37	0.39	0.49	0.428
Isoleucine (Iso)	0.16	0.21	0.29	0.37	0.393
Leucine (LEU)	0.82	0.85	0.91	0.98	0.551
Lysine (LYS)	0.11	0.13	0.24	0.29	0.436
Total essential amino acids	**2.62**	**2.82**	**3.45**	**3.99**	
Non-essential amino acid (NEAA)					
Aspartic (ASP)	0.40	0.47	0.60	0.71	0.601
Alanine (ALA)	0.51	0.52	0.55	0.60	0.370
Glutamic (GLU)	1.32	1.42	1.51	1.67	0.478
Argnine (ARG)	0.22	0.29	0.45	0.53	0.381
Proline (PRO)	0.65	0.68	0.67	0.64	0.260
Glycine (GLY)	0.22	0.26	0.35	0.42	0.207
Serine (SER)	0.29	0.35	0.40	0.44	0.796
Total nonessential amino acids	**3.61**	**3.99**	**4.53**	**5.01**	

These results agree with Natsir *et al*. (2019), who showed that glutamic acid was an amino acid with the highest concentration, while cysteine was the lowest in moringa leaf. Glutamic acid, as an acidic amino acid, has inhibitory activity against DPPH radicals (Udenigwe and Aluko, 2011). The increasing substitution of QSF and TMLP led to an increase in total essential amino acids from 2.62 for the control to 3.99 g/100 g protein for B3, and an increase in nonessential amino acids from 3.61 for the control to 5.01 g/100 g protein for B3.

Except for cystine and methionine, Blend 3 had higher values of all amino acids compared to the control. This is due to the increased substitution of QSF and TMLP. This indicates that the higher the concentration of hydrophobic, aromatic, and acidic amino acids in a sample, the better its potential as an antioxidant, which will protect the lipid fraction in the extrudates from oxidation and extend its shelf life and storage times (Wang and Padua, 2004; Udenigwe and Aluko, 2011).

4. Thiobarbituric acid (TBA) values of stored extrudates.

The thiobarbituric acid (TBA) value was used to determine the degree of lipid oxidation in the snack blends. Unsaturated system oxidation products react with TBA acid to give color, and only fatty acids with three or more double bonds release significant amounts of TBA-reactive material. Tables 5 and 7 show the changes in TBA values of cheese flavored and non-flavored formulated extrudates with different substitution levels of QSF and TMLP during storage for 3 months at ambient temperature (25±2ºC).

Generally, there was a significant ($p \leq 0.05$) difference in TBA value (mg malonaldehyde/kg) between flavored (0.571) and non-flavored extrudates (0.489). The higher fat content in flavored extrudates compared with non-flavored (Table 3) led to an increase in the amount of TBA-reactive compounds that were produced because of lipid oxidation and the formation of volatile metabolites, which contributed to the increase in TBA value. Generally, TBA mean values of all samples (flavored and non-flavored) were significantly increased ($p \leq 0.05$) by increasing the storage period of the snack blends from 0.304 to 0.781 malonaldehyde/kg sample; on the other hand, Capriles *et al*. (2009) indicated that no significant differences in TBARS concentration among samples were observed during the storage period.

A significant decrease ($p \leq 0.05$) in TBA mean values was noticed by increasing the substitution level of QSF and TMLP as compared with the control; the highest value of TBA was observed in the control (0.565), followed by B1 (0.536), B2 (0.516), and B3 (0.503). This may be a result of increased protein content, which is considered an antioxidant agent that reduces oxidation and might be due to the antioxidant properties of QSF and TMLP. This finding agrees with that of Kenawi *et al.* (2022), who found that quinoa had an inhibitory effect on the production of oxidative chemicals because the TBA values for the control samples were higher than the extended samples produced from QSF. Because of its phenolic and flavonoid content, quinoa has excellent and higher antioxidant activity than some cereals and can be used as a source of substances that scavenge free radicals (James, 2009).

Ponbhagavathi *et al*. (2020) recorded that the TBA value of the extrudates increased from an initial value of 0.154 to 0.173 when stored at 25°C because of an increase in lipid oxidation, especially in maize lipids, which are abundant in polyunsaturated fatty acids. The presence of oxygen and heat may aid the oxidation of lipids resulting in the formation of oxidative products.

Yadav *et al*. (2018) recorded an increase in TBA value in extruded maize snacks stored at 25±ºC for 20 weeks. Also, they elucidated that the extrusion rate also affects expansion, and products with a higher degree of expansion are more likely to have large cells and thinner cell walls, thereby increasing oxygen exposure and making them more susceptible to oxidation. Also, Patel *et al.* (2018) and Gulla and Waghray (2012) observed an increase in the TBA value of deep-fat fried corn extrudates stored at room temperature.

Ahmad *et al*. (2017) mentioned that the TBA value of the snack food samples in fresh condition were found between 0.072 and 0.080 mg/kg of malonaldehyde. The TBA values increased with increasing storage period, from 0.092 at zero time to 0.125 at the end of storage, according to Deepika *et al*. (2022). The low TBARS value and the absence of off-flavors indicate that the lipid oxidation did not progress significantly during the studied period, which explains why it resulted from lipid oxidation and the production of volatiles as recorded by Capriles *et al*. (2009).

5. Water activity.

The degree to which water binds to various non-aqueous components and solids is evaluated as "water activity." It is a crucial tool for predicting and managing food goods' shelf life (Yadav *et al*., 2018). Water activity is a measure of the safety and quality of extruded food products (Syed *et al.*, 2019). Data presented in Table 6 and 7 showed the effect of different levels of QSF and TMLP, flavoring, and 3 months storage at ambient temperature (25±2ºC) on the a_w of the snack extrudates.

There was no significant ($p>0.05$) difference in snack extrudates a_w between flavored and non-flavored blends. On the other side, the water activity of the snacks was decreased ($p\leq0.05$) by increasing the substitution of QSF and TMLP compared with the control. Similar ($p>0.05$) a_w values were recorded for blends B1 and B2, while B3 was higher ($p\leq0.05$) than them and all of them lower than the control. These results agree with the results of Makowska *et al. (2014),* who reported that the addition of 3% whey contributed to a significant reduction of 8.7% of a_w in puffs and at 10% addition of whey proteins, a 16.6% reduction in a_w was recorded.

Table 5. Thiobarbituric acid (TBA) values of cheese flavored and non-flavored extrudates formulated with different levels of quinoa and moringa during storage at 25±2ºC for 3 months.

Storage period (month)	Flavored							
	Non-flavored				Flavored			
	Control	B1	B2	B3	Control	B1	B2	B3
0	0.307±0.012	0.265±0.008	0.257±0.008	0.250±0.008	0.367±0.016	0.346±0.012	0.328±0.008	0.315±0.012
1	0.445±0.008	0.421±0.008	0.400±0.012	0.390±0.008	0.507±0.008	0.484±0.008	0.484±0.008	0.476±0.008
2	0.577±0.008	0.562±0.008	0.554±0.008	0.536±0.012	0.632±0.008	0.624±0.008	0.601±0.008	0.593±0.008
3	0.744±0.012	0.725±0.008	0.710±0.008	0.694±0.008	0.944±0.008	0.863±0.012	0.796±0.008	0.772±0.016

Each value in the table is the mean ± standard deviation of three replicates (as dry weight basis).

Table 6. Water activity of cheese flavored and non-flavored extrudates formulated with different levels of quinoa and moringa during storage at 25±2ºC for 3 months.

Storage period (month)	**Flavored**							
	Non-flavored				Flavored			
	Control	**B1**	**B2**	**B3**	**Control**	**B1**	**B2**	**B3**
0	0.39±0.006	0.29±0.004	0.29±0.003	0.29±0.001	0.37±0.002	0.30±0.001	0.31±0.003	0.31±0.003
1	0.39±0.007	0.29±0.001	0.30±0.001	0.33±0.002	0.39±0.002	0.31±0.002	0.32±0.001	0.34±0.002
2	0.46±0.001	0.35±0.016	0.36±0.017	0.39±0.007	0.41±0.003	0.42±0.001	0.35±0.01	0.38±0.001
3	0.54±0.001	0.49±0.007	0.51±0.002	0.53±0.006	0.53±0.008	0.49±0.009	0.49±0.002	0.52±0.004

Each value in the table is the mean ± standard deviation of three replicates (as dry weight basis).

Table 7. Statistical analysis of thiobarbituric acid (TBA) and water activity (a_w) as affected by blends, flavored, and storage.

Parameters	Blends				LSD	Flavored		LSD	Storage (month)				LSD
	Control	B1	B2	B3		Non-flavored	Cheese flavored		0	1	2	3	
TBA	0.565^{a}	0.536^{b}	0.516^{c}	0.503^{d}	0.005	0.489^{b}	0.571^{a}	0.004	0.304^{d}	0.451^{c}	0.585^{b}	0.781^{a}	0.005
A_w	0.43^{a}	0.37^{c}	0.37^{c}	0.39^{b}	0.003	0.388^{a}	0.389^{a}	0.002	0.32^{d}	0.34^{c}	0.39^{b}	0.51^{a}	0.003

Means in the same row with different letters are significantly different ($p \leq 0.05$).
Interaction between blends × flavored is significant ($p \leq 0.05$).
Interaction between blends × storage period is significant ($p \leq 0.05$).
Interaction between storage period × flavored is significant ($p \leq 0.05$).
Interaction between blends × flavored × storage is significant ($p \leq 0.05$).

However, water activity was increased ($p \leq 0.05$) by increasing the storage period of the snack blends. Water activity increased by 59.38% during the storage period (from 0.32 to 0.51), which was in agreement with Hussain *et al.* (2015), Nazir *et al.* (2017), Yadav *et al*. (2018), and Syed *et al.* (2019). The humid environment may be responsible for the increase in water activity in extrudates (Hussain *et al.*, 2015). Chowdhury *et al.* (2011) reported that moisture and a_w values increased over time, whereas sensory scores declined. They also confirmed that a_w contributed additional information by considering the water availability for degrading reactions. The increase in a_w values of the extrudates may be related to the hygroscopic properties of the extruded food and the environment's high humidity levels (Syed *et al*., 2019).

All results indicated that the a_w values of all various QSF and TMLP extrudates were within the standards' limits for dry food (0.3 and 0.5). Controlling a_w in food is one of the most significant preservation methods to assure food safety against microbiological and chemical degradation, which can lengthen shelf life and enhance convenience with new food products. As a result, several food preservation procedures concentrate on reducing the a_w to slow microbial development and chemical reactions(Deepika *et al*., 2022).

Reddy *et al.* (2014) indicated that more air spaces in the extruded products cause an increase in the moisture content of the ready-to-eat extruded products during storage. The a_w of the extruded product incorporated increased during storage and was found to be 0.564 to 0.594, which is attributed to a change in the humidity levels of the surrounding environment.

6. The sensory properties of a snack extrudates during storage.

The consumer acceptability of the snacks depends mainly on the sensory properties measured, such as appearance, texture, color, flavor, crispness, and taste. The sensory evaluation of extruded snacks prepared with different substitution levels of QSF and TMLP is shown in Table 8.

Results showed that the appearance scores of formulated extrudates were decreased ($p \leq 0.05$) by substitution levels of QSF and TMLP compared with the control; blend 1 had the highest value (17.43), while the control and blend 3 had the lowest values (15.6 and 15.43, respectively), while all flavored extrudates appearance had the highest ($p \leq 0.05$) scores (17.23), and the appearance of all extrudates decreased ($p \leq 0.05$) by increasing the storage period from 16.79 to 15.84.

The highest color scores were recorded in B1 (17.34), followed by B2 (16.41), while the lowest scores were observed in blend 3 (15.29) and the control (15.53). The decrease in color may be due to the Millard reaction and/or the green color of the moringa leaf. The flavored extrudates had higher ($p \leq 0.05$) scores (16.94) compared to the non-flavored (15.34). The color decreased (p≤0.05) by increasing the storage period from 16.71 to 15.54. Generally, the color of flavored extrudates up to 45% substitution levels showed significant (p≤0.05) acceptability by the panelists, whereas the color of non-flavored extrudates was acceptable up to 30% substitution levels (Picture 1). Color is essential in attracting customers before they purchase a product (Rampersad *et al*., 2003).

Generally, B1 had the highest (p≤0.05) scores of flavor (17.31), followed by B2 (16.71), then the control (15.79), whereas B3 had the lowest scores (15.06). All mean flavored extrudates had higher (p≤0.05) scores (17.26) compared to the non-flavored (15.18) due to the highest value of fat (Table 2), where lipids affect food flavor through influencing flavor feeling (mouth-feel, taste, and aroma), flavor stability, and flavor development (Guichard, 2002). While the color scores decreased with increasing storage.

With regards to crispness, we found that the mean scores of crispness significantly (p≤0.05) decreased by increasing the substitution levels of QSF and TMLP. Blend 1 and B2 had the highest scores, followed by B3, then the control. By increasing the storage period, crispness decreased (p≤0.05) from 17.54 to 16.33. Crispness scores were significantly (p≤0.05) improved with adding QSF and TMLP compared to the control, which appeared to be smooth in texture. That may be due to the fact that during the extrusion cooking of biopolymers, the viscoelastic material is forced through the die so that the sudden pressure drop causes the evaporation of a part of the water, giving an expanded porous structure (Sawant *et al*., 2013). Patil and Kaur (2018) stated that the hardness and crispness are associated with the expansion and cell structure of the extruded product.

While taste and overall acceptance scores were the highest (p≤0.05) in B1, followed by B2, B3, and the control. The flavored extrudates had higher scores in taste and overall acceptance (17.15 and 17.29) compared to the non-flavored extrudates (15.2 and 15.43). All mean scores decreased with increasing storage periods for taste and overall acceptance.

Blend 1 is the highest in appearance, color, flavor, crispness, taste, and overall acceptance (17.43, 17.34, 17.31, 17.85, 17.02, and 17.43, respectively), followed by blend 2, then blend 3, and the control is the lowest in the most sensorial properties.

These results agree with the results of Yağci and Göğüş (2008), which produced extrudates from partially defatted hazelnut flour with a protein content of 33.51% and a fat content of 17.26%, where the products were acceptable.

Although the nutritional attributes of the snack extrudates are the most important consideration, these properties are related to the number and size of air cells formed during the extrusion, which depend on the proportion and type of the starch and the kind of raw materials. However, the blending of these ingredients somehow limited the release of aroma components upon cooking. The major volatiles during extrusion are lipid breakdown compounds, with a few coming from the Maillard reaction (Forsido *et al.*, 2019).

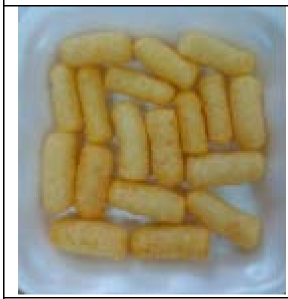
There were significant (P≤0.05) improvements in all tested sensory attributes by increasing the levels of QSF and TMLP by up to 25 and 5%, respectively, compared to the control. That may be due to the fact that during extrusion cooking of biopolymers, the viscoelastic material is forced through the die so that the sudden pressure drop causes the evaporation of part of the water, giving an expanded porous structure (Sawant *et al*., 2013).

Overall sensory quality indicated that the snacks had acceptable textural attributes and an improved the mouth feel and nutritional profile at the 30% level of substitution; pretreatment also showed lower solubility, possibly due to the leaching of soluble proteins during the pretreatment with calcium oxide. The TMLP reduced levels of polyphenols may be a suitable ingredient in the development of functional food products (Devisetti *et al.,* 2016).

Table 8. Sensory properties of snack extrudates.

Sensory properties	Blends				LSD	Non-flavored	Flavored	LSD	Storage(month)				LSD
	control	B1	B2	B3					0	1	2	3	
Appearance	15.6 ± 1.25^{c}	17.43 ± 1.31^{a}	16.8 ± 1.26^{b}	15.43 ± 1.21^{c}	0.240	15.39 ± 1.18^{b}	17.23 ± 1.20^{a}	0.170	16.79 ± 1.66^{a}	16.4 ± 1.42^{b}	16.23 ± 1.36^{b}	15.84 ± 1.43^{c}	0.240
Color	15.53 ± 1.06^{c}	17.34 ± 1.48^{a}	16.41 ± 1.41^{b}	15.29 ± 1.41^{c}	0.262	15.34 ± 1.21^{b}	16.94 ± 1.48^{a}	0.185	16.71 ± 1.74^{a}	16.25 ± 1.66^{b}	16.06 ± 1.39^{b}	15.54 ± 1.22^{c}	0.262
Flavor	15.79 ± 1.38^{c}	17.31 ± 1.47^{a}	16.71 ± 1.33^{b}	15.06 ± 1.55^{d}	0.242	15.18 ± 1.35^{b}	17.26 ± 1.27^{a}	0.171	16.91 ± 1.77^{a}	16.45 ± 1.57^{b}	15.99 ± 1.54^{c}	15.53 ± 1.48^{d}	0.242
Crispness	15.48 ± 1.50^{c}	17.85 ± 1.38^{a}	17.68 ± 1.05^{a}	16.78 ± 1.23^{b}	0.236	16.03 ± 1.39^{b}	17.86 ± 1.24^{a}	0.167	17.54 ± 1.50^{a}	17.15 ± 1.42^{b}	16.76 ± 1.54^{c}	16.33 ± 1.70^{d}	0.236
Taste	15.36 ± 1.40^{c}	17.02 ± 1.07^{a}	16.58 ± 1.19^{b}	15.56 ± 1.85^{c}	0.244	15.2 ± 1.31^{b}	17.15 ± 1.20^{a}	0.173	16.79±1.60a	16.38±1.49b	16.04±1.43c	15.5±1.58d	0.244
Overall acceptability	15.55 ± 1.01^{c}	17.43 ± 1.18^{a}	16.84 ± 1.11^{b}	15.62 ± 1.30^{c}	0.136	15.43 ± 1.02^{b}	17.29 ± 0.08^{a}	0.096	16.95±1.51a	16.53±1.30b	16.21±1.28c	15.75±1.25d	0.136

The scores ± S.D in the same row with different letters are significantly different ($p \leq 0.05$)
The interaction between blends × storage period is significant ($p \leq 0.05$).
The interaction between blends × flavored is significant ($p \leq 0.05$).
The interaction between storage period × flavored is significant ($p \leq 0.05$).
The interaction between blends × flavored × storage is significant ($p \leq 0.05$).

			
Control	**Blend 1**	**Blend 2**	**Blend 3**
			
Control Flavored	**Blend 1 Flavored**	**Blend 2 Flavored**	**Blend 3 Flavored**

Picture (1): Snack extrudates are prepared by incorporating corn flour with different levels of quinoa seed flour and treated moringa leaf powder.

Conclusion

The goal of this study was to create a new protein-rich extruded corn snack by substituting levels of both QSF and TMLP. Our findings illustrate that alkali pretreatment of moringa leaf is effective in producing extrudates with acceptable sensory properties. The formulated snack with a substitution level up to 30% of both QSF and TMLP in order to produce breakfast cereals with acceptable chemical, functional, and nutritional properties. The blends had significant protein and fiber content and amino acid composition, particularly glutamic acid and lysine, and appropriate nutritional quality and shelf stability without affecting their sensory properties. When consumed, this type of breakfast cereal can improve human health and nutritional status.

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إنتاج وجبات خفيفة مبثوقة حرارياً غنية بالبروتين باستخدام خلطات من دقيق الكينوا واوراق المورينجا

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قسم علوم وتكنولوجيا الأغذية - كلية الزراعة – جامعة المنوفية شبين الكوم

الملخص العربى

تم تحضير ثلاث وجبات خفيفة من الذرة بنسب استبدال (15 و30 و45٪) من كلا من دقيق بذور الكينوا (QSF) بنسبة 12.5 و25 و37.5٪، ومسحوق أوراق المورينجا المعالج بالقلوي (TMLP) بنسبة 2.5 و5 و7.5٪ مع وبدون طعم الجبنة. تم تقييم التركيب الكيميائي والأحماض الأمينية والصفات الحسية للسناكس. كما تم دراسة تأثير التخزين لمدة 3 أشهر عند درجة حرارة الغرفة (25 ± 2 درجة مئوية) على قيم حامض الثيوباربوتريك (TBA)، ودرجة النشاط المائي (a_w)، والخصائص الحسية. ولقد أظهرت النتائج المتحصل عليها أنه زاد محتوى السناكس من البروتين والرماد والدهون ($p \leq 0.05$) مع زيادة مستويات الاستبدال بـ QSF وTMLP، فلقد ارتفع متوسط قيم محتوى البروتين ($p \leq 0.05$) من 10.35٪ للعينة الضابطة إلى 21.01٪ للخلطة B3، بينما انخفضت الكربوهيدرات. وكانت السناكس بطعم الجبنة تمثل أعلى القيم ($p \leq 0.05$) من محتوي الرماد والدهون وأقل القيم ($p \leq 0.05$) من محتوي الألياف والكربوهيدرات. وأظهرت النتائج أيضا انه مع زيادة مستويات QSF وTMLP تحسن في قيم الأحماض الأمينية (خاصة حمض الجلوتاميك) للسناكس غير المطعمة بالجبنة. وأثناء التخزين تراوحت قيم الـ TBA من 0.304 عند التصنيع إلى 0.781 في نهاية التخزين، وانخفضت من 0.565 للعينة الضابطة إلى 0.503 للخلطة B3، وبشكل عام، زادت قيم الـ a_w لجميع السناكس ($p \leq 0.05$) من 0.32 إلى 0.51، بينما انخفضت ($p \leq 0.05$) من 0.43 إلى 0.37 مع زيادة نسب الاستبدال لكلا من QSF وTMLP. وكانت الصفات الحسية للسناكس مقبولة أثناء التخزين. وفي الختام، نجد أنه استبدال الذرة بكلا من QSF وTMLP بنسبة تصل إلى 30٪ حقق أفضل النتائج في قيم كلا من الـ TBA، النشاط المائي، الخصائص الحسية، والقيمة الغذائية للسناكس المنتجة.

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