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ORIGINAL PAPER

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FORMULATION AND QUALITY EVALUATION OF NOODLES WITH STARCHY FLOURS CONTAINING HIGH LEVELS OF RESISTANT STARCH

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ABSTRACT

Background. Increased consumption of foods high in resistant starch (RS) has been shown to prevent or manage type 2 diabetes, cardiovascular disease, and colon cancer.

Materials and methods. The current study was carried out to identify the effects of supplementing noodles with high RS flour from red kidney beans, black turtle beans, mung beans, and potato starch on their RS content, quality properties, morphological appearance and consumer perception. The noodles were labelled F0 with 100% wheat flour, F1 with 22.5% high RS flour, F2 with 30% high RS flour, and F3 with 37.5% high RS flour.

Results. The obtained results showed that the content of resistant starch in the noodles increased when some of the wheat flour was added/replaced with flour high in resistant starch content. The bright color of the noodles, *L**, decreased significantly from the control sample F0 to the F3 formulation of noodles, which was attributed to the dark color of the supplemented flour, and the yellowness of the noodles also decreased. The addition of high RS flour had no significant effect on the hardness of the noodles. However, the cooking loss increased in the noodles from 6.09% in F0 to 9.87% in F3. The images from scanning electron microscopy showed increased pores in the noodles supplemented with high RS flour, which may explain the increased cooking loss. Consumers preferred the F2 noodles with 30% high RS flour supplementation. The incorporation of high RS flour into the noodle formulation increased RS content, but it had some negative effects on the quality parameters of the noodles.

Conclusion. In order to achieve high RS noodles with acceptable quality, a suitable balance with the percentage of flour ought to be established when formulating products supplemented with high RS flour.

Keywords: noodles, quality parameters, sensory evaluation, high RS flours, SEM

INTRODUCTION

The popularity of noodles is attributed to their ease of preparation, sensory appeal, and affordability, as well as their long shelf life (Omeire et al., 2014). Due to the recent increase in cases of non-communicable diseases mostly resulting from poor dietary choices, various approaches have been put in place to manage them. Among these are the incorporation of high RS flours in commonly consumed food products, which help lower the glycemic index of foods and improve their nutrient content (Chillo et al., 2010; Teterycz et

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al., 2020). The benefits of supplementing noodles with highly nutritious flour have been shown by Topping et al. (2008). Legume flour incorporation has been shown to improve protein content, dietary fiber, and product colour, as well as the RS content of pasta products (Chen et al., 2010). Resistant starch is described as starch that resists digestion in the small intestine and undergoes fermentation in the large intestine (Englyst et al., 1992). Resistant starch has several benefits including management of type 2 diabetes, weight management, and prevention of colon cancer, reducing the incidence of coronary cases and maintaining a healthy colon (Sajilata et al., 2006). The addition of non-conventional flours such as high RS flours to pasta formulations increases the cooking losses of the products, as reported by Chillo et al. (2010). These high RS flours include mung bean flour, black bean flour, red kidney bean flour, and potato starch (Eashwarage et al., 2017; Yadav et al., 2010). The addition of supplementary flour to pasta has an impact on the color of pasta products. The lightness L^* and yellowness b^* decrease with an increase in legume and sweet potato flours, which is associated with low acceptability among consumers (Morris, 2018). The hardness of noodles increases with increased supplementation of chayotextle flour (Victoriano et al., 2020). In order to achieve acceptable products, a balance has to be established between consumer acceptability, quality characteristics, and nutrient content in the formulation of pasta products. The supplementation of pasta products with high RS flour affects their microstructure, increasing pore sizes, as is evident in scanning electron microscopy (SEM) analyses (Han et al., 2021). Several studies have been carried out on the effects of supplementing pasta products with specific starchy vegetable flour high in resistant starch content (noodles) (Tangthanantorn et al., 2021). However, limited research has been carried out on the effects on noodles of combining several starchy vegetable flours containing resistant starch. The aim of this study was to formulate noodles with combined starchy sources, determine the resistant starch content of the noodles made with several starchy flours, and evaluate the effects of supplementing noodles with mung bean flour, black bean flour, red kidney bean flour, and potato starch on the quality of those noodles.

MATERIALS AND METHODS

Materials

The materials used in the experiments were mung bean flour, black bean flour, red kidney bean flour, potato starch, wheat flour, semolina, salt, eggs, water, and xanthan gum (E415) purchased from a local market and MegaMarket in Can Tho, Vietnam. A PHILIPS pasta maker (HR2375/06) was used in extrusion of the dough used to make the noodles. A resistant starch (RS) assay kit (Megazyme, Bray, Ireland) was used to measure the RS content of the prepared samples. All of the chemicals used in this study were of analytical grade.

Preparation of noodles

The flours were mixed into four formulas according to the specified ratio of flours to process the noodles, as shown in Table 1. The control sample was formulated with whole wheat flour, while the other formulations had high resistant starch flours of 22.5% of the total components of the noodles in F1, 30% in F2, and 37.5% in F3. The process of making the noodles was carried out according to Thuy et al. (2020). The prepared noodles were dried in an oven at 65°C until the moisture content of the dried sample was around 6–7%, and was ground before measurement of the RS content.

Table 1. Formulation of noodles, g

Ingredients	F0	F1	F2	F3
Mung bean flour	0	15	20	25
Red kidney bean flour	0	15	20	25
Black turtle bean flour	0	15	20	25
Potato starch	50	50	50	50
Wheat flour	200	155	140	125
Semolina	40	40	40	40
Salt	2	2	2	2
Egg	65	65	65	65
Water	63	63	63	63
Xanthan gum	5.8	5.8	5.8	5.8
Total	425.8	425.8	425.8	425.8

Resistant starch and amylose measurement. Resistant starch – RS tests were adapted for each matrix of formulation using the Association of Official Analytical Chemists (AOAC) Method 2002.02 (McCleary and Monaghan, 2002) according to Ang (2011). The content of amylose was measured using the method of Ronoubigouwa et al. (2010).

Hardness testing. The texture attribute hardness of the noodles was analyzed with a Brookfield CT3 Texture Analyzer equipped with a 1,500 g load cell and software version 1.8 (Brookfield Engineering Laboratories, Middleboro, MA, USA) as described by Thuy et al. (2020).

Cooking quality analysis. The cooking quality was analyzed by measuring cooking loss (%), rehydration rate (%), and volume increase (%). The cooked noodles were separated from the cooking water using a strainer as described by Gelencsér et al. (2008); the collected cooking water was dried in an oven at 103°C for cooking loss (CL) determination using equation 1 according to Wang and Ratnayake (2016). The cooked noodles were dried in an oven at 103°C for 20 hours to estimate the rehydration rate (RR) using equation 2 according to Kamolchote et al. (2010), and the volume increase (%) was determined as shown in equation 3 (Thuy et al., 2020).

$$\text{CL, \%} = \frac{\text{weight of residue from cooking water, g}}{\text{weight of noodle sample, g}} \times 100 \quad (1)$$

$$\text{RR, \%} = \frac{\text{WCN, g} - \text{OWN, g}}{\text{OWN, g}} \times 100 \quad (2)$$

where WCN is the weight of the cooked noodles and OWN is the original weight of the noodles.

$$\text{Volume increase, \%} = \frac{\text{volume of cooked noodles} - \text{volume of uncooked noodles}}{\text{volume of uncooked noodles}} \times 100 \quad (3)$$

Color analysis. The color of both the cooked and uncooked noodles was measured on the hunter scale for L^*, a^*, and b^* using a Minolta Chroma meter (CR 400 Konica Minolta, Tokyo, Japan). Ten measurements were carried out on each sample. The color differences between the samples were calculated using equation 4.

$$\Delta E^*_{ab} = \sqrt{\left(L^*_2 - L^*_1\right)^2 + \left(a^*_2 - a^*_1\right)^2 + \left(b^*_2 - b^*_1\right)^2} \quad (4)$$

where the subscripts 1 and 2 represent the test and reference, respectively.

Sensory evaluation. Quantitative Descriptive Analysis (QDA) and Check All That Apply (CATA) were applied for the sensory evaluation. It was carried out by ten untrained panellists who with an average age of 22, who consumed noodles often. The CATA questions multiple choice, which is commonly used in marketing research in order to reduce responses. The questions contained a list of words where the panellists selected those attributes that described the samples appropriately (Espitia-López et al., 2019). The data was recorded in binary format (0 – attributes not ticked and 1 – attributes ticked) for CATA, and the rating scale of intensities for QDA was from 0 (not detected) to 5 (detected strongly).

Scanning electron microscopy (SEM). The noodles were cut using a razor blade and the samples mounted onto brass stubs using double-sided carbon conductive adhesive tape (Thuy et al., 2020). The sample was examined at 15 kV, with the sample distance of 7 cm to the ejection glass, and 230X magnifications using a JEOL model J550 scanning electron microscope (Japan).

Statistical analysis

The data obtained were analyzed using Analysis of Variance (ANOVA), and Multiple Range Tests were used to determine significant differences between the samples ($P < 0.05$). The software used was STATGRAPHICS CENTURION XVI.I, and sensory analysis was carried out using XLSTAT 2014 (Addinsoft, New York).

RESULTS AND DISCUSSION

Effects of high RS flour addition on the appearance of noodles

The control sample of noodles, F0, had a deep yellow color, while the noodles supplemented with starchy

a – uncooked noodles

b – cooked noodles

Fig. 1. Pasta noodles are prepared according to different formulations designed according to the experiment: a – uncooked noodles, b – cooked noodles

flour had a dark appearance (Fig. 1). After cooking, the brightness of the noodles increased slightly. The addition of mung bean, black bean and red kidney bean to the noodles resulted in a darkening of the noodles. During formulation of the noodles, different ingredients had specific functionalities.

Gluten protein in wheat flour enhanced dough formation due to its viscoelastic properties, while semolina provided the products with excellent ductility after heat treatment and a stable yellow colour (Messia et al., 2021). Potato starch provided RS, fillers, and binders, and formed a starch-protein network structure with gluten, which was conducive to improving the hardness of the noodles (Tao et al., 2020).

Table 2. Proportion of starchy flour and RS content of four noodle formulations

Proportion (mung bean flour: red kidney bean flour: black bean flour: potato starch: wheat flour)	RS content, %		Amylose content %
	before cooking	after cooking	
F0 0:0:0:20:80	11.39 ±0.06[a]	0.53 ±0.01[a]	15.94 ±0.90[b]
F1 6:6:6:20:62	14.96 ±0.07[b]	1.24 ±0.01[b]	13.49 ±0.00[a]
F2 8:8:8:20:56	16.10 ±0.05[c]	1.34 ±0.01[c]	13.54 ±0.58[a]
F3 10:10:10:20:50	17.43 ±0.03[d]	1.45 ±0.01[d]	14.48 ±1.01[ab]

Values are expressed as the mean ±SD. Values with different superscripts in the same column are significantly different according to LSD test ($p < 0.05$). F0 – control sample.

Effects of high RS flour addition on resistant starch and amylose content of pasta (noodles)

The RS content in the prepared noodles increased significantly with an increase in the percentage of supplemented high RS flour (Table 2). Specifically, F3 recorded the highest content of resistant starch with 17.43%, followed by F2 with 16.10% RS, and F1 had 14.96%, which was the least RS content among the supplemented noodles, but the control sample, F0, recorded the least content generally, with 11.39% in the uncooked samples. The amylose content of the three samples supplemented with high RS flour had no significant difference ($P > 0.05$), but there was an increasing trend with an increased content of high RS flour supplemented.

The increase in RS content of the noodles after supplementation was attributed to the high RS content in the legume flours used to supplement them. Azkia et al. (2021) found the RS content of noodles formulated with sorghum, mung bean, and sago starch to range between 16.35 and 21.57%, which is comparable with the current study. However, the Chinese diet by Chen et al. (2010) found the RS content of noodles using mung bean starch to be 34.1 g/100 g total starch (TS), which is higher than the current study. The RS content of the noodles reduced significantly after cooking, caused by a higher degree of gelatinization of starch within the noodles which exposed them to digestive enzymes (Tian et al., 2020). Fabbri et al. (2016) also found a reduction in RS content of black beans after boiling for 90 minutes. The long unbranched chain of amylose explains the correlation between RS content and amylose content. Amylose polymers have a smaller surface area and more intracellular hydrogen bonds, which decrease the accessibility of α-amylase enzymes. The high amylose content of F0 may have resulted from long chain amylopectin branches, which may bind to iodine leading to over estimation of amylose content (Hoover et al., 2001).

Effects of high RS flour addition on quality of noodles

The hardness, cooking loss, rehydration ratio, and volume increase of noodles made with four formulations are presented in Table 3.

Hardness of noodles. The results indicated no significant differences ($P > 0.05$) in the hardness of the noodles made with four formulations. The hardness ranged from 150.25 g in formulation F1, to 146.75 g in F3, 136.33 g in F0, and 128.50 g in F2. Texture analysis is a quality control measure that ensures the production of consistent and high-quality noodles. Starch characteristics play a major role in governing the texture of cooked pasta (Smewing, 2016). The effects of supplementing noodles with high RS flour were insignificant, indicating that the desired hardness of the noodles was retained. Different studies have shown various effects on noodles with the addition of high RS flours. Wu et al. (2015) studied the effects of mung beans on the quality of rice noodles and found that the hardness of the noodles increased with an increase in the amount of mung beans. A contradictory result was obtained by Zhang et al. (2019), indicating a decrease in the hardness of noodles with an increase in the content of mung bean flour because mung bean does not contain gluten.

Cooking loss. Formulation F3 of the noodles recorded the highest cooking loss, which was significantly different ($P < 0.05$) from the rest of the noodle samples. The cooking loss increased with an increase in the percentage of high RS flour supplemented in the noodles. However, formulation F2 recorded the lowest cooking loss with 6.03%, followed by F0 which had 6.09%, while F1 had 6.80% and the high cooking loss of F3 was 9.87%. It is evident that the high RS flour content caused this high cooking loss. The addition of high RS flour resulted in an increased cooking loss as the percentage increased. The significant cooking loss obtained in F3 may have resulted from the reduced gluten strength in high RS flours. Therefore, the noodles' structure experienced disruption and weakening, which allowed the leaching of many soluble solids from the noodles into the cooking water (Espinosa-Solis et al., 2019; Kuen et al., 2017). Since the cooking losses in all four formulations were less than 12%, it was an indication that all the noodles produced were of good quality and highly accepted by consumers (Fu, 2008).

Rehydration rate. The rehydration rate of the noodles presented no significant differences ($P < 0.05$) between F0 and F2. However, F1 and F3 had a significant difference from the other samples. The highest rehydration rate was in the control formulation,

Table 3. Hardness, cooking loss, rehydration ratio, and volume increase of noodles made with four formulations

Sample	Hardness (g-force)	Cooking loss, %	Rehydration rate, %	Volume increase, %
F0	136.33 ±20.80^{a}	6.09 ±0.13^{a}	91.99 ±0.03^{c}	100 ±0.00^{b}
F1	150.25 ±17.37^{a}	6.80 ±0.02^{a}	87.32 ±0.30^{b}	100 ±0.00^{b}
F2	128.50 ±11.33^{a}	6.03 ±0.43^{a}	90.55 ±0.63^{c}	100 ±0.00^{b}
F3	146.75 ±18.72^{a}	9.87 ±0.41^{b}	84.58 ±1.36^{a}	87.5 ±0.00^{a}

Values are expressed as mean ±SD. Values with different superscripts in the same column are significantly different according to LSD test ($P < 0.05$).

F0, with 91.98%, the second was F2 with 90.54%, and low rehydration was recorded in F1 and F3 with 87.32% and 84.57%, respectively. With the addition of high RS flour, the rehydration rate of the noodles decreased. The high rehydration rate of sample F0 of the noodles may be due to the high content of amylopectin in the control sample, which improved rehydration and aided in gelatinization within the noodle. The linear structure of amylose in F1, F2, and F3 may have decreased the breakdown viscosity, hence requiring a longer time for water penetration (Tangthanantorn et al., 2021). Generally, a higher water rehydration rate is a desirable property for noodle products (Hastuti et al., 2021).

Volume increase. Formulation F3 had a significant difference in the volume increase in the noodles compared to the other samples of noodles (F0, F1, and F2). The highest volume increase was recorded in three formulations, F0, F1, F2 having 100%, while F3 had the least increase in volume with 87.5%. The high-volume increase is a desirable property in noodle products and is preferred by consumers. The low-volume increase shown in F3 may have resulted from the significantly high cooking loss that occurred in the F3 noodles. The degree of volume increase during boiling of the noodles was affected by starch gelatinization and protein hydration related to the size of the starch (Kang et al., 2017). Kuen et al. (2017) found the rehydration rate of noodles to range between 97.22% and 98.35%, which is slightly above the current study, while Özyurt et al. (2015) reported the volume increase of noodles to be in the range of 45% to 124%, which is comparable with the results obtained in the current study of 83.53% to 100%.

Effects of high RS flour addition on the color of noodles

The increase in the ratio of high RS flour supplemented in the noodles resulted in a significant difference in their color (Table 4). The highest brightness L^* was recorded in control sample F0 with 83.1 ±1.85, followed by F1 with 75.4 ±4.48, while F2 had 63.7 ±4.08 and finally, F3 had 65.2 ±3.19. The lightness L^* of the uncooked and cooked noodles varied slightly, with an increase in L^* after cooking.

Similar observations were obtained for the redness of the noodles where the redness of the control noodles, F0, decreased from 4.6 ±1.07 in the uncooked noodles to 0.9 ±0.04 after cooking, while in F3, the uncooked noodles had 4.8 ±0.42, which decreased to 0.9 ±0.12 after cooking.

The yellowness of the noodles decreased after cooking from 44.4 ±1.26, 24.8 ±1.93, 24.7 ±1.25, and 23.6 ±0.84 in F0, F1, F2, and F3 respectively, to 31.0 ±2.0 in F0, 5.8 ±1.40 in F1, 8.0 ±0.67 in F2, and 6.6 ±0.70 in F3. Color is an important parameter in the acceptability of food products by consumers (Morris, 2018).

Table 4. Color change between uncooked and cooked noodles

Sample	Formulation	L^*	a^*	b^*	ΔE
Uncooked noodles	F0	83.10 ±1.85^c	4.60 ±1.07^b	44.4 ±1.26^b	
	F1	75.40 ±4.48^b	3.70 ±0.82^a	24.80 ±1.93^a	21.08
	F2	63.70 ±4.08^a	5.80 ±0.63^c	24.70 ±1.25^a	27.67
	F3	65.20 ±3.19^a	4.80 ±0.42^b	23.60 ±0.84^a	27.44
Cooked noodles	F0	84.60 ±3.66^c	0.90 ±0.04^b	31.00 ±2.00^c	
	F1	68.80 ±5.87^a	0.30 ±0.08^a	5.80 ±1.40^a	29.75
	F2	73.20 ±2.62^b	1.00 ±0.00^b	8.00 ±0.67^b	25.67
	F3	68.40 ±3.31^a	0.90 ±0.12^b	6.60 ±0.70^a	29.29

Values are expressed as mean ±SD. Values in the same column with different superscripts per column are significantly different $p < 0.05$.
L^* – lightness (0–100, 0 – black, 100 – white), a^* ($-a^*$ – greenness, $+a^*$ – redness), b^* ($-b^*$ – blueness, $+b^*$ – yellowness).

Lightness is an indispensable characteristic of noodles that is used to demonstrate high quality. The color parameters (L^*, a^*, b^*) of raw and cooked noodles changed significantly with the addition of the flours. The ΔE obtained using equation 4 showed that there was a visible change in color in the control noodles and partially supplemented noodles (Table 4). According to Zhao et al. (2005) and Wood (2009), the lightness L^* of all spaghetti products containing legume flours decreased significantly ($P < 0.05$), which is in agreement with the results in this study. The decrease in L^* lightness of the noodles resulted from the dark color of the black beans, red kidney beans, and mung beans incorporated into the noodles. As a result of cooking the noodles, lightness increased slightly, while redness and yellowness decreased. Similar results were obtained by Petitot et al. (2010). The increase in protein content in the noodles also resulted in the darkening of the noodles, which further explains the darkening of noodles in the current study (Morris, 2018).

Sensory evaluation

The principal component analysis (PCA) was used to outline the relationship between the various attributes used in the analysis of the noodles and the effects of high RS flour addition on the cooked noodles. The PCA revealed that three principal components (PCs; F1–F3) explained the variance among the data, and the first two PCs accounted for 90.76% of the total variation (Fig. 2A). The first component, F1, explained 69.18% of the total variance, and the second component, F2, explained 21.58% of the total variance. The first two PCs had variables that differentiated the tested attributes. Attributes including sweetness, strength, acceptability, greenness, blackness, redness, and cooked bean smell had positive correlation loadings for PC1, and salty, egg smell, and yellowness had negative correlation loadings for PC1. The red color and bean smell had negative correlation loadings, while sweetness, yellow color, and egg smell had positive correlation loadings for PC2. The noodle formulations, F0, F1, F2, and F3, were scattered based on the attributes that best represented them. The control sample, F0, was characterized by an egg smell and a yellow color. F2, on the other hand, was represented by acceptability and a green and red color, and F3 was characterized by strength and a sweet flavour.

CATA analysis identified how well the noodles were liked (Fig. 2B). The noodles with a green color, red color, and bean smell were preferred by the consumer in relation to Figure 2A, therefore, the noodles preferred were the F2 formulation noodles. In the sensory analysis, PCA explained the effects of the addition of mung beans, black beans, and red kidney beans on the sensory attributes of the noodles. The control sample, F0, was characterized by a yellow color and

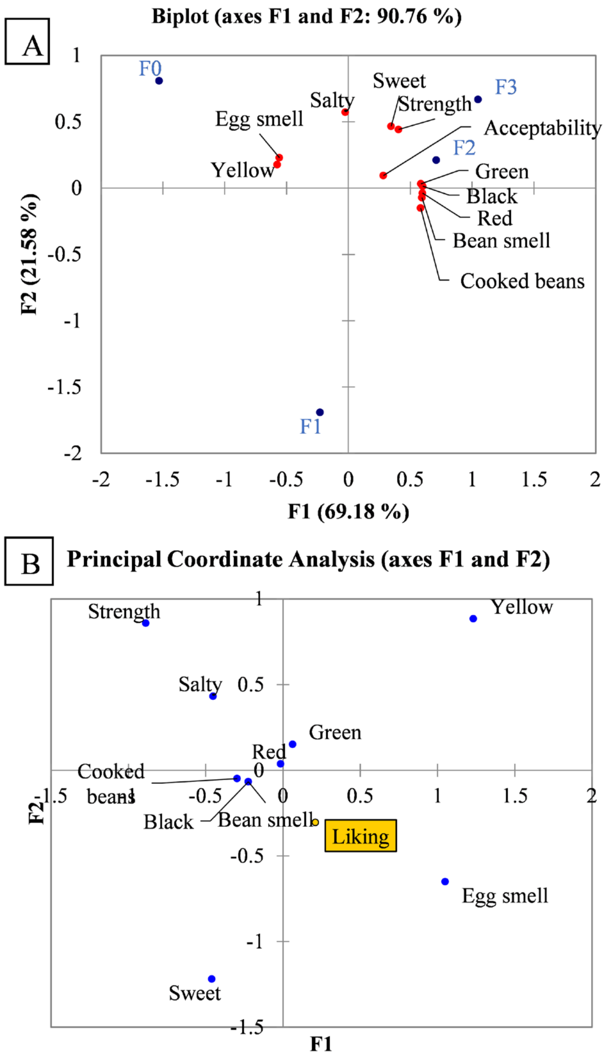

Fig. 2. PCA of various attributes of noodles supplemented with high RS flour from red kidney beans, black beans, and mung beans (**A**); and CATA analysis of noodles (**B**): F0 – control sample, F1 – 22.3% supplemented flour, F2 – 25.84% supplemented flour, F3 – 29.35% supplemented flour

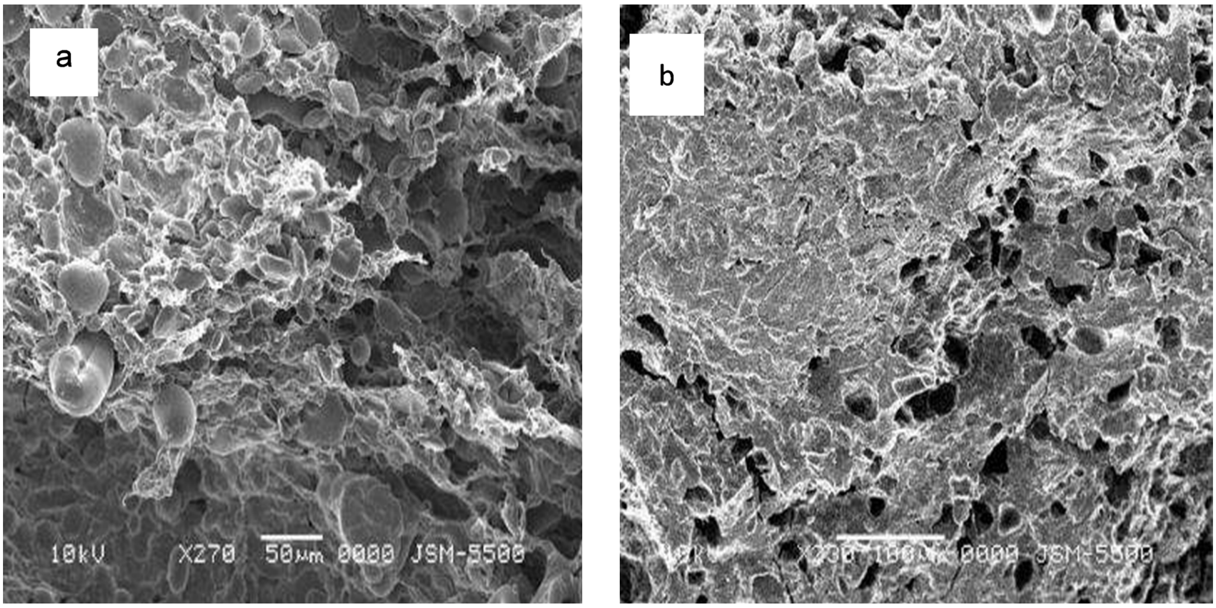

Fig. 3. SEM of control noodle samples (F0) with 0% supplementation (**a**) and F2 sample with 25.84% supplementation of flour (**b**)

an egg smell since supplementary flour was not used. Sample F2, on the other hand, was highly acceptable to consumers and was characterized by a green and red color, while F3 was characterized by strength due to a higher percentage of supplemented flour in its formulation.

Morphological properties of noodles by SEM

To expound on the effects of high RS flour addition on the noodles, the microstructure of the noodles was observed using SEM, as shown in Figures 3a and 3b.

The control sample, F0, and the noodles in formulation F2 were the preferred samples based on sensory analysis. The SEM showed that, in the control sample F0, the majority of the starch was still visible on the surface of the noodles, while in F2, due to the addition of high RS flour, some starch had escaped, resulting in perforations. The microstructure of the noodles showed that sample F0 was tightly packed, and after the addition of starchy flour, visible pores were present in the F2 noodles. The structural appearance of the noodles may have resulted from loosely bound fibers from high RS flours dissolving in water, leaving air spaces (Kuen et al., 2017). Another reason could be that the control sample and F2 have a different pasting degree, and the quantities of soluble amylose and amylopectin vary between them (Guo et al., 2006). The addition of high RS flour also affected the morphology of the noodles. Gluten and starch in the control noodles, F0, supported a protein network responsible for stability, hence it had smaller pores, while in F2, reduced gluten due to high RS flour addition resulted in the starch being exposed, giving an irregular shape and larger pores (Sun et al., 2019). This observation explains the increased cooking loss as high RS flour percentage increased in the noodle formulations.

CONCLUSION

The nutrient capacity of the noodles improved with the addition of high RS flour; however, some quality properties of the noodles were affected. Darkening of the noodles and increased cooking loss led to a reduction in quality which resulted from the addition of starchy flour in the noodles. The effects of high RS flour addition were ascertained by scanning electron microscopy, which indicated increased pores in the supplemented noodles compared to the control sample. Despite the positive impact on nutrient content after supplementation with starchy flour, a balance should be established when formulating noodles in order to retain desirable quality characteristics.

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