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ENGINEERING SIENCES

Development of Extruded Noodles Incorporated with Dried Vegetables and the Evaluation of Quality Characteristics

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Abstract: In this study, extruded noodles incorporated with dried green bean, tomato, and okra seed powder was produced using an extruder at 80 °C and 100 °C barrel temperatures. Vegetable powder was blended with wheat flour at weight ratios of 0:100, 4:96, 8:92, and 12:88 to formulate composite flour. Quality characteristics, such as cooking properties, color, and textural properties together with antioxidant activities, total phenolic contents, sensory properties, and microstructures of the products were determined. In addition, the lycopene and β-carotene contents in noodles enriched with tomato powder were determined. The increase in the ratio of vegetable powder caused a decrease in the cooking time and water absorption capacity. The noodle products exhibited low cooking loss (less than 4%) and cooking time (less than 6 min). The *L**, *a**, and *b**values of noodles varied from 53.76–78.30, 2.29–15.23, and 14.52–28.85, respectively. The β-carotene and lycopene contents increased with the increase of the tomato powder ratio. The antioxidant activity and the total phenolic content increased as the ratio of the vegetable powder used in all enriched noodle products increased. The noodles enriched with green bean and tomato powder gave the highest score of 7.40 in terms of the overall acceptance.

Key words: Extrusion cooking, wheat noodle, vegetable powders, antioxidant activity.

INTRODUCTION

Changes in a society's lifestyle have caused changes in eating habits, consequently increasing the tendency toward quickly consumable foods. The trend toward this type of food has made the extrusion technology increasingly important in the food processing industry. Extrusion technology is food processing technique classified as a high temperature-short time process that integrates stirring, mixing, crushing, heating and drying into a one-step. It has many advantages including versatility, adaptability, high productivity, low cost, high product quality and low energy consumption (Wang et al. 2022). During extrusion cooking, raw materials entering the extruder undergo chemical, microbiological, and structural changes according to the feed mix properties, process variables, and product characteristics (Kolniak-Ostek et al. 2017). A product with specific features can be obtained by controlling process parameters such as barrel temperature, screw speed, feed moisture, and feed rate (Mosibo et al. 2022). Wang et al. (2016) investigated the effects of extrusion temperature and screw speed on the qualities of brown rice pasta. They reported that extrusion temperature and screw speed significantly affected the cooking quality and textural properties of brown rice pasta.

Thanks to the extrusion cooking technology, the production of a wide variety of food products, such as pasta, baby food, breakfast cereals, snack food products, confectionery, textured protein food products, and pet foods has become easier (Sawant et al. 2015). However, a decrease in the nutritional value of the products has been observed when performing extrusion cooking. Therefore, products that will help enrich fiber and bioactive components are added during food extrusion. The most used products for this purpose are fruits and vegetables, such as legume flour (Bouasla et al. 2017), carrot (Shirazi et al. 2020), broccoli (Bisharat et al. 2013), banana flour (Sukumar & Athmaselvi 2019). Bouasla et al. (2017) reported that the precooked pasta products enriched with legumes flours up to 30 g/100 g had good quality and these blends can successfully be used in nutritionally valuable gluten-free pasta formulation.

Common bean and okra are traditional foods in the human diet, which are low in fat and rich in proteins, vitamins, minerals, complex carbohydrates, polyphenols, and antioxidant activities. Tomato is a good source of bioactive molecules, especially carotenoids, such as β-carotene and lycopene (Maskan & Altan 2012). In addition, potato starch is preferred in noodle production because it provides a smooth and shiny texture in noodles and has a highwater absorption ability (Noda et al. 2006).

This study aims to investigate the effects of different levels of dried green bean, tomato, and dried okra seed powder additions and extruder barrel temperature on the important quality parameters (i.e., cooking properties, texture characteristics, color, microstructure, antioxidant activities, total phenolic content, and β-carotene and lycopene contents) of noodles prepared by the twin-screw extrusion process.

MATERIALS AND METHODS

Materials

Wheat flour, potato starch, salt, potassium carbonate, sodium carbonate, dried green bean powder (17.92% protein, 67.59% carbohydrate, 2.60% fat, 1.49% ash, and 10.40% moisture), tomato powder (10.70% protein, 77.40% carbohydrate, 1.20% fat, 2.60% ash, and 8.10% moisture), and okra seed powder (20.63% protein, 60.17% carbohydrate, 6.40% fat, 3.10% ash, and 9.70% moisture) were used as the raw materials. Wheat flour (10.26% protein, 77.11% carbohydrate, 0.80% fat, 0.53% ash, and 11.3% moisture content) was purchased from Çınar Mayacılık, İzmir, Türkiye. Potato starch (12% moisture content) was obtained from the local market. Potassium carbonate (K_2CO_3) and sodium carbonate (Na_2CO_3) were purchased from Tekkim Kimya, Bursa, Türkiye. Tomato powder was from Kurucum Gıda, Isparta, Türkiye. Okra seeds were obtained from a local store and grinded using a hammer mill (Abencor Hammer Mill, Sevilla, Spain). Fresh green beans were purchased from a local market, cut into 3 cm, dried in shade (7 days) until 9%–10% water content (wet base) was reached, and grinded to an average size of 250 μm.

Sample preparation

The samples were prepared using the following ingredients: 25-g starch, 2.5-g salt, and 0.25-g alkaline salt (sodium carbonate:potassium carbonate: 1:1) per 100 g of wheat flour used as control; dried green bean, tomato, and okra seed powder added to the wheat flour in ratios of 0:100, 4:96, 8:92, and 12:88; and 25% potato starch, 2.5% salt, and 0.25% alkali added to this mixture. The ingredients were mixed with a KitchenAid mixer (KitchenAid, St. Joseph, MI, USA) at a speed of 250 rpm for 10 min to prepare the samples to be used in the extruder. Table I lists the product

Table I. Compositions and codes of the products enriched with dried green bean, tomato, and okra seed powder.

Samples	Barrel Temperature (°C)	Wheat flour (g)	Okra seed powder (g)	Green bean powder (g)	Tomato powder (g)	Potato starch (g)	Salt (g)	Alkali salt (g)
C-80	80	100				25	2.5	0.25
C-100	100	100				25	2.5	0.25
O4-80	80	96	4			25	2.5	0.25
O4-100	100	96	4			25	2.5	0.25
O8-80	80	92	8			25	2.5	0.25
O8-100	100	92	8			25	2.5	0.25
O12-80	80	88	12			25	2.5	0.25
O12-100	100	88	12			25	2.5	0.25
G4-80	80	96		4		25	2.5	0.25
G4-100	100	96		4		25	2.5	0.25
G8-80	80	92		8		25	2.5	0.25
G8-100	100	92		8		25	2.5	0.25
G12-80	80	88		12		25	2.5	0.25
G12-100	100	88		12		25	2.5	0.25
T4-80	80	96			4	25	2.5	0.25
T4-100	100	96			4	25	2.5	0.25
T8-80	80	92			8	25	2.5	0.25
T8-100	100	92			8	25	2.5	0.25
T12-80	80	88			12	25	2.5	0.25
T12-100	100	88			12	25	2.5	0.25

compositions and codes (C: control, G: green bean, T: tomato, O: okra).

Production of noodles

The noodle samples were produced using a corotating twin-screw extruder (Feza Machine Co. Ltd., Istanbul, Türkiye) equipped with a cylindrical preconditioner. The screw diameter was 25 mm, and the length-to-diameter ratio was 25:1. A circular die with 1 mm × 7 (diameter × no. of holes) was used. The feeding rate was 55 ± 1 g/min. The screw speed was kept constant at 100 rpm. The barrel temperatures were maintained at 50 °C in the first zone, 70 °C in the second, and 80 °C in the fourth zone. The temperature in the third zone was varied at 80 °C and 100 °C. The water was injected into the extruder using a liquid pump at 24 ml/min rate; thus, the final mixture had 40% moisture content. The extruded noodles were dried at 95 °C for 90 min in a tray dryer (Eksis Makine, Isparta, Türkiye).

Cooking quality

The cooking qualities of noodles were determined based upon the AACC Method 66-50 (AACC 2000). Next, 25-g of each sample of the noodles was hydrated with 450 ml of hot water (100 °C). The noodle product was sampled one by one and squeezed between transparent glass plates every 10 s. The cooking time of noodle products corresponded to the moment of disappearance of a white inside core of the noodle strand when squeezing it two transparent glass plates. After the samples were kept for the cooking time, the hydrated sample rinsed with cold water (20 °C), and drained for 3 min. They were weighed, and water absorption was calculated as the increase of products weight and expressed as a percentage of sample weight before hydration. Both hydrating and rinsing water were placed in glass beaker and completed to 500 ml with distilled water. After mixing, 50 ml of this water was taken into 100 ml glass beakers, which were previously tared. The beakers were then dried in an air oven set at 105 °C until they reached a constant weight. The cooking loss of the samples was reported as percentage of dry sample weight before the hydration. All tests were performed in triplicate for each noodle sample.

Textural properties

A 35 mm cylindrical probe (P/35) was used for the texture profile analysis of the products. Measurements were then taken with the TA.XT Express Texture Analyzer (Stable Microsystems, Godalming, Surrey, UK). The noodle samples were initially hydrated to their predetermined optimal cooking time, and five hydrated and drained noodle strands were placed in parallel on the test platform. The samples were compressed to 75% of their original thickness at a test speed of 2 mm/s. The first and second compression intervals were 2 s. At least seven measurements were recorded for each sample.

Color

A portable spectrophotometer (CM-700D, Konica Minolta Sensing, Inc.,Tokyo, Japan) was used to evaluate the color analysis of the noodles produced by the extrusion technique. The results were obtained with the CIE *L**, *a**, and *b** color system, where *L** indicates brightness (100: white; 0: black); *a** indicates redness/greenness; and *b** indicates yellowness/blueness. Susbequently, 20–25-g of sample was finely grounded and placed in transparent sealed bags. Ten results were recorded by taking measurements from each bag surface (Choy et al. 2013).

Antioxidant activity and total phenolic content

The following steps were applied to extract the antioxidant activity and the total phenolic content of the noodles: 5-g of powdered noodle sample was weighed, and 20 ml of 70% methanol was added; and the volumes were recorded for all samples, from which the supernatants were taken after centrifugation at 10000 rpm for 15 min after being kept in the incubator at 25 °C–27 °C in the dark overnight (Kolniak-Ostek et al. 2017).

Antioxidant activity

The antioxidant activity was investigated according to the DPPH (2,2'-diphenyl-1-picrylhydrazyl) radical scavenging method described by Pavithra & Vadivukkarasi (2015). Accordingly, 1.0 ml of multiple extract concentrations (2–10 mg/ml) was mixed with 1.0 ml of 0.8-mmol/L DPPH solution. The mixture was vortexed and left for 30 min, and the absorbance was measured at 517 nm against a blank solution. Gallic acid was used as a standard. The inhibition percentage for scavenging DPPH radical was calculated as follows (Eq 1):

$$\%\text{decolorization} = \left[1 - \left(\frac{A\,sample}{A\,control}\right)\right] * 100 \quad (1)$$

Total phenolic compounds

The amount of the total phenolic compounds was determined using the Folin–Ciocalteau reagent (Kocadağ-Kocazorbaz et al. 2017). Briefly, 50 µL of dried extract in 80% methanol was mixed with 10% (v/v) Folin–Ciocalteu reagent. After 5 min incubation at room temperature, 50 µL of 10% (w/v) Na_2CO_3 was added and left in the dark for 30 min at room temperature. The sample absorbance was measured at 760 nm. Gallic acid was used as the standard. The results were expressed as mg gallic acid equivalent per 100-g sample.

β-carotene and lycopene contents

Carotenoid analysis was performed according to the method reported by Chusak et al. (2020). The sample powder (approx. 3-g) was extracted with 30 ml of 80% methanol for 2 h at 1000 rpm. The supernatant was dried with an evaporator, and the dried sample was stored at –20 °C before analysis. The carotenoid quantification was determined using the ODS reverse phase column (250 × 4.6 mm ID, Column Phenomenex C8 250 * 4.60 mm * 5 μm) and High-performance liquid chromatography (HPLC) with the detector set at 450 nm wavelength. The column was isocratically separated with the mobile phase (methanol:hexane = 75:25) at a flow rate of 0.8 ml/min. The results are expressed in μg/100-g flour.

The method of Chusak et al. (2020) was used for the lycopene analysis, as in the β-carotene analysis. The chromatography conditions are as follows: 468 nm; flow rate: 0.8 ml/min; analysis time: 15 min; column phenomenex: C8 250 * 4.60 mm * 5 μm; and mobile phase methanol:hexane (75:25).

Microstructure of noodles

A scanning electron microscope (SEM) was used to characterize the surface microstructure of the noodles. Small dry noodle specimens were mounted on carbondiscs using a silver tape and sprayed with gold in a vacuum sublimator (Leica EM ACE600, Wetzlar, Germany). The SEM (Thermo Scientific Apreo S, Waltham, MA, USA) operating at 10 kV accelerating voltage was used to examine the surface microstructure of samples at ×1000 magnification.

Sensorial analysis

The evaluation of sensory properties 1–9 hedonic scale was used to evaluate the samples. Panelists rated each sensory attribute with 1 (dislike extremely), 5 (neither like nor dislike), and nine points (like extremely) (Lim et al. 2011). The noodles were prepared on white plates after cooling in room temperature. They were then evaluated in terms of appearance, odor, taste–flavor, and overall acceptability.

Statistical analysis

The data were presented as means ± standard deviations. SPSS software (IBM SPSS Statistics 25; IBM, Chicago, IL, USA) was used to perform the statistical analysis. The differences among the results were analyzed by one-way ANOVA, followed by Duncan post-hoc test. A 0.05 significance level was considered for all the tests.

RESULTS AND DISCUSSION

Cooking quality

Table II presents the summarized results of the cooking quality of the samples. As the vegetable powder ratio used in the noodles produced at both 80 °C and 100 °C increased, the cooking time decreased; the cooking loss increased; and the water absorption capacity decreased. The cooking time decrease was attributed to the fact that the vegetable powder used in the noodles decreased the gluten content, and the structure tightness weakened because of the non-starch polysaccharides of the noodles (Nakhon et al. 2018). The cooking loss occurred due to the structure tightness weakening. During cooking, the soluble parts of the starch passed through the water and resulted in a more cloudy cooking water (Altan et al. 2008). Noodles with a high cooking loss value also exhibited a high water absorption capacity. This may be due to the

Table II. Cooking and color properties of the noodle samples.

	Cooking properties			Color properties		
Samples	**Cooking time (s)**	**Cooking loss (%)**	**Water absorption (%)**	**(*L**)**	**(*a**)**	**(*b**)**
C-80	276.67 ± 5.77^{fg}	3.75 ± 0.02^{j}	80.79 ± 0.32^{b}	78.30 ± 0.64^{o}	2.29 ± 0.11^{a}	21.37 ± 0.42^{ef}
C-100	323.33 ± 5.77^{j}	3.37 ± 0.05^{i}	102.93 ± 0.15^{g}	77.85 ± 0.35^{o}	2.47 ± 0.35^{a}	21.79 ± 1.16^{fg}
G4-80	233.33 ± 5.77^{d}	1.55 ± 0.01^{d}	114.44 ± 0.41^{l}	73.28 ± 0.49^{n}	3.07 ± 0.28^{b}	26.76 ± 0.60^{l}
G4-100	320.00 ± 10.00^{h}	0.81 ± 0.18^{b}	123.67 ± 0.31^{p}	70.43 ± 0.75^{l}	3.89 ± 0.21^{c}	23.27 ± 1.55^{i}
G8-80	210.00 ± 10.00^{bc}	1.82 ± 0.03^{e}	107.21 ± 0.22^{i}	69.64 ± 0.53^{k}	4.72 ± 0.32^{de}	27.62 ± 0.81^{l}
G8-100	306.67 ± 5.77^{i}	1.50 ± 0.03^{d}	111.04 ± 0.10^{k}	68.16 ± 0.48^{j}	5.00 ± 0.36^{e}	24.54 ± 1.18^{jk}
G12-80	173.33 ± 5.77^{a}	3.42 ± 0.11^{m}	99.29 ± 0.28^{d}	63.44 ± 1.24^{g}	5.91 ± 0.46^{f}	28.85 ± 0.78^{m}
G12-100	286.67 ± 5.77^{gh}	2.88 ± 0.13^{g}	108.27 ± 0.30^{j}	62.75 ± 1.03^{f}	6.48 ± 0.49^{g}	25.14 ± 0.78^{k}
T4-80	306.67 ± 5.77^{i}	1.21 ± 0.03^{c}	116.16 ± 0.24^{m}	62.00 ± 0.61^{e}	11.20 ± 0.42^{h}	22.60 ± 0.93^{ghi}
T4-100	353.33 ± 5.77^{k}	1.18 ± 0.01^{c}	118.96 ± 0.10^{o}	57.97 ± 0.30^{bc}	11.51 ± 0.31^{i}	20.70 ± 1.81^{e}
T8-80	273.33 ± 5.77^{f}	1.42 ± 0.01^{d}	107.88 ± 0.28^{j}	60.06 ± 0.54^{d}	12.81 ± 0.37^{j}	24.19 ± 1.04^{j}
T8-100	323.33 ± 5.77^{j}	1.22 ± 0.03^{c}	117.03 ± 0.09^{n}	57.66 ± 0.56^{b}	13.13 ± 0.72^{k}	21.96 ± 1.15^{fgh}
T12-80	206.67 ± 5.77^{b}	2.91 ± 0.02^{l}	104.28 ± 0.31^{h}	58.39 ± 0.29^{c}	14.47 ± 0.38^{l}	25.32 ± 1.03^{k}
T12-100	320.00 ± 10.00^{j}	2.44 ± 0.08^{f}	108.52 ± 1.03^{j}	53.76 ± 0.34^{a}	15.23 ± 0.28^{m}	22.80 ± 1.21^{hi}
O4-80	260.00 ± 10.00^{e}	0.77 ± 0.05^{ab}	100.19 ± 0.33^{e}	71.49 ± 0.95^{m}	3.96 ± 0.20^{c}	17.21 ± 0.49^{d}
O4-100	353.33 ± 5.77^{k}	0.64 ± 0.01^{a}	126.91 ± 0.76^{r}	71.06 ± 0.78^{m}	4.03 ± 0.19^{c}	16.29 ± 0.98^{c}
O8-80	236.67 ± 5.77^{d}	1.48 ± 0.04^{d}	84.13 ± 0.24^{c}	66.13 ± 0.41^{i}	4.51 ± 0.33^{d}	15.54 ± 1.08^{bc}
O8-100	343.33 ± 5.77^{k}	1.25 ± 0.03^{c}	101.08 ± 0.14^{f}	64.87 ± 0.79^{i}	4.60 ± 0.43^{d}	14.93 ± 0.96^{ab}
O12-80	220.00 ± 10.00^{c}	3.94 ± 0.07^{k}	71.05 ± 0.30^{a}	64.41 ± 0.94^{h}	4.02 ± 0.43^{c}	15.46 ± 0.44^{abc}
O12-100	336.67 ± 5.77^{j}	2.93 ± 0.24^{h}	99.09 ± 0.20^{d}	62.78 ± 1.13^{f}	4.04 ± 0.49^{c}	14.52 ± 0.46^{a}

Data are expressed as mean values of replicates ± standard deviation.
Different letters within the same column indicate significant differences ($p < 0.05$) according to Duncan multiple comparison test.

low degree of gelatinization and the weakened starch network, making it easier for water to penetrate the interior (Almanza-Benitez et al. 2015).

The cooking time increased, and the cooking loss decreased in all enriched noodles when the temperature increased from 80 °C to 100 °C. This situation can be attributed to the stronger shell structure of the noodles produced at high temperatures (Nakhon et al. 2018). In addition, the water absorption increased because the cooking loss reduction induced a more solid structure (Wang et al. 2016). The cooking loss in all the noodles produced in this study was less than 12%. According to Hoseney (1999), the cooking loss should be less than 12% in pasta products.

Textural properties

The textural properties of the noodle samples are presented in Table III. The hardness value of the control samples were not affected by the temperature increase, but an increase in the hardness value of the enriched samples were detected. This may be due to the higher fiber and protein contents of the enriched noodles than the control groups. It has been reported the denaturation and aggregation of proteins at high temperatures would promote the formation of a strengthened structure (Petitot et al. 2010). When the results were examined for the noodles produced at both 80 °C and 100 °C extrusion temperatures, the product hardness increased as the vegetable powder rate increased. This might have been caused by the fiber content in the vegetable powders used. The fibers increased the cell wall thickness by creating an air bubble in the product cooked by extrusion. They also caused a decrease of the porosity in the final product and hardened it (Dehghan-Shoar et al. 2010). The gumminess values of the products decreased as the vegetable powder ratio increased. While a harder product was formed with the increased protein and fiber content, the decrease in the gumminess was an expected result. In addition, the adhesiveness values increased, and the cohesiveness values generally decreased as the vegetable powder rate increased. The products can have higher adhesiveness properties as a result of the increase in the protein content of the noodles (Chillo et al. 2009). The resilience values of the products partially increased as the dried vegetable powder and barrel temperature increased. The noodles produced at 100 °C had higher diameters, which affected the structure in terms of keeping its shape without deterioration during compression.

Color

Color is an important quality factor in noodle products. Table II presents the color values of the noodles produced in this study. The color analysis results showed that the L^* values decreased with the temperature. The highest a^* value was observed in noodles containing 12% tomato powder. The highest b^* value was found in noodles containing 12% green bean powder. The C100 and C80 samples had higher L^* values than the enriched products because the vegetable powders negatively affected the product brightness (Altan et al. 2008). The a^* values were significantly higher in the tomato-powdered noodles than the others because tomato has a red color caused by lycopene. Therefore, the a^* value of the noodles increased, and the L^* value decreased as the tomato powder increased (Dehghan-Shoar et al. 2010). The increase in the a^* value of the noodles produced in different temperatures can also be described as the breakdown of non-heat-resistant pigments as a result of the Maillard reaction (Altan et al. 2008). The okra seed-powdered noodles, especially O12-100 and

Table III. Textural properties of the noodle samples.

Samples	Hardness (g)	Adhesiveness (g.s)	Springiness (mm)	Cohesiveness	Gumminess	Resilience
C-80	4634.20 ± 300.89^{d}	−254.84 ± 11.64^{b}	0.90 ± 0.02^{bcd}	0.71 ± 0.01^{de}	3422.63 ± 276.58^{e}	0.65 ± 0.02^{fg}
C-100	4741.46 ± 274.42^{d}	−93.86 ± 8.76^{fg}	0.91 ± 0.02^{bcde}	0.77 ± 0.02^{gh}	3734.01 ± 293.46^{efg}	0.70 ± 0.02^{hi}
G4-80	2803.37 ± 169.44^{a}	−293.14 ± 26.54^{a}	0.90 ± 0.01^{bc}	0.73 ± 0.07^{ef}	3611.54 ± 287.51^{ef}	0.42 ± 0.04^{a}
G4-100	4892.18 ± 300.12^{d}	−147.83 ± 11.87^{e}	0.92 ± 0.01^{ef}	0.79 ± 0.01^{h}	4305.06 ± 295.96^{i}	0.68 ± 0.02^{gh}
G8-80	3601.51 ± 129.60^{b}	−166.78 ± 6.49^{d}	0.91 ± 0.00^{bcde}	0.68 ± 0.02^{c}	2462.19 ± 63.40^{c}	0.61 ± 0.02^{de}
G8-100	5707.39 ± 218.22^{f}	−79.11 ± 6.82^{gh}	0.91 ± 0.03^{bcde}	0.77 ± 0.01^{gh}	4997.02 ± 380.03^{j}	0.70 ± 0.02^{hi}
G12-80	4219.33 ± 407.83^{c}	−138.73 ± 11.91^{e}	0.94 ± 0.01^{f}	0.67 ± 0.01^{c}	992.05 ± 54.28^{a}	0.67 ± 0.06^{fgh}
G12-100	6369.34 ± 454.56^{g}	−75.38 ± 6.43^{h}	0.90 ± 0.02^{bcde}	0.74 ± 0.02^{fg}	3601.92 ± 181.86^{ef}	0.71 ± 0.02^{hi}
T4-80	3281.96 ± 297.79^{b}	−199.59 ± 15.19^{c}	0.89 ± 0.01^{b}	0.68 ± 0.03^{cd}	2275.31 ± 200.62^{bc}	0.55 ± 0.04^{b}
T4-100	4126.41 ± 389.04^{c}	−80.32 ± 7.82^{gh}	0.91 ± 0.01^{bcde}	0.77 ± 0.01^{gh}	3786.37 ± 325.57^{fgh}	0.63 ± 0.02^{ef}
T8-80	3407.66 ± 278.32^{b}	−150.14 ± 12.56^{e}	0.89 ± 0.01^{b}	0.64 ± 0.01^{b}	2333.07 ± 210.20^{c}	0.57 ± 0.03^{bc}
T8-100	4855.72 ± 460.27^{d}	−75.33 ± 7.78^{h}	0.91 ± 0.01^{bcde}	0.76 ± 0.01^{gh}	3806.38 ± 330.14^{fgh}	0.67 ± 0.03^{fgh}
T12-80	3579.11 ± 337.3^{b}	−97.25 ± 8.52^{f}	0.90 ± 0.01^{bcde}	0.60 ± 0.04^{a}	1998.36 ± 160.04^{b}	0.59 ± 0.05^{cd}
T12-100	5054.14 ± 358.82^{de}	−47.84 ± 3.90^{i}	0.92 ± 0.01^{cdef}	0.73 ± 0.03^{ef}	3087.25 ± 300.14^{d}	0.68 ± 0.03^{ghi}
O4-80	3263.59 ± 319.89^{b}	−241.10 ± 18.01^{b}	0.90 ± 0.01^{bcde}	0.72 ± 0.02^{ef}	2248.37 ± 195.42^{bc}	0.55 ± 0.04^{bc}
O4-100	5091.69 ± 442.13^{de}	−80.62 ± 6.77^{gh}	0.91 ± 0.01^{bcde}	0.78 ± 0.03^{h}	4071.57 ± 288.07^{hi}	0.69 ± 0.02^{hi}
O8-80	3327.92 ± 301.25^{b}	−212.06 ± 18.71^{c}	0.87 ± 0.04^{a}	0.68 ± 0.02^{cd}	2927.61 ± 166.11^{d}	0.56 ± 0.02^{bc}
O8-100	5337.39 ± 509.70^{f}	−80.45 ± 6.49^{gh}	0.92 ± 0.01^{def}	0.77 ± 0.01^{gh}	4829.89 ± 330.37^{j}	0.70 ± 0.02^{hi}
O12-80	4029.22 ± 359.05^{c}	−200.07 ± 9.94^{c}	0.89 ± 0.02^{b}	0.68 ± 0.03^{cd}	2310.76 ± 98.16^{bc}	0.68 ± 0.03^{gh}
O12-100	6257.33 ± 492.84^{g}	−66.75 ± 4.86^{h}	0.91 ± 0.02^{bcde}	0.77 ± 0.02^{gh}	3950.51 ± 322.43^{gh}	0.72 ± 0.04^{i}

Data are expressed as mean values of replicates ± standard deviation.
Different letters within the same column indicate significant differences (*p* <0.05) according to Duncan multiple comparison test.

O12-80, showed the lowest *b** values among all noodle types because they were the brownest products and gave the lowest yellowness. The dried green bean noodles had a greenish color; hence, G12-100 and G12-80 had the highest *b** values.

Statistically, the *L** values were significantly affected by the extruder temperature in the enriched products ($p < 0.05$). For all types of noodles, the products produced at 80 °C yielded a higher *L** value than those produced at 100 °C. A darker product was formed in the extruder as the temperature increased. With the temperature increase, the Maillard reaction started, and the components causing the browning of the final product came out (Wang et al. 2016), leading to a decrease in the *L** value. However, no significant change was found in the *L** values in the control products ($p > 0.05$). The *a** values of the tomato noodles produced at 100 °C were higher than those produced at 80 °C because of the browning reactions with the increasing temperature (Altan et al. 2008). The *b** value also decreased in all the enriched products as the temperature increased.

Antioxidant activities and total phenolic contents

Table IV presents the results of the chemical properties. In each noodle enrichment with vegetable powder, the increment in antioxidant activities and total phenolic substances of the samples was statistically significant when the vegetable powder ratios were increased ($p < 0.05$). The highest values for the antioxidant activity and the total phenolic content were found in the tomato powder products. A sharp increase was observed in the total phenolic content of the T12-80 and T12-100 products compared to the other product groups. The high amounts of carotenoids, ascorbic acid, and phenolic components, which are among the main antioxidants, in tomatoes were the most effective factors in this increase (Dehghan-Shoar et al. 2010). A comparison of the dried green bean and okra seed powder noodles showed that the former had lower antioxidant activity and total phenolic content than the latter. This was interpreted to be caused by the okra seed containing more phenolic substances than the green beans (Adelakun & Olusegun 2011, Mastura et al. 2017).

When the extrusion temperature increased from 80 °C to 100 °C, both the antioxidant activity and total phenolic content increased in the okra seed and green bean noodles. This result can be attributed to the increase in antioxidant activity of brown compounds formed as a result of Maillard reaction with temperature increase (Kahlon et al. 2007), destruction of the cell wall and revealing high molecular weight phenolic substances (Oomah et al. 2005). According to results obtained by Žilić et al. (2013), although infrared heating affected the reduction of phenolic compounds, the total antioxidant capacity was increased in all heat-treated flours. They reported that the decrease of the natural antioxidants in maize could be balanced by the formation of new compounds with antioxidant activities. In tomato noodles, the antioxidant activity and total phenolic content decreased as the temperature increased. This was thought to be caused by the decarboxylation of phenolic components, polymerization of phenols and tannins, and loss of bioactive components, such as carotenoids, due to high temperature (Dehghan-Shoar et al. 2010). Table V presents the β-carotene and lycopene contents of the tomato noodles, which increased as the tomato powder increased. These values decreased when the temperature increased from 80 °C to 100 °C. The chemical composition of the subtances was effective in destroying the heat-labile components. The degradation of lycopene was higher for extruded products containing wheat which had a lower starch and higher protein content compared to rice and corn (Dehghan-Shoar et al. 2010).

Microstructure of noodles

The surface microstructure of the uncooked noodle samples enriched with vegetable powder observed on the SEM showed that the noodle surface microstructure was affected by the amount of powder and the barrel temperature (Fig. 1). The surface of the samples observed with ×1000 magnification was significantly influenced by the barrel temperature during processing on the outside uniformity. The noodles processed at 80 °C showed a rough surface, while those at 100 °C resulted in a uniform and smooth product surface. Adding powder to enrich the wheat noodle products induced a more uniform surface. As the percentage of vegetable powder used in noodles increased, the fiber content of the products increased, and this fiber caused the gas cells to rupture, reducing the cell size, reducing the expansion and creating a less porous structure (Altan et al. 2008). Rekha et al. (2013) reported that the microstructure of pasta

Table IV. Antioxidant activity and total phenolic content of all noodles fortified with vegetable powder and β-carotene and lycopene contents of the noodles fortified with tomato powder.

Samples	Antioxidant activity (%)	Total phenolic content (mg)	β-carotene content (ppm)	Lycopene content (ppm)
G4-80	3.57 ± 0.27^{a}	135.36 ± 6.10^{a}		
G4-100	39.15 ± 1.19^{f}	300.97 ± 15.11^{e}		
G8-80	6.24 ± 0.49^{ab}	189.18 ± 5.05^{bc}		
G8-100	64.63 ± 3.29^{i}	361.26 ± 20.27^{f}		
G12-80	9.25 ± 0.11^{bc}	218.98 ± 1.55^{c}		
G12-100	65.20 ± 1.48^{ij}	416.21 ± 25.67^{g}		
T4-80	60.66 ± 2.14^{h}	453.48 ± 23.31^{h}	2.26 ± 0.51^{b}	17.22 ± 0.75^{c}
T4-100	22.53 ± 1.87^{d}	364.43 ± 18.74^{f}	0.26 ± 0.58^{a}	6.17 ± 0.12^{a}
T8-80	68.32 ± 3.07^{j}	804.31 ± 16.63^{k}	2.76 ± 0.20^{c}	21.50 ± 0.29^{e}
T8-100	34.78 ± 2.07^{e}	731.44 ± 27.58^{j}	0.33 ± 0.06^{a}	10.52 ± 0.24^{b}
T12-80	73.86 ± 1.47^{k}	1031.31 ± 37.36^{l}	5.75 ± 0.19^{e}	36.57 ± 0.95^{f}
T12-100	37.75 ± 3.03^{ef}	799.31 ± 27.98^{k}	3.86 ± 0.19^{d}	19.29 ± 0.11^{d}
O4-80	9.45 ± 0.73^{c}	172.56 ± 1.63^{b}		
O4-100	53.04 ± 1.15^{g}	327.70 ± 2.57^{e}		
O8-80	21.27 ± 1.59^{d}	250.05 ± 2.82^{d}		
O8-100	65.08 ± 0.73^{ij}	440.48 ± 2.01^{gh}		
O12-80	23.85 ± 1.93^{d}	360.40 ± 19.71^{f}		
O12-100	67.47 ± 1.17^{ij}	508.84 ± 15.50^{i}		

Data are expressed as mean values of replicates ± standard deviation.
Different letters within the same column indicate significant differences ($p < 0.05$) according to Duncan multiple comparison test.

was altered with addition of vegetable purees, and this could be because of the starch granules and protein matrix network which was affected by fibers present in the vegetables.

Sensorial properties of the noodles

Table V presents data from the sensory evaluation of the noodles containing dried vegetable powders. The sensory properties, namely color, taste–flavor, odor, appearance, and overall acceptability, were negatively affected by the enrichment with okra seed powder in the noodles. In terms of appearance, the noodles with green beans and tomatoes were preferred more than the control and those with okra seeds. The highest scores in terms of odor were acquired by the green bean noodles. Meanwhile, the vegetable powder and temperature conditions had no significant effect on the sensory properties of the noodles enriched with green beans and tomato powder. The highest scores in terms of color were obtained by the control samples and the tomato noodles, while the lowest scores were acquired by the okra seed noodles. The general acceptance scores ranged from 5.10 to 7.40. The G4-80 and T4-80 products yielded the highest score of 7.40 in terms of the overall acceptance. The O12-100 and O12-80 products received the least overall acceptance with scores of 5.10 and 5.30, respectively.

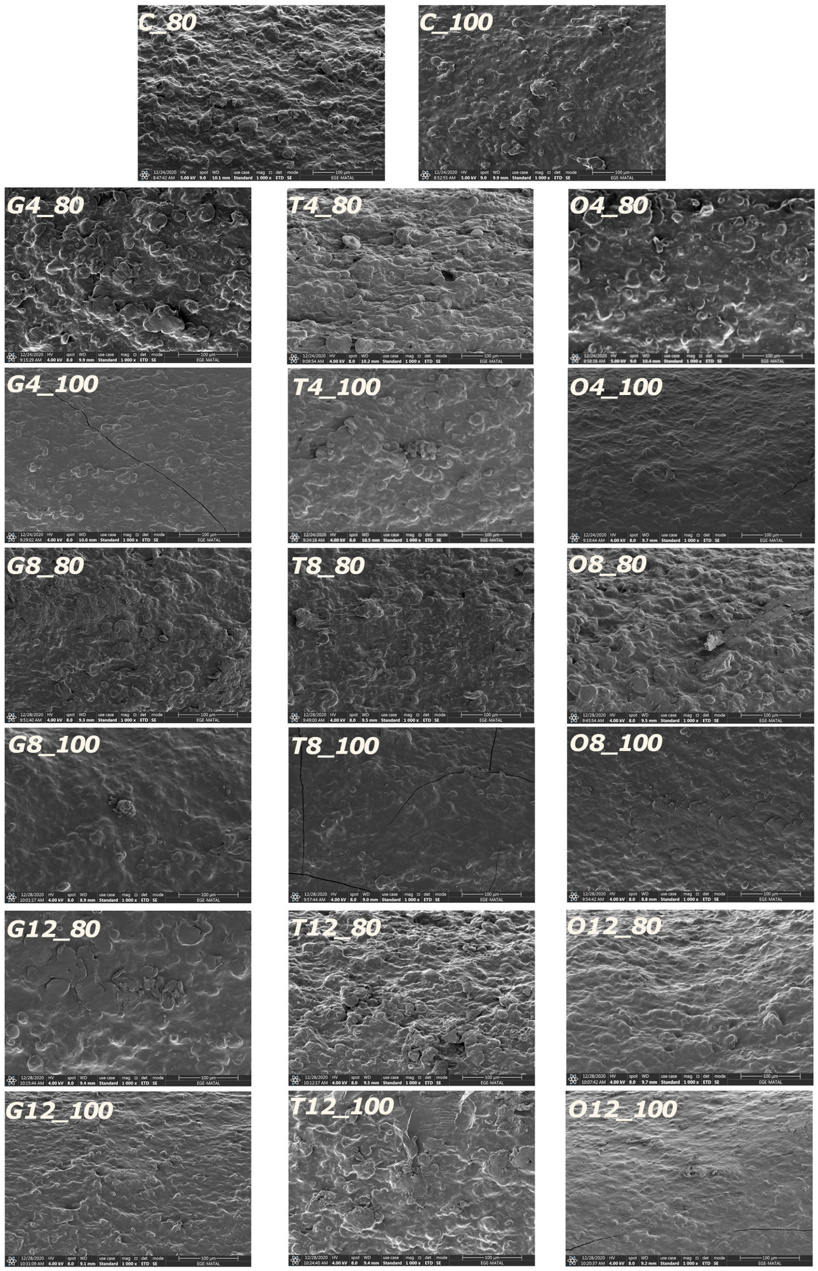

Figure 1. **Surface microstructure of the uncooked noodle processed at 80 °C and 100 °C barrel temperatures in ×1000 magnification.**

CONCLUSIONS

In this study, the barrel temperatures and addition of dried vegetable powder had significant effects on the cooking quality. As the ratio of the vegetables used in the noodles increased, the cooking loss increased; the cooking time and the water absorption capacity decreased. When the extruder barrel temperature increased, the cooking time increased, and the cooking loss decreased. Both the vegetable powder ratio and the temperature were positively correlated with the product hardness values. The highest *L** value was obtained for control group processed at 80 °C. The *a** value of noodles increased when the barrel temperature increased. The highest antioxidant activity and the total phenolic content of the tested products were observed

Table V. Sensorial properties of the noodles.

Samples	Appearance	Odor	Color	Taste–Flavor	Overall acceptance
C-80	5.00 ± 0.82[ab]	7.50 ± 0.53[fgh]	7.90 ± 0.57[gh]	6.80 ± 0.63[cd]	6.40 ± 0.52[de]
C-100	5.80 ± 0.92[cd]	7.60 ± 0.70[fgh]	8.00 ± 0.82[gh]	7.00 ± 0.67[cd]	6.90 ± 0.57[efgh]
G4-80	7.00 ± 0.67[fg]	7.40 ± 0.84[fg]	7.80 ± 0.79[fgh]	7.20 ± 0.42[ef]	7.40 ± 0.52[h]
G4-100	7.30 ± 0.67[gh]	7.20 ± 0.79[f]	7.80 ± 0.92[fgh]	7.30 ± 0.48[d]	7.10 ± 0.74[gh]
G8-80	7.30 ± 0.48[gh]	7.80 ± 0.63[fgh]	7.40 ± 0.84[efg]	6.80 ± 0.63[cd]	6.60 ± 0.52[efg]
G8-100	7.40 ± 0.70[gh]	7.80 ± 0.63[fgh]	7.20 ± 0.79[def]	6.80 ± 0.63[cd]	6.60 ± 0.52[efg]
G12-80	6.20 ± 0.63[de]	7.90 ± 0.74[gh]	6.80 ± 0.79[cde]	6.70 ± 0.67[cd]	6.90 ± 0.57[efgh]
G12-100	6.80 ± 0.63[efg]	8.10 ± 0.74[h]	6.60 ± 0..97[cd]	7.10 ± 0.74[cd]	7.10 ± 0.74[gh]
T4-80	7.80 ± 0.92[h]	6.10 ± 0.74[de]	8.00 ± 0.67[gh]	7.00 ± 0.67[cd]	7.40 ± 0.52[h]
T4-100	7.10 ± 0.74[fg]	6.50 ± 0.53[e]	8.20 ± 0.63[h]	7.30 ± 0.48[d]	7.30 ± 0.48[h]
T8-80	7.30 ± 0.67[gh]	6.00 ± 0.67[cde]	8.20 ± 0.63[h]	6.60 ± 0.52[c]	7.00 ± 0.47[fgh]
T8-100	7.90 ± 0.74[h]	5.90 ± 0.74[cde]	8.20 ± 0.42[h]	7.20 ± 0.42[cd]	7.30 ± 0.48[h]
T12-80	7.90 ± 0.74[h]	5.80 ± 0.79[cd]	8.20 ± 0.63[gh]	7.30 ± 0.48[d]	7.40 ± 0.52[h]
T12-100	7.90 ± 0.74[h]	5.80 ± 0.79[cd]	8.00 ± 0.67[gh]	7.20 ± 0.79[cd]	7.30 ± 0.67[h]
O4-80	6.50 ± 0.53[ef]	5.50 ± 0.53[bcd]	6.20 ± 0.63[bc]	5.40 ± 0.52[b]	6.50 ± 0.53[ef]
O4-100	6.50 ± 0.53[ef]	5.40 ± 0.52[bc]	6.50 ± 0.53[c]	5.00 ± 0.47[b]	6.40 ± 0.52[de]
O8-80	5.40 ± 0.52[bc]	4.90 ± 0.74[ab]	5.30 ± 0.48[a]	5.20 ± 0.42[b]	5.70 ± 0.67[bc]
O8-100	5.70 ± 0.48[cd]	5.30 ± 0.48[bc]	5.70 ± 0.67[ab]	4.80 ± 0.63[ab]	5.90 ± 0.32[cd]
O12-80	4.50 ± 0.53[a]	4.40 ± 0.52[a]	5.20 ± 0.42[a]	5.00 ± 0.47[b]	5.10 ± 0.32[a]
O12-100	4.80 ± 0.79[ab]	4.60 ± 0.52[a]	5.30 ± 0.48[a]	4.30 ± 1.25[a]	5.30 ± 0.48[ab]

Data are expressed as the mean values of replicates ± standard deviation.
Different letters within the same column indicate significant differences ($p < 0.05$) according to Duncan multiple comparison test.

in the sample enriched with tomato powder. The β-carotene and lycopene ratio were positively correlated with the tomato powder in the noodles. The highest general acceptance scores were obtained by the G4-80 and T4-80. These results could be used as indicators for selecting the appropriate mixture for extruded noodle manufacturing. Further studies on digestibility of the samples are required.

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