Acta Alimentaria 50 (2021) 3, 310–321
DOI: 10.1556/066.2020.00297

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Effect of shrimp fortification level on nutritional value, cooking quality and microstructure of freeze-dried noodles

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ORIGINAL RESEARCH PAPER

Received: November 9, 2020 • Accepted: February 21, 2021
Published online: May 12, 2021

ABSTRACT

A product with increased quality and nutritional value can be developed by enriching noodles with shrimp meat (SM). The formulation of noodle dough was supplemented with SM (10, 20 and 30% w/w). The noodles were freeze-dried due to the susceptibility of added SM to spoilage. Water activity values of all samples were below 0.35. The highest protein (19.37 ± 1.04%), lipid (39.30 ± 1.69%), moisture (6.31 ± 0.42%) and energy (571.14 ± 10.16 kcal/100 g) contents were determined in noodles with 30% shrimp meat content (30S). Carbohydrate value of noodles decreased with the SM fortification level. Cooking quality characteristics of SM added noodles, especially 10S, were better in terms of weight gain, volume increase and cooking loss. The highest L^* and b^* values, which are expected to be high by the consumers, were reached with 10S and 30S, respectively. The value of a^* increased with the addition of SM. Hardness, cohesiveness and chewiness values of the noodles increased with an increase in the level of shrimp content. Addition of SM improved the microstructure of noodles due to enriched protein matrix. Nutritious noodles with high cooking quality and a potential for long shelf life are intended for athletes and individuals with special nutritional needs.

KEYWORDS

noodle, egg-noodle, pasta, shrimp, freeze-drying

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1. INTRODUCTION

Pasta is the most consumed food after bread, easy to obtain, low cost, long shelf life and preferred by all age groups. Although providing energy due to its significant quantities of complex carbohydrate content, it remains weak in terms of other nutrients such as minerals, vitamins and lipids (Fradique et al., 2013; Aranibar et al., 2018; Rani et al., 2019). Pastas are fortified with whole egg, egg yolk or egg white powder ranging from 17 to 30% in order to enrich the nutritional value and improve texture (Xie et al., 2020). FDA defines egg added pasta as "egg noodle" or "enriched noodle" (FDA, 2019). Egg noodles are a traditional element of oriental cuisine.

Beside egg, many studies have been performed by enriching the pasta or noodle with some additives such as banana powder, bovine meat, omega-3 rich spirulina, fish flour, chia seed, fruits and many others (Ovando-Martinez et al., 2009; Liu et al., 2016; Aranibar et al., 2018; Desai et al., 2018; Monteiro et al., 2019; Fradinho et al., 2020). Kadam and Prabnasankar (2010) summarised the functional properties of marine foods and their usage as functional ingredients in bakery and pasta products in a review.

Shrimp is nutritious seafood with protein content of 17–18 g/100 g (Sriket et al., 2007). Also, shrimps are good sources of omega-3 fatty acids. Fatty acids profile of nine different shrimp species that were caught in the Gulf of Antalya was investigated. Total lipid contents of the shrimps were 1.04–2.46 g/100 g and EPA + DHA content in total fatty acids ranged from 23.64 to 29.06% (Yerlikaya et al., 2013). *Parapenaeus longirostris*, the subject of this study, is a commercially important deep water shrimp species and consumed with appreciation. Compared to fish, shrimps are more acceptable to the consumer in terms of odour. Moreover, its pinkish colour makes them more charming. These characteristics enable shrimp to be used as fortification agent of protein and omega-3 in foods such as noodle.

Noodles have long shelf life. However, when fortified with shrimp, it becomes more prone to spoilage and oxidation. It is known that strengthening the protein network by drying process enables an extended shelf life. However, high temperatures during drying process decrease protein digestibility and lysine bioavailability (Wójtowicz and Moscicki, 2014). Moreover, polyunsaturated fatty acids, which are prone to oxidation, are also damaged by heat exposure (Gokoglu et al., 2012). Therefore, freeze-drying method is applied in order to avoid heat damage. This method takes places at low temperature under vacuum and is suitable for drying of small particles.

Consumers demand to ensure wellness through diet. Therefore, highly nutritional quality foods that are widely appreciated are in focus of researchers and manufacturers. The aim of this study is to produce a newly designed egg noodle enriched with shrimp meat (SM). Due to its high protein content, it can be a product that fills the gap in the diet of individuals with special nutritional needs.

2. MATERIALS AND METHODS

2.1. Materials

Fresh shrimp (*P. longirostris*) was obtained from fishermen. Shrimps were immediately packed in crushed ice and transferred to the laboratory. After washing and beheading, SM was picked by hand and minced manually. Whole egg (Keskinoglu, Turkey), *durum* semolina flour (Efsane Un, Turkey) and iodised sodium chloride (Billur Tuz, Turkey) were used in the noodle formulation. Chemical reagents used were of analytical grade and purchased from Merck (New York, NY, USA) without further purification.

2.2. Noodle preparation

Each noodle was composed of 100 g flour, 2 g salt and 60 g egg. Shrimps were steam boiled before the process. Four kinds of noodle were prepared, 18, 33 and 49 g shrimp were used in order to prepare 10% (10S), 20% (20S) and 30% (30S) shrimp added noodle doughs, respectively and dough without shrimp was regarded as control group (C). After mixing, a kitchen aid mixer (Karaca Maestro Chef, Istanbul, Turkey) was used for 4 min in order to ensure uniform blending and reach an adequate consistency. The doughs were laminated with a roller by hand. Laminated doughs were cut and left to dry for 10 h at room temperature. The samples were frozen at −40 °C (Dairei-Europe ULTF-80, Denmark) before freeze-drying (−50 °C, 18 h) (Telstar, Lyoquest -55 plus eco Telstar, Spain). The average length, width and thickness of the noodle ($n = 30$ for each group) were 32.05 ± 2.32 mm, 7.65 ± 0.58 mm and 1.06 ± 0.06 mm, respectively. Noodles were stored in airtight bags at room temperature (24 °C). All assays were conducted on duplicate samples of the homogenates for each of three replications.

2.3. Proximate composition and water activity (a_w)

The moisture content of noodle was determined after a constant weight was obtained in an air oven (AACC, method 44-15), and ash content was determined by dry ashing according to the basic method (AACC, method 18-01) (AACC, 2000). Protein content was calculated by converting the nitrogen content determined by Kjeldahl's method with the conversion factor of 6.25 due to contained egg and SM (AACC, method 46-10) (AACC, 2000). Fat was determined by the method described by Bligh and Dyer (1959). Carbohydrate was calculated by subtracting total protein, lipid, ash and moisture values from 100. The energy value of noodle was calculated by Eq. (1) (Desai et al., 2018):

$$\text{Energy value}(\text{kcal}/100\,\text{g}) = 4 \times \text{protein}(\%) + 9 \times \text{lipid}(\%) + 4 \times \text{carbohydrate}(\%) \quad (1)$$

Water activity values were determined by a_w measuring device (Aqua Lab 4TE DUO Decagon, USA). The process lasted for about 32 hours.

2.4. Technical properties of noodles

Weight gain (WG) was obtained by recording the noodles before and after cooking. The difference between the two weighing shows the increase in weight. The ratio of the volume increase of the same weight of cooked and uncooked samples in equal amount of sunflower oil indicates volume increase (VI). Twenty individual noodle samples were used to determine WG and VI. Cooking loss (CL) was the amount of solid material lost in the cooking water during cooking period. The samples (2 g) were boiled in 200 mL water. Then the noodle was filtered and adjusted to 250 mL with distilled water. 10 g of the mixture was dried in an oven at 80 °C for 2 hours. The calculation of cooking loss was performed by Eq. (2):

$$\text{Solid loss \%} = \text{latter dry matter} \times 250\ \text{mL} \times 100/2\ \text{g} \times 10\ \text{mL} \tag{2}$$

2.5. Colour and texture properties

The colour of the noodle was determined using CR-400 Minolta chromometer instrument. Triplicate measurements were taken for each sample using CIE Lab L^* (lightness), a^* (redness) and b^* (yellowness) system ($n = 10$). The perceptible difference between colours were indicated by the ΔE^* Lab value and calculated using Eq. (3):

$$\text{Colour differential index } \Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b^2)} \tag{3}$$

Texture profile analysis was done using TA-XT2 (Stable Micro System, Godalming, Surrey, UK). Texture profile analysis of freshly cooked noodles was performed by using a cylindrical plunger (35 mm aluminium probe diameter SMSP35). The probe is programmed to enter until a depth of 40% of the sample, and two consecutive compaction operations are applied at a speed of 5 mm/s from the moment it comes into contact with the surface. Ten repeat measurements were taken for each type of noodles ($n = 10$). Hardness (N), cohesiveness (ratio), adhesiveness (Ns), springiness (mm) and chewiness (Nmm) were determined from the texture profile analysis force-time graph.

2.6. Scanning electron microscopy (SEM)

Microstructure determinations of noodle samples were made using scanning electron microscopy (SEM) (Carl Zeiss Leo 1430, Germany). The samples covered with thin golden layer were placed between carbon layers. The measurements were performed by applying 15 kV.

2.7. Statistical analysis

Analysis of variance (ANOVA) was carried out. Duncan's multiple range test was performed in case of significance between main effects or interactions. Statistical analysis was performed using the SAS program (Statistical Analytical Systems, Cary, NC, USA).

3. RESULTS AND DISCUSSION

3.1. Proximate composition and a_w

The nutritional value and a_w of noodle samples is given in Table 1. SM supplemented samples had significantly ($P < 0.01$) higher protein content than control samples. Similarly, lipid content increased with the increasing shrimp supplementation. Carbohydrate content was the highest in control samples (C) (72.21 ± 1.00 g/100 g). Meanwhile, energy was the highest in 30S samples with 571.14 ± 10.16 kcal/100 g due to increased lipid content by the addition of SM. Egg noodles have the advantage that they contain more protein than ordinary noodles or pasta owing to egg addition. Aranibar et al. (2018) and Desai et al. (2018) reported pasta with 11.04 ± 0.03% and 12.21 ± 0.20% protein content, respectively, which is similar to the C samples of this study. It was reported that pasta enriched with fish (*Pseudophycis bachus*) in different proportions increased protein, lipid and ash contents (Desai et al., 2018). It is

Table 1. Proximate composition of noodles

Noodle	Protein (g/100 g)	Lipid (g/100 g)	Moisture (g/100 g)	Ash (g/100 g)	Carbohydrate (g/100 g)	Energy (kcal/100 g)	a_w
Control	11.60 ± 0.62^d	10.40 ± 0.42^d	5.73 ± 0.04^{ab}	0.04 ± 0.00^a	72.21 ± 1.00^a	428.88 ± 2.31^d	0.34 ± 0.00^a
10% S	13.11 ± 0.77^c	22.50 ± 0.28^c	6.10 ± 0.21^{ab}	0.04 ± 0.00^a	58.25 ± 0.71^b	487.94 ± 2.26^c	0.32 ± 0.00^b
20% S	16.51 ± 0.75^b	33.75 ± 0.07^b	5.48 ± 0.22^b	0.02 ± 0.00^b	44.32 ± 0.91^c	546.73 ± 1.26^b	0.30 ± 0.00^c
30% S	19.37 ± 1.04^a	39.30 ± 1.69^a	6.31 ± 0.42^a	0.02 ± 0.00^b	34.99 ± 2.32^d	571.14 ± 10.16^a	0.32 ± 0.00^b

Values are means ± standard deviation of the analysis.
Values bearing and different letters (a, b, c) are significantly ($P < 0.05$) different.

remarkable that the moisture content in this study, ranging between 5.48 and 6.31%, is very low compared to other studies. Moreover, a_w values were recorded between 0.30 and 0.34. SM, susceptible to spoilage, can easily be damaged by conventional drying methods. With freeze-drying, both a_w was reduced and the shrimps were safely dried without exposure to heat and oxygen.

3.2. Technical properties of noodles

Cooking characteristics such as weight gain (WG), volume increase (VI) and cooking loss (CL) of noodles are summarised in Table 2.

WG is the indicator of the yield of the noodle after cooking, and is expected to be approximately 2 times the original weight (200%) (Garcia et al., 2016). WG scores of noodles were high in all samples. The lowest WG of 241.46 ± 2.63% was recorded in control samples ($P < 0.01$). Addition of SM into the noodle formulation increased WG values. There were no statistical differences between the WG values of 10S (261.78 ± 3.82%) and 20S (260.81 ± 6.93%). Aranibar et al. (2018) reported that the presence of partially-deoiled chia flour did not change the WG value of wheat pasta. However, the addition of micro and macro algae was reported to increase WG of pasta (Prabhasankar et al., 2009; Fradique et al., 2013; Ozyurt et al., 2015). VI of shrimp enriched noodles ranged from 214 to 226%. Weight gain and volume increase are caused by similar reasons, the substances added into the formulations with high water holding capacity. Differences in the values of VI were due to the egg and shrimp contents. Moreover, the content and quality of the protein that hydrates and absorbs water during the mixing of the dough can affect VI values (Garcia et al., 2016).

The higher CL results in greater solids leakage into the cooking water, thereby losing more nutrients. Contrarily, lower cooking loss indicates higher quality noodles. The lowest CL scores were obtained for shrimp enriched samples, especially 10S (4.81 ± 0.21) and 30S (4.94 ± 0.03). Prabhasankar et al. (2007) mentioned that the protein content should be at least 11% for acceptable cooking quality of spaghetti. Even the protein content of 20S was 16.51 ± 0.75. This could be attributed to the initially low moisture content of 20S. Its structure tended to soften in water and triggered the migration of nutrients into water. The CL values of control samples were significantly ($P < 0.01$) higher than others. It is known that technologically acceptable limit of CL is below 8 g/100 g (Dick and Youngs, 1988). All noodle samples can be considered as acceptable. Xie et al. (2020) found that the values of CL in egg white enriched pasta ranged between 2.6 and 3.0%, which was lower than of control samples. According to their investigation, this can be attributed to the weak cross-linking characteristics of gluten in semolina flour with other polymers. Therefore, starch molecules can escape from the weak frame. Similarly, Wójtowicz and Moscicki (2014) reported that non-gluten proteins and insoluble fibres weaken the structure of pasta and CL increases. Desai et al. (2018) found higher CL values with the addition of fish powder. In this study, the presence of gluten, egg and increased shrimp content allowed good CL values to be achieved.

3.3. Colour of noodles

The colour of pasta derives from the ratio and original characteristics of the ingredients (Monteiro et al., 2019). Colour measurements of the noodles in terms of brightness (L^*),

Table 2. Cooking quality and colour of noodles

Noodle	Weight gain (%)	Volume increase (%)	Cooking loss (%)	L^*	a^*	b^*	ΔE
Control	241.46 ± 2.63^{b}	214.00 ± 15.55^{b}	7.57 ± 0.15^{a}	74.99 ± 0.20^{b}	5.87 ± 0.16^{a}	17.30 ± 1.07^{a}	
10% S	261.78 ± 3.82	261.75 ± 16.61^{a}	4.81 ± 0.21^{c}	78.60 ± 0.22^{a}	5.90 ± 0.46^{a}	10.94 ± 0.36^{c}	5.75 ± 1.12^{a}
20% S	260.81 ± 6.93^{a}	251.37 ± 5.12^{ab}	6.02 ± 0.29^{b}	75.48 ± 1.49^{b}	6.29 ± 0.22^{a}	13.94 ± 0.06^{b}	3.16 ± 1.16^{b}
30% S	257.22 ± 7.74^{ab}	226.00 ± 19.09^{ab}	4.94 ± 0.03^{c}	72.04 ± 0.31^{c}	6.50 ± 0.00^{a}	18.76 ± 0.12^{a}	2.94 ± 0.56^{b}

Values are means ± standard deviation of the analysis.
Values bearing and different letters (a, b, c) are significantly (P <0.05) different.

redness (a^*) and yellowness (b^*) are summarised in Table 2. Lightness values of 10% shrimp added noodle reached 78.60 ± 0.22 ($P < 0.01$). L^* value decreased in 30S noodles. Contrarily, as a result of the transfer of the original red colour of SM to the noodle, the value of a^*, ranging from 5.90 to 6.50, also increased with the increase in the contribution rate but not significantly. b^* value increased with the SM fortification, and 30S samples did not differ statistically from control samples, while the lowest b^* score was 10.94 ± 0.36 for 10S followed by 13.94 ± 0.06 for 20S. Mostly, consumers prefer pasta with bright yellow colour. In this study, bright colour was achieved with 10S, however, the same noodle had the lowest yellowness. Aranibar et al. (2018) reported that the increasing partially-deoiled chia flour ratio makes pasta darker. Similarly, pasta enrichment with fish powder and shrimp showed lower L^* values than control samples (Kadam and Prabhasankar, 2012; Desai et al., 2018; Monteiro et al., 2019). Ramya et al. (2015) reported that the addition of SM powder (2.5–10 g/100 g) increased the b^* value.

ΔE evaluates the colour differences between control and SM fortified noodles. ΔE value of 10S was significantly higher than those of 20S and 30S. ΔE value of 20S and 30S were in the range of "$2 < \Delta E < 3.5$" which was defined as unexperienced observer also notices the difference. However, 5.75 score of 10S sample was "$5 < \Delta E$", which means observer notices two different colours (Mokrzychi and Tatol, 2012). Previously it was reported that the b^* value came closer to control samples with the increase of SM addition. The expected yellow colour of a traditionally produced noodle had been achieved, and the colour differentiation between 20s and 30s decreased from the control samples. Contrarily, Desai et al. (2018) reported that ΔE values increased with the increasing level of fish powder in pasta formulation.

3.4. Texture properties

Texture of the noodles was determined from texture profile analysis graphs (Table 3). The hardness (N) is the force needed to compress a sample to a fixed point. The hardness values of the noodles increased with the increasing SM content ($P < 0.01$). Xie et al. (2020) mentioned that consumers preferred a paste with a firm texture. This goal was achieved by 30S noodles. Textural properties of pasta are developed mainly by starch and protein. Protein and starch compete for the water during cooking in order to hydrate/coagulate and swell/gelatinise, respectively. In case of a predomination of protein coagulation, starch molecules are embedded into the gluten network; thus, pasta firmness is promoted (Foschia et al., 2014;

Table 3. Texture profile of noodles

Noodle	Hardness (N)	Cohesiveness	Adhesiveness (Nmm)	Springiness (mm)	Chewiness (Nmm)
Control	321.10 ± 28.52^d	0.79 ± 0.01^b	-7.13 ± 0.90^a	0.85 ± 0.01^a	219.05 ± 9.47^d
10% S	490.51 ± 59.00^c	0.80 ± 0.02^b	-9.34 ± 1.35^a	0.86 ± 0.01^a	324.80 ± 49.29^c
20% S	1018.90 ± 6.99^b	0.86 ± 0.01^a	-9.69 ± 2.31^a	0.86 ± 0.02^a	686.91 ± 16.91^b
30% S	1176.92 ± 32.36^a	0.89 ± 0.01^a	-11.08 ± 0.28^a	0.87 ± 0.03^a	868.30 ± 36.12^a

Values are means ± standard deviation of the analysis.
Values bearing and different letters (a, b, c) are significantly ($P < 0.05$) different.

2015). In this study, the combined effect of wheat, egg and shrimp proteins made the noodles harder than control samples. Cohesiveness is the deformation that occurs when biting the specimen using teeth before it ruptures. When this value falls below 1, the deformation created by the initial compression becomes irreversible. The lowest cohesiveness value was determined as 0.79 ± 0.01 for the control group, while this value was determined as 0.89 ± 0.01 for 30S. Adhesion values of the noodles ranged between −7.13 and −11.08 Nmm and decreased with the increasing SM addition without any statistical difference. Springiness is the ability of the sample to return to its original state after the deforming force is removed. There was no statistical difference in elasticity values of shrimp added noodles, however C had lower elasticity values than the others. Monteiro et al. (2019) found similar springiness results for pasta enriched with fish (*Oreochromis niloticus*) waste flour. Chewiness is the energy required for a solid sample to become swallowable by chewing. The highest chewiness score, 868.36 ± 36.12 Nmm, was determined in 30S noodles due to the combined effect of gluten, egg and shrimp proteins ($P < 0.01$). These proteins are linked together by disulfide, hydrogen and hydrophobic bonds to form a matrix and generate the viscoelastic properties of noodles. These inter- and intra-molecular bonds gradually disintegrate during cooking, textural parameters are affected because of releasing exudates during starch granule gelatinisation (Foschia et al., 2014).

3.5. Scanning Electron Microscopy (SEM)

Surface characteristics of the noodle samples were visualised with a scanning electron microscope. Micrographs of control and shrimp enriched noodles are presented in Fig. 1A–H. Control noodles showed a heterogeneous surface. Although the structure of the control sample provides integrity, it contains partial pores. The homogenous but porous surface could be a result of embedded starch granules in a protein matrix (Liu et al., 2016). Obvious cracks were observed in 10S noodles compared to control samples. The addition of 20% shrimp into the noodle formulation triggered a smooth surface structure and reduced bumps and gaps. The microstructure was improved in 30S noodles. The number of granules decreased. A smoother surface was obtained with increasing shrimp addition. The protein matrix was enhanced by SM. A tighter network structure among proteins resulted in improvement in microstructure (Kim et al., 2014).

4. CONCLUSIONS

Noodles, such a widely consumed food, why not be more nutritious? In addition to its widespread consumption, many features have been improved by adding SM into egg-noodle. A product with increased nutritional value and improved cooking quality and microstructure was achieved. Thus, it will contribute to increasing the consumption of seafood. Especially, a functional product with rich protein content, easy to consume and suitable for consumers of all ages has been produced. As it is a high energy food, it is thought to be a high protein product intended for athletes and individuals with special nutritional needs. It has the potential to be a product with a long shelf life thanks to its a_w value detected between 0.30 and 0.34. According to the findings, a successful noodle can be obtained by adding 30% SM.

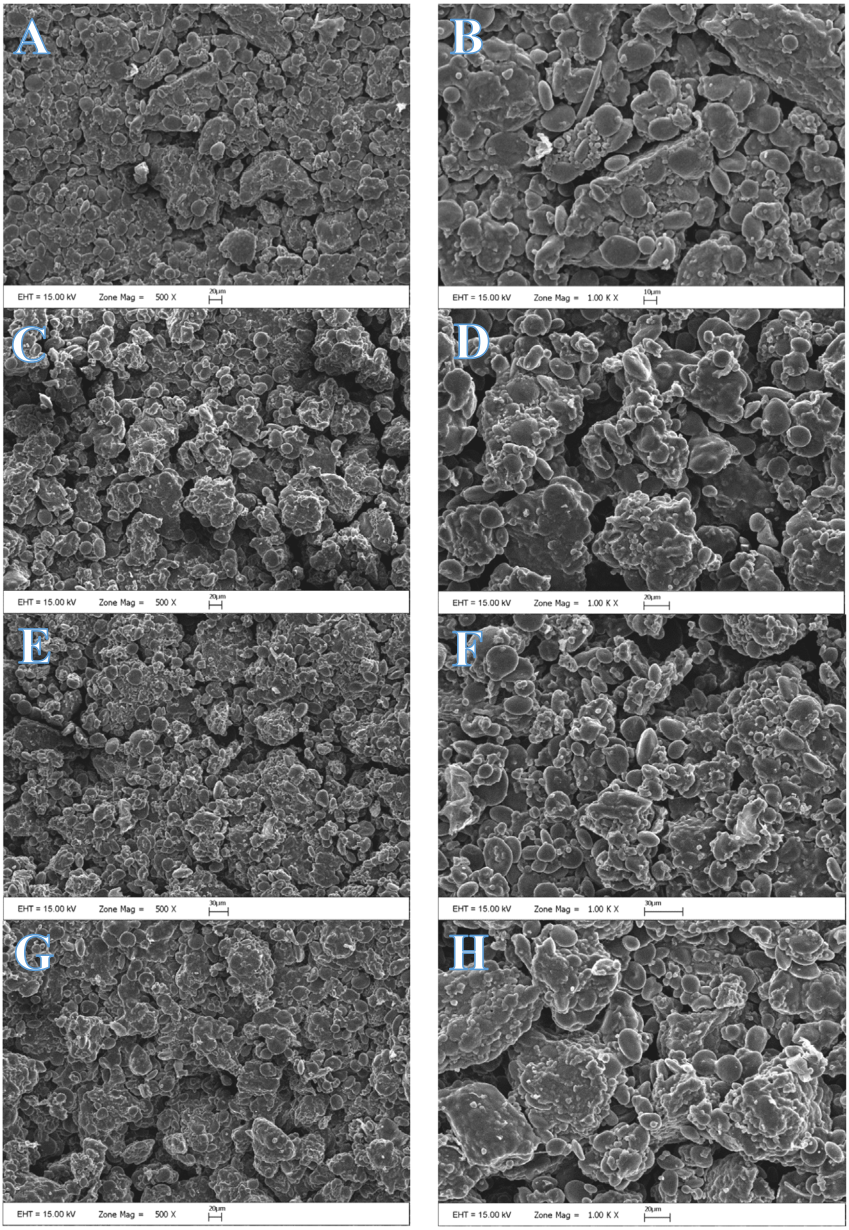

Fig. 1. Scanning electron micrographs of noodles. 500 × magnification: Control (A), 10% shrimp (B), 20% shrimp (C), and 30% shrimp (D); 1,000 × magnification: Control (E), 10% shrimp (F), 20% shrimp (G) and 30% shrimp (H)

Further studies may be performed on the shelf-life of freeze-dried SM supplemented egg-noodles.

ACKNOWLEDGEMENT

The Scientific Research Projects Administration Unit of Akdeniz University supported this research.

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