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ORIGINAL ARTICLE

Extrusion cooking of immature rice grain: under-utilized by-product of rice milling process

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Abstract Immature rice grain is one of the by-products of paddy milling process. Due to being "whole grain", immature rice grains comprise the fat-rich bran layer which bring along high nutritional value as well as susceptibility to rancidity. Therefore, they are generally used as "feed" rather than "food". In this study, the potential of utilizing immature rice grain as a food ingredient was investigated. For this purpose, raw (unprocessed) and infrared (IR) stabilized immature rice grain flours (IRGF) were extruded at different exit-die temperatures (130 °C and 150 °C) and feed moisture contents (16%, 18%, 20%) and the effects of these parameters on chemical composition (moisture, crude fat, protein, ash, soluble and insoluble dietary fiber and phytic acid contents), physicochemical properties (solubility, water binding capacity, expansion index and bulk density), thiamine, riboflavin and tocopherol contents, textural and sensorial properties of the extrudates were investigated. Either thiamine or tocopherol contents of the extrudates made of unprocessed IRGF were higher than that of the extrudates made of IR stabilized IRGF ($p < 0.05$). Additionally, higher extrusion temperature and lower feed moisture content resulted in further loss in both vitamins. On the other side, riboflavins showed a relatively heat-stable behavior. Rancid flavor and bitter taste scores of the extrudates which were made of unprocessed IRGF were significantly higher than their counterparts made of IR stabilized IRGF ($p < 0.05$). Toothpack was the most dominant sensory attribute in all extrudates.

Keywords Extrusion · Immature rice · Infrared · Dietary fiber · Tocopherols · B vitamins

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Introduction

Modernization and changes in lifestyles have increased the demand for ready-to-eat foods and snacks. Besides, due to rising awareness of the relationship between nutrition and health, there is also a growing demand for nutritious snacks which contain ingredients that have health benefits. Since most of the snacks are typically composed of carbohydrates and fat and considered as junk foods, development of nutritious snacks is important to meet the demands of new consumer profile.

Extrusion cooking has gained popularity over the last 20 years in food industry because it allows to produce a wide range of products by changing the ingredients, operating conditions and dies, and it has lower processing costs compared to many other cooking and forming processes (Guy 2001). Extruders can operate continuously with high throughput which makes the process productive. Besides, extrusion cooking is a high temperature-short time process which enables retaining heat sensitive food components.

Moreover, it is an environmentally friendly process since it does not produce significant process effluents and reduces water treatment costs (Guy 2001).

Immature rice grain is one of the by-products of paddy milling process. Before harvest, rice grains which have a moisture content exceeding 22% are considered as immature, while after harvest, immaturity is defined as either thin kernels with various levels of chalkiness or as kernels that have green seed coat (Buggenhout et al. 2013). Although harvest starts when rice grains are generally mature, individual kernel moisture content vary widely and thus, some kernels are mature while others may still be immature (Buggenhout et al. 2013). Therefore, immature rice grains are always formed to some extent depending on the variety and climatic conditions (Bhattacharya and Ali 2015).

In paddy milling process, immature rice grains are easily broken during dehulling and whitening steps due to being chalky and brittle, thus resulting in reduced head rice yield and excessive production of bran and broken grains (IRRI 2017). Therefore, they are separated during cleaning and grading of paddy and are mostly evaluated as feed. The most important reason of the undervalued use of immature rice grains is rancidity problem. Due to being whole grains, immature rice grains comprise the fat-rich bran layer which bring along high nutritional value as well as susceptibility to rancidity. In a recent study, it was found that free fatty acid content of immature rice grain increased from 5.49 to 35.71% in 3 months of storage at room temperature (Yılmaz et al. 2018). Therefore, stabilization process is essential either for utilizing immature rice grains as food or for storage purposes. On the other side, immature rice grains include many bioactive components such as B group vitamins, dietary fiber, tocopherols, gamma-oryzanol, phenolics and antioxidants (Yılmaz et al. 2018; Tuncel and Yılmaz 2011) and hence, they are very suitable for use as a nutritious ingredient in food matrices. Nevertheless, the potential of the use of alternative nutritive sources such as immature rice grains has been scarcely exploited. Rice, especially low-grade rice, have been used for extrusion cooking to produce expanded crunchy snacks for value addition (Fellows 2017). However, to our knowledge, there is no report related to the direct use of immature rice grains in extruded snacks production. Furthermore, we could not reach to any study regarding the use of immature rice grains as a food ingredient in any type of food product except for a previous study (Özer et al. 2018) which showed the use of immature rice grain flour in gluten-free bread preparation.

A wide range of products, including breakfast cereals, snackfoods, biscuits, pasta, and soya-based meat analogues, as well as petfoods and fish feeds, can be produced using extrusion technology. However, extrusion cooking results in a large number of complex changes to foods including hydration, gelatinization of starches, denaturation or reorientation of proteins, melting of fats, formation of glassy states, and plastisication of the material (Fellows 2017). Therefore, the effects of the extrusion conditions also matter in product development.

The aims of this study were to produce extruded snacks from either unprocessed or infrared (IR) stabilized immature rice grain flours (IRGF) to understand the potential of utilizing IRGF as "food" and to understand the effects of the type of raw material and extrusion conditions on chemical composition, physico-chemical properties, vitamins (B_1, B_2 and tocopherols) contents, and textural and sensorial properties of the extrudates.

Materials and methods

Material

Immature rice grains (variety of Luna) were procured from a rice milling factory (Özer Gıda Ltd. Şti) in Çanakkale, Turkey. Immature rice grains were transferred to the laboratory immediately after milling and were cleaned using a laboratory-scale trieur (CRM-1252 T, Yaşar Makina, Samsun, Turkey). Half of the cleaned grains was stabilized using IR radiation and the other half was used directly (unprocessed) to produce the extrudates. Either IR stabilized, or unprocessed immature rice grains were ground using a micronizer mill (Yuhong, IC-02A, China) and sieved through 100 mesh sieves before extrusion process.

Infrared stabilization

Cleaned grains (500 g) were soaked in water for 10 min and were allowed to drain for another 10 min before stabilization. Afterwards, the grains were stabilized using a laboratory-type IR stabilization system which was explained in detail in previous studies (Yılmaz et al. 2014a, b). In the present study, medium wave IR emitter (Item no: 09755054) (Heraeus Noblelight, Hanau, Germany) was used as the IR source and the distance between the emitters and the sample (belt) was maintained constant at 15 cm throughout the experiment. IR processing conditions were 1600 W emitter power and 4 min process time.

Extrusion process

Unprocessed or IR stabilized IRGF were extruded using a co-rotating twin-screw extruder (THK 31, Incheon Machinery Co., Incheon, Korea). The screw length-to-diameter ratio (L/D) was 25:1. The extruder was equipped with a circular die of 2 mm diameter.

To preliminarily identify an optimal extrusion condition to produce an acceptable snack, IRGF samples were produced at different exit-die temperatures (110, 130, 150 °C), feed moisture contents (18, 20, 22, 24%), and screw speeds (150, 200, 250 rpm) and expansion index, bulk density and color characteristics of the samples were measured (data not shown). Based on the obtained results, the optimum extrusion conditions were determined as follows: 16, 18, 20% feed moisture content; 130, 150 °C exit die temperature and 250 rpm constant screw speed. The selected conditions allowed to produce extrudates which have expansion index higher than 2 and bulk density lower than 0.5 g/cm^3. Tap water was pumped into the first barrel section to adjust the moisture content. Extrudates were collected when the extrusion system reached a steady state as indicated by constant torque, temperature, and pressure. The feed rate was controlled at 3 kg/h. All samples produced at the noted selected conditions were oven-dried at 50 °C to decrease the moisture content of the extrudates below 10%. Then, the extrudates were placed in air-tight plastic bags and stored at 4 °C until analysis.

Chemical composition

Moisture (Method No: 44–19), crude fat (Method No: 30–10), protein (Method No: 46–12), and ash (Method No: 08–01) contents of the extrudates were determined according to the standard methods (AACC 2000). Soluble dietary fiber (SDF) and insoluble dietary fiber (IDF) contents of the extrudates were analyzed according to the enzymatic–gravimetric method (Method No: 32–07) using Megazyme enzyme kits (Megazyme, Wicklow, Ireland) (AACC 2000). Total dietary fiber (TDF) represents the sum of SDF and IDF. Phytic acid content was measured spectrophotometrically using the anion-exchange method (Method No: 986.11) (AOAC 2000).

Physico-chemical properties

Water solubility (WS) and water binding capacity (WBC) of the extrudates were determined using the method outlined by Singh and Singh (2003). Ground extrudates were mixed with distilled water (1:10, w/v) by vortexing for 15 s in every 5 min (totally 1 h). Then, the content was centrifuged at 4000 × *g* for 10 min and either the supernatants or the precipitates were dried in an oven (Memmert, UN75, Schwabach, Germany) at 100 °C for overnight. WS and WBC of the extrudates were determined using the formulas shown below:

$$\text{WS } (\%) = \frac{\text{Weight of the dried supernatant}}{\text{Weight of the sample}} \times 100$$

$$\text{WBC } (\%) = \frac{\text{(Weight of the wet precipitate) - (Weight of the dried precipitate)}}{\text{Weight of the sample}} \times 100$$

For the determination of expansion index, the extrudates were dried in oven for overnight and cut into equal short segments of about 10 cm long. The diameter of the each extrudate (10 segments for each extrusion condition) was measured using calipers and the expansion index was determined by dividing the diameter of the extrudates to the diameter of the die (2 mm). Bulk density of the extrudates was determined according to Hwang and Hayakawa (1980) and Meng et al. (2010) using the volume replacement method. Three measurements were done for each extrusion condition. Bulk density (g/cm^3) was calculated using the formulas shown below, where; ρb is the bulk density of the extrudate, *W*ex (g) is the weight of the extrudate, *V*c (cm^3) is the volume of the graduate cylinder, *W*rps (g) is the weight of the rapeseeds, which is used for volume replacement, at specific volume, and *W*ex + rps (g) is the weight of extrudate and the weight of the rapeseeds at specific volume.

$$\rho_b = \frac{W_{ex}}{V_c \times \left(1 - \frac{W_{ex+rps}}{W_{rps}}\right)}$$

Determination of Vitamins B_1, B_2 and E

Thiamin (Vitamin B_1), riboflavin (Vitamin B_2) and tocopherol (Vitamin E) contents of the extrudates were determined according to the methods reported in previous studies (Yılmaz and Tuncel 2015; Yılmaz et al. 2014a, b).

Descriptive sensory analysis

Sensory properties of the extrudates were evaluated by a roundtable discussion with a six-member panel. Panelists (23–48 years of age, 5 female and 1 male) were staff and graduate students from the Department of Food Engineering at Çanakkale Onsekiz Mart University. Informed consent to participate to the study is obtained from the panelists. Primarily, the panelists, who already have sensory evaluation experience, were intensively trained about the descriptive sensory evaluation and asked to specify and define descriptive terms for representative samples. The sensory terms that best described the flavor, taste and texture of the extrudates were determined by consensus and redundant terms were eliminated. The selected 10 sensory attributes, their definitions and references were presented on Table 1. Reference and test product attribute scores were based on a 15-point scale anchored on the left with

Table 1 Sensory terms, their definitions and references

Terms	Definitions	References
Flavor and taste		
Cooked	Aromatics related with cooked rice	Fresh cooked white rice
Rancid	Aromatics related with oxidized oil (such as paint and varnish)	Oxidized olive oil
Nutty	Aromatics related with nuts	Roasted and ground hazelnut
Cereal / bran	Aromatics related with wholegrain cereals	Wet cracked wheat or wet brown rice
Pop-corn	Aromatics related with pop-corn	Fresh popped corn
Bland	Poor flavor and taste	Unsalted bread
Bitter	Taste sensation elicited by caffeine	0.08% caffeine solution in water
Texture		
Hardness	Force required to compress and bite through	Cracker, grissini
Tooth pack	Amount of sample packed in between molars after swallowing	Puffed rice
Crispness	Intensity of audible noise during eating	Chips

"not" and on the right "very" according to Meilgaard et al. (1999). After training, 12 samples, which were consisted of different raw materials and/or were extruded at different conditions, were formally evaluated at 6 sessions due to the sheer number of samples. Samples were presented in white plastic dishes coded with 3-digit random numbers. Each sample was evaluated 2 times. Drinking water was provided to clean and rinse the mouth between samples. Panelists were asked to wait 1–2 min between samples.

Instrumental texture analysis

One cycle texture analysis was carried out in compression mode using a texturometer (Brookfield, CT3-4500, Massachusetts, USA). Extrudates were placed in an Ottawa cell assembly (TA-OC) with a grid base plate and compressed with TA3/100 probe using 4500 g trigger force. The target value was 5 mm and the test speed was 2 mm/s. Hardness, adhesiveness, and fracturability were calculated by the software.

Statistical analysis

The effects of type of raw material (unprocessed or IR stabilized IRGF), exit-die temperature, feed moisture, and their interactions on the noted parameters were evaluated with analysis of variance (ANOVA) using MINITAB (ver. 16.1, StatSoft, Inc., Tulsa, OK, USA) at a significance level of 0.05 following the statistical model noted below

$$Y_{ijk} = \mu + \alpha_i + \beta_j + \gamma_k + (\alpha\beta)_{ij} + (\alpha\gamma)_{ik} + (\beta\gamma)_{jk} + (\alpha\beta\gamma)_{ijk} + \varepsilon_{ijk}$$

where $Y_{ijlk}$is the measured value using *i.* type of material, *j.* exit-die temperature and *k.* feed moisture, μ is the general population mean, $\alpha_i$is the effect of type of raw material *i* (unprocessed or IR stabilized IRGF), $\beta_j$is the effect of exit-die temperature *j* (130 °C, 150 °C), $\gamma_k$is the effect of feed moisture *k* (16%, 18%, 20%), $(\alpha\beta)_{ij}$ is the interaction between type of raw material x exit-die temperature, $(\alpha\gamma)_{ik}$ is the interaction between type of raw material x feed moisture, $(\beta\gamma)_{jk}$is the interaction between exit-die temperature x feed moisture, $(\alpha\beta\gamma)_{ijk}$ is the interaction between type of raw material x exit-die temperature x feed moisture, $\varepsilon_{ijk}$is random error.

Additionally, one-way ANOVA was conducted to be able to present the statistics on a single table (i.e. unprocessed IRGF, 130 °C exit-die temperature and 16% feed moisture as one factor). Tukey's test was used for multiple comparisons ($p < 0.05$). All data were expressed as mean ± standard error. All means were an average of at least 3 replicates. Solely the results of the descriptive sensory analysis were evaluated with Kruskal Wallis test due to being non-parametric data. When significant effects were observed, Dunn's test was used for comparison ($p < 0.05$).

Results and discussion

Chemical composition

The images of the extruded snacks were presented in Fig. 1. Moisture content of the extrudates ranged between 3.90% and 5.20% (Table 2). The extrudates were allowed to wait at 50 °C in an oven for overnight after production and therefore, moisture content of the extrudates may not be associated with the extrusion conditions. Crude fat, protein and ash contents of the extrudates varied between 0.92–1.60%, 11.00–11.40%, and 1.68–1.82%, respectively. Although the effect of the extrusion conditions on some of

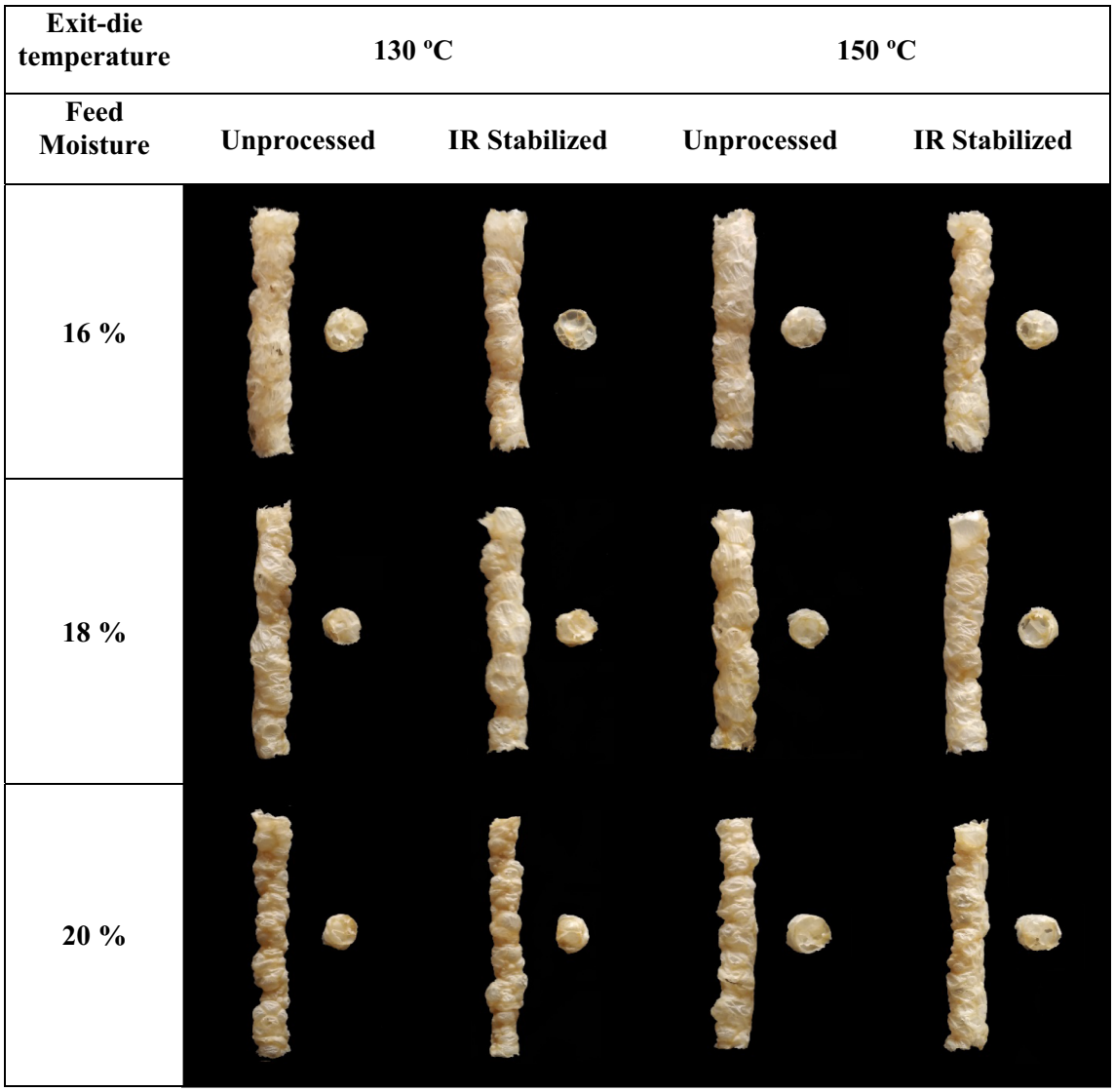


Fig. 1 Images of the extrudates made of unprocessed and infrared stabilized immature rice grain flour

the noted parameters was found statistically significant (Table 2), specified variations were neither mathematically nor practically important for such macro analyses.

IDF contents of the extrudates made of either unprocessed or IR stabilized IRGF were almost as twice as higher than SDF (Table 2). Neither the effect of the type of material (unprocessed or IR stabilized) nor the extrusion conditions (exit-die temperature and feed moisture content) were significant on SDF content ($p > 0.05$). The effects of the type of material and the content of the feed moisture were also insignificant on IDF and TDF ($p > 0.05$). However, either IDF or TDF contents of the extrudates which were extruded at 150 °C were significantly higher than those which were extruded at 130 °C ($p < 0.05$). Similarly, Vasanthan et al. (2002) reported an increase in either SDF or TDF content of barley flour which were extruded at 90–140 °C and 20–50% moisture level. The authors also indicated that the increase in IDF content was variety dependent and could be due to the formation of retrograded amylose (resistant starch (RS3)) during extrusion cooking and subsequent cooling. Adversely, Rashid et al. (2015) stated that IDF content of either wheat flour or wheat bran decreased after extrusion with varying process parameters. The authors attributed the decrease in IDF and a subsequent increase in SDF during extrusion to the disruption of covalent and noncovalent bonds in the carbohydrate and protein moieties which lead to smaller and more soluble fragments. Phytic acid content of the extrudates made of unprocessed IRGF (3.73 mg/g) was significantly higher than that of the extrudates made of IR stabilized IRGF (3.25 mg/g), while the effects of either exit-die temperature or feed moisture were statistically

Table 2 Chemical composition of the extrudates

Raw material	Barrel temperature (°C)	Feed moisture (%)	Moisture (%)	Crude fat (%, d.w.)	Protein (%, d.w.)	Ash (%,d.w.)	SDF (%)	IDF (%)	TDF (%)	Phytic acid (mg/g)
Unprocessed immature rice grain	130	16	4.16 ± 0.10^{DEF}	1.06 ± 0.02^{AB}	11.21 ± 0.02	1.79 ± 0.01^{ABC}	2.41 ± 0.10	4.74 ± 0.14^{BC}	7.15 ± 0.24	4.26 ± 0.33
		18	3.90 ± 0.02^{F}	0.92 ± 0.01^{B}	11.30 ± 0.10	1.79 ± 0.01^{AB}	2.90 ± 0.40	5.41 ± 0.20^{ABC}	8.31 ± 0.60	3.86 ± 0.22
		20	4.73 ± 0.06^{B}	1.23 ± 0.10^{AB}	11.27 ± 0.05	1.77 ± 0.04^{ABCD}	3.54 ± 0.05	4.61 ± 0.22^{C}	8.15 ± 0.27	3.50 ± 0.13
	150	16	4.02 ± 0.11^{EF}	1.18 ± 0.18^{AB}	11.21 ± 0.15	1.79 ± 0.01^{ABC}	3.36 ± 0.09	5.68 ± 0.22^{AB}	9.04 ± 0.31	3.61 ± 0.14
		18	4.01 ± 0.06^{EF}	1.40 ± 0.25^{AB}	11.00 ± 0.24	1.78 ± 0.02^{ABC}	2.95 ± 0.07	5.49 ± 0.11^{ABC}	8.44 ± 0.18	3.17 ± 0.10
		20	4.63 ± 0.06^{BC}	1.23 ± 0.13^{AB}	11.09 ± 0.03	1.82 ± 0.01^{A}	2.49 ± 0.11	5.74 ± 0.12^{AB}	8.23 ± 0.01	3.99 ± 0.04
IR stabilized immature rice grain	130	16	4.30 ± 0.07^{DE}	1.60 ± 0.01^{A}	11.26 ± 0.04	1.69 ± 0.01^{DE}	2.73 ± 0.31	5.21 ± 0.21^{ABC}	7.94 ± 0.52	3.11 ± 0.16
		18	4.29 ± 0.02^{DE}	1.59 ± 0.01^{A}	11.27 ± 0.06	1.72 ± 0.02^{BCDE}	2.80 ± 0.21	5.32 ± 0.21^{ABC}	8.12 ± 0.42	3.21 ± 0.17
		20	5.20 ± 0.04^{A}	1.45 ± 0.06^{AB}	11.40 ± 0.03	1.74 ± 0.01^{ABCDE}	2.75 ± 0.42	5.45 ± 0.05^{ABC}	8.21 ± 0.37	3.02 ± 0.48
	150	16	4.39 ± 0.05^{CD}	1.19 ± 0.01^{AB}	11.22 ± 0.19	1.70 ± 0.01^{CDE}	3.12 ± 0.23	5.55 ± 0.25^{ABC}	8.68 ± 0.49	3.44 ± 0.24
		18	4.00 ± 0.05^{EF}	1.24 ± 0.02^{AB}	11.08 ± 0.04	1.68 ± 0.01^{E}	3.49 ± 0.27	5.44 ± 0.18^{ABC}	8.93 ± 0.45	3.37 ± 0.23
		20	4.30 ± 0.05^{DE}	1.28 ± 0.01^{AB}	11.06 ± 0.04	1.68 ± 0.01^{E}	2.88 ± 0.38	5.82 ± 0.16^{A}	8.70 ± 0.54	3.35 ± 0.23
p			0.000	0.016	0.363	0.000	0.119	0.011	0.223	0.056

*Means followed by different capital letters in the same column are significantly different by Tukey ($p < 0.05$)

insignificant ($p > 0.05$). Similarly, significant decrease (up to 6%) in phytic acid content of IR stabilized rice bran compared to raw bran was also found in a previous study (Yılmaz and Tuncel 2015). On the other hand, Sharma et al. (2004) reported significant reductions in phytic acid contents of both dry heat treated and extruded rice bran. Varying results in the literature may be attributed to different process conditions.

Physico-chemical properties of the extrudates

Water solubility of the extrudates which were made of IR stabilized IRGF was higher than that of the extrudates which were made of unprocessed IRGF ($p < 0.05$) (Table 3). Increasing feed moisture content resulted in a significant decrease in WS and a significant increase in WBC of the extrudates especially at higher extrusion temperatures ($p < 0.05$). Higher WBC and lower WS results with increasing feed moisture content were also reported by other researchers (Masatcıoğlu et al. 2014; Chang and Ng 2011) and these results were attributed to the decrease in degradation of starch due to the presence of excess water which acts as a plasticizer at high moisture contents. Furthermore, Masatcıoğlu et al. (2014) indicated that higher extrusion temperatures can increase the degree of starch gelatinization which in turn results in lower WBC and higher WS. Higher WS of the extrudates made of IR stabilized IRGF with regard to the WS of the extrudates made of unprocessed IRGF can also be explained with the same mechanism since IR radiation might have increased starch gelatinization.

During extrusion cooking of starch-based products, increasing feed moisture causes starch granules to swell and become hydrated while increasing temperature causes starch to gelatinise and form a viscous plasticised fluid melt which forms the walls of foam bubbles that contain superheated water vapour. Expansion occurs at the die of an extruder due to the sudden drop in pressure (Fellows 2017). Expansion index of the extrudates ranged between 4.96 and 6.33. The effect of the type of raw material was insignificant on expansion index ($p > 0.05$). However, samples extruded at higher exit-die temperature with a lower feed moisture had significantly higher expansion index than their counterparts ($p < 0.05$). Similarly, Gat and Ananthanarayan (2015) reported a decrease in expansion of rice-based extruded snacks with increasing feed moisture content.

Expansion index and bulk density are inversely related measures of the extent of puffing. Bulk density of the extrudates significantly increased with increasing feed moisture content and decreasing exit-die temperature ($p < 0.05$). The increase in bulk density with increasing feed moisture content was more pronounced at 130 °C.

Table 3 Physico-chemical properties of the extrudates

Raw material	Barrel temperature (°C)	Feed moisture (%)	Solubility (%)	Water binding capacity (%)	Expansion index	Bulk density (g/cm^3)
Unprocessed	130	16	46.36 ± 0.04^{ABC}	169.41 ± 7.93^{D}	6.04 ± 0.05^{A}	0.064 ± 0.002^{DE}
immature		18	44.33 ± 0.11^{CD}	201.59 ± 2.04^{BC}	5.44 ± 0.06^{B}	0.096 ± 0.004^{BC}
rice grain		20	45.29 ± 0.01^{BC}	206.86 ± 1.80^{AB}	4.96 ± 0.06^{D}	0.148 ± 0.006^{A}
	150	16	46.27 ± 0.45^{ABC}	177.09 ± 4.39^{BCD}	6.28 ± 0.05^{A}	0.049 ± 0.002^{E}
		18	46.33 ± 0.61^{ABC}	190.05 ± 3.57^{BCD}	6.15 ± 0.07^{A}	0.056 ± 0.001^{DE}
		20	42.84 ± 0.03^{D}	236.00 ± 3.19^{A}	5.27 ± 0.05^{BC}	0.084 ± 0.003^{BCD}
IR stabilized	130	16	47.18 ± 0.13^{AB}	174.53 ± 4.71^{CD}	5.48 ± 0.10^{B}	0.069 ± 0.001^{CDE}
immature		18	45.45 ± 0.75^{ABC}	206.20 ± 0.73^{AB}	5.21 ± 0.05^{BCD}	0.111 ± 0.001^{B}
rice grain		20	46.30 ± 0.32^{ABC}	204.23 ± 6.56^{BC}	5.04 ± 0.06^{CD}	0.168 ± 0.018^{A}
	150	16	47.05 ± 0.60^{AB}	176.70 ± 13.80^{BCD}	6.32 ± 0.05^{A}	0.055 ± 0.002^{DE}
		18	47.50 ± 0.18^{A}	184.84 ± 0.37^{BCD}	6.33 ± 0.06^{A}	0.053 ± 0.002^{E}
		20	47.25 ± 0.26^{AB}	206.56 ± 2.57^{AB}	6.04 ± 0.09^{A}	0.066 ± 0.001^{DE}
p			0.000	0.000	0.000	0.000

*Means followed by different capital letters in the same column are significantly different by Tukey ($p < 0.05$)

Similarly, Gupta et al. (2008) obtained the highest bulk density values at higher moisture contents and lower temperatures in barley flour containing rice-based extruded snacks.

Vitamins

Thiamine and riboflavin contents of the extrudates ranged between 1.10–2.49 mg/kg and 2.17–2.92 mg/kg, respectively (Table 4). Thiamine content of the extrudates made of unprocessed IRGF was significantly higher than that of the extrudates made of IR stabilized IRGF ($p < 0.05$). Yılmaz and Tuncel (2015) have reported that IR processing resulted in a significant decrease which ranged from 20 to 42% in thiamine content of rice bran compared to raw bran. The authors also indicated that the highest decomposition due to IR processing was observed in thiamine content among the analyzed B group vitamins in an agreement with Ball (2006) who stated that thiamine is the most heat labile of B group vitamins. Furthermore, the samples which made of unprocessed IRGF and extruded at 150 °C exit-die temperature showed lower thiamine content compared to their counterparts extruded at 130 °C, whereas thiamine contents of the samples made of IR stabilized IRGF were not statistically different regarding exit-die temperature. Additionally, thiamine content of the extrudates which were made of unprocessed IRGF and extruded using 16% of feed moisture were significantly lower than those extruded using higher feed moisture content ($p < 0.05$).

The effect of the type of raw material was not significant on riboflavin content. In other words, the effect of IR stabilization on the riboflavin content of IRGF was insignificant ($p > 0.05$). Similarly, Yılmaz and Tuncel (2015) have reported that riboflavin content of IR stabilized rice bran was not statistically different from that of raw bran ($p > 0.05$). However, the effects of exit-die temperature, feed moisture and their interactions were found significant on riboflavin content ($p < 0.05$). Still, mean riboflavin contents of the samples extruded at 130 °C and 150 °C exit-die temperature were 2.44 and 2.57 mg/kg, respectively. Therefore, it can be concluded that riboflavin showed a relatively heat-stable behavior during either IR or extrusion processes at the noted conditions when compared to thiamine. On the other hand, lower feed moisture (16%) resulted in a significant decrease in riboflavin content of the extrudates excluding the samples made of IR stabilized IRGF and processed at 150 °C exit-die temperature. Athar et al. (2006) investigated the retention of thiamin, riboflavin, niacin and pyridoxine during extrusion processing of whole oat grain, maize and pea grits and concluded that thiamin showed the greatest reduction, while riboflavin and niacin having the highest stability. Riaz et al. (2009) reviewed that the vitamins most sensitive to the extrusion process are vitamin A and vitamin E among fat soluble vitamins, and vitamin C, thiamin, and folic acid among water soluble vitamins. The authors also noted that B group vitamins, namely riboflavin, niacin, Ca-pantothenate, B6, B12, and biotin, are mostly stable during extrusion except for thiamin.

Among the tocopherol isomers α, β, and γ-tocopherols were quantified, while δ-tocopherol could not be detected in the extrudates. Besides, α-tocopherol constituted almost 75% of the total tocopherol content. The contents of α, β, and γ-tocopherols ranged between 4.18–9.65 mg/kg,

Table 4 B and E vitamin contents of the extrudates

Raw material	Barrel temperature (°C)	Feed moisture (%)	Vitamin B_1 (Thiamine) (mg/kg)	Vitamin B_2 (Riboflavin) (mg/kg)	α-Tocopherol (mg/kg)	β-Tocopherol (mg/kg)	γ-Tocopherol (mg/kg)	Total Tocopherol (mg/kg)
Unprocessed	130	16	1.72 ± 0.01^{BCDE}	2.30 ± 0.19^{BC}	8.44 ± 0.09^{B}	0.51 ± 0.01^{A}	2.06 ± 0.02^{A}	11.01 ± 0.12^{B}
immature		18	2.42 ± 0.08^{AB}	2.53 ± 0.02^{ABC}	8.46 ± 0.05^{B}	0.48 ± 0.01^{B}	1.96 ± 0.01^{B}	10.90 ± 0.06^{B}
rice grain		20	2.49 ± 0.39^{A}	2.53 ± 0.01^{ABC}	9.65 ± 0.05^{A}	0.52 ± 0.01^{A}	2.04 ± 0.01^{A}	12.22 ± 0.05^{A}
	150	16	1.31 ± 0.10^{CDE}	2.42 ± 0.02^{ABC}	7.92 ± 0.02^{C}	0.49 ± 0.01^{B}	1.91 ± 0.01^{C}	10.32 ± 0.02^{C}
		18	1.99 ± 0.01^{ABC}	2.92 ± 0.13^{A}	6.36 ± 0.04^{G}	0.41 ± 0.01^{DE}	1.57 ± 0.01^{E}	8.35 ± 0.03^{G}
		20	1.83 ± 0.13^{ABCD}	2.57 ± 0.02^{ABC}	6.81 ± 0.04^{E}	0.42 ± 0.01^{D}	1.66 ± 0.01^{D}	8.89 ± 0.04^{E}
IR stabilized	130	16	1.23 ± 0.09^{DE}	2.17 ± 0.02^{C}	5.00 ± 0.03^{H}	0.32 ± 0.01^{F}	1.19 ± 0.01^{G}	6.51 ± 0.04^{H}
immature		18	1.41 ± 0.07^{CDE}	2.33 ± 0.16^{BC}	7.27 ± 0.01^{D}	0.45 ± 0.01^{C}	1.65 ± 0.01^{D}	9.37 ± 0.01^{D}
rice grain		20	1.33 ± 0.04^{CDE}	2.84 ± 0.16^{AB}	6.84 ± 0.01^{E}	0.39 ± 0.01^{E}	1.45 ± 0.01^{F}	8.68 ± 0.01^{EF}
	150	16	1.10 ± 0.01^{E}	2.57 ± 0.08^{ABC}	4.18 ± 0.01^{I}	0.30 ± 0.01^{G}	1.07 ± 0.01^{H}	5.54 ± 0.01^{I}
		18	1.32 ± 0.01^{CDE}	2.54 ± 0.04^{ABC}	4.80 ± 0.01^{H}	0.31 ± 0.01^{FG}	1.14 ± 0.01^{G}	6.25 ± 0.02^{H}
		20	1.30 ± 0.03^{CDE}	2.44 ± 0.01^{ABC}	6.59 ± 0.02^{F}	0.42 ± 0.01^{D}	1.59 ± 0.01^{E}	8.60 ± 0.03^{FG}
p			0.000	0.006	0.000	0.000	0.000	0.000

*Means followed by different capital letters in the same column are significantly different by Tukey ($p < 0.05$)

0.30–0.52 mg/kg, and 1.07–2.06 mg/kg, respectively (Table 4). The highest and the lowest variations were observed in α-tocopherol and β-tocopherol, respectively. Similarly, Shin et al. (1997) extruded rice bran at 110–140 °C with post extrusion holding times of 0–6 min and stated that the order of stability of vitamin E in extruded rice bran for all extrusion temperatures was α-tocopherol < γ-tocopherol < β-tocopherol < δ-tocopherol.

The effects of the type of raw material, extrusion conditions, and their interactions were significant on the content of all tocopherol isomers ($p < 0.05$). Tocopherol content of the extrudates made of unprocessed IRGF (10.28 mg/kg on average) was higher than that of the extrudates made of IR stabilized IRGF (7.49 mg/kg on average) ($p < 0.05$) for all isomers. This result indirectly showed that IR stabilization caused a noticeable loss of tocopherols. Similar findings were also reported in a previous study (Yılmaz et al. 2014a). The authors declared an almost 50% loss in tocopherol content of rice bran that was stabilized using near-IR radiation. Moreover, tocopherol content of the samples which was extruded at 130 °C were higher than that of the samples extruded at 150 °C for all tocopherol isomers. Furthermore, the lower the feed moisture is, the higher the loss in tocopherol content (Table 4).

Sensory evaluation

Descriptive sensory analysis consists of formal procedures for assessing, in a reproducible manner, specific attributes of a sample and rating intensity on a suitable scale and can be used to evaluate aroma, flavor, appearance, and texture, separately or in combination (ISO, 1994). After training, 10 sensory attributes that best described the flavor (cooked, rancid, nutty, cereal/bran, pop-corn, bland), taste (bitter), and texture (hardness, tooth pack, crispness) of the extrudates were determined by the panelists and the extrudates were compared with eachother regarding the noted properties (Table 5). Among them, the difference between the samples regarding cooked, nutty, popcorn, cereal / bran flavors were insignificant ($p > 0.05$).

Fellows (2017) stated that cooked flavors may not be produced at high temperature short time conditions in extrusion cooking. Flavors may be produced by Maillard reactions at suitable extrusion conditions, but added flavors are volatilized when the extrudate emerges from the exit-die. Therefore, additional processes may be required to enhance flavor and color. For instance, it has been reported that breakfast cereals are toasted after extrusion, to caramelize sugars, to introduce flavors and to obtain a darker color (Fellows 2017).

On the other hand, either rancid flavor or bitter taste scores of the extrudates which were made of unprocessed IRGF was significantly higher than that of the extrudates made of IR stabilized IRGF ($p < 0.05$). Similarly, the noted attributes of the samples which were made of unprocessed IRGF and extruded at 130 °C, were higher than that of the samples extruded at 150 °C. However, the effect of exit-die temperature was insignificant on either rancid flavor or bitter taste scores of the extrudates which were made of IR stabilized IRGF ($p > 0.05$). These results

Table 5 Results of descriptive sensory analysis and instrumental texture scores

Extrusion conditions			Descriptive Sensory Attributes										Instrumental texture properties		
Raw material	Barrel temperature (°C)	Feed moisture (%)	Cooked	Rancid	Nutty	Cereal/bran	Popcorn	Bland	Bitter	Hardness	Tooth pack	Crispness	Hardness (g)	Adhesiveness (mJ)	Fracturability (g)
Unprocessed	130	16	7.4	1.0^{AB}	2.9	6.7	7.5	2.6^{B}	0.6^{A}	6.5^{BC}	13.1^{AB}	13.8	1495.1 ± 28.8^{BC}	0.11 ± 0.01	508.9 ± 20.5
immature		18	7.5	1.4^{A}	3.0	7.4	6.6	2.9^{AB}	1.0^{A}	8.7^{AB}	13.8^{AB}	14.1	1313.1 ± 94.8^{BC}	0.11 ± 0.01	489.1 ± 13.4
rice grain		20	7.5	0.6^{AB}	2.6	6.7	6.3	3.5^{AB}	0.5^{AB}	10.6^{A}	14.4^{A}	13.6	3643.0 ± 485.0^{A}	0.20 ± 0.03	601.9 ± 78.2
	150	16	7.5	0.2^{B}	2.6	6.5	7.1	3.6^{AB}	0.0^{B}	6.4^{BC}	12.8^{B}	14.3	1141.0 ± 49.8^{C}	0.10 ± 0.01	576.5 ± 26.4
		18	7.3	1.0^{AB}	3.0	6.3	7.0	3.7^{AB}	0.4^{AB}	6.8^{BC}	13.4^{AB}	13.5	1338.9 ± 21.2^{BC}	0.15 ± 0.01	535.9 ± 18.9
		20	7.8	0.7^{AB}	3.1	6.6	6.7	3.7^{AB}	0.4^{AB}	7.9^{ABC}	13.3^{AB}	13.5	1688.1 ± 57.4^{BC}	0.15 ± 0.02	590.4 ± 57.7
IR stabilized	130	16	7.9	0.4^{AB}	2.9	6.4	6.6	4.1^{A}	0.0^{B}	7.6^{ABC}	13.9^{AB}	14.0	1136.0 ± 61.8^{C}	0.17 ± 0.04	488.9 ± 58.0
immature		18	7.6	0.8^{AB}	2.5	7.2	6.4	3.5^{AB}	0.5^{AB}	10.0^{A}	13.9^{AB}	14.1	1442.0 ± 111.0^{BC}	0.13 ± 0.02	499.6 ± 17.6
rice grain		20	7.6	1.1^{AB}	2.9	6.8	6.3	3.6^{AB}	0.7^{AB}	12.6^{A}	13.7^{AB}	13.8	1992.0 ± 103.0^{B}	0.18 ± 0.03	496.1 ± 21.5
	150	16	7.6	0.2^{B}	2.4	6.1	6.6	3.8^{AB}	0.0^{B}	6.1^{BC}	13.1^{AB}	14.5	1192.1 ± 64.0^{C}	0.18 ± 0.01	552.6 ± 27.4
		18	7.6	0.7^{AB}	3.2	6.6	6.9	3.7^{AB}	0.4^{AB}	6.5^{BC}	13.8^{AB}	13.7	1000.4 ± 73.1^{C}	0.13 ± 0.03	498.1 ± 13.1
		20	7.9	0.1^{B}	2.5	6.5	7.2	3.4^{AB}	0.0^{B}	6.0^{C}	13.0^{AB}	14.4	995.5 ± 70.3^{C}	0.11 ± 0.04	511.4 ± 22.5
p			0.476	0.003	0.471	0.170	0.374	0.020	0.000	0.000	0.009	0.688	0.000	0.100	0.305

*For instrumental texture results, means followed by different capital letters in the same column are significantly different by Tukey ($p < 0.05$)

**For descriptive sensory results, means followed by different capital letters in the same column are significantly different by Dunn's test ($p > 0.05$)

show that extrusion process (at the noted conditions) alone was not intense enough to prevent rancidity in IRGF. Lipase activity is mainly responsible from the formation of free fatty acids which in turn resulted in rancid flavor and soapy taste. Yılmaz et al. (2018) showed that IRGF is very susceptible to rancidity and free fatty content of unprocessed IRGF increased from 5.49 to 35.71% in 3 months of storage at room temperature. Therefore, stabilization procedure is essential in order to use IRGF as a food ingredient especially for sensorial acceptability. Besides, it should be noted that either rancid or bitter scores of the panelists were below 1 on the 15-point hedonic scale (Table 5). The extent of rancidity is strongly associated with the time passed between rice milling and stabilization. The immature rice grains used in this study were freshly milled and immediately stabilized. Moreover, unprocessed IRGF was also in fresh state before extrusion. Otherwise, extrudates would have been more rancid or bitter, since lipid degradation starts immediately after milling and acceleration of free fatty acids and rancidity occurs especially in the first 15 days followed by milling (Yılmaz et al. 2014a, 2018).

Among flavor attributes, bland flavor was also more predominant in extrudates made of IR stabilized IRGF when compared to those made of unprocessed IRGF ($p < 0.05$). The highest bland score was given for the sample which was made of IR stabilized IRGF extruded at 130 °C and 16% of feed moisture.

The effect of the type of raw material was insignificant on all sensorial texture scores namely hardness, toothpack, and crispness ($p > 0.05$). Hardness scores of the samples which were extruded at 130 °C was higher than that of the samples extruded at 150 °C. Additionally, hardness decreased with decreasing feed moisture content. These findings are in accordance with the instrumental hardness results. Similarly, toothpack scores of the samples extruded at 130 °C was higher than that of the samples extruded at 150 °C ($p < 0.05$), while neither the effect of the type of raw material nor the effect of feed moisture was significant on toothpack ($p > 0.05$).

Toothpack, which was defined as the amount of sample packed in between molars after swallowing, was the most dominant sensory attribute in extrudates, since the scores of the panelists ranged between 12.8 and 14.4 on the 15-point hedonic scale. Although crispness in one commodity may not mean the same in terms of textural quality as crispness in another, for instance crispness in potato chips and crispness in nuts, crispness is generally defined as the quality of fracturing into many small pieces under compressive pressure and associated with brittleness (Mallikarjunan 2004). The effects of type of raw material, exit-die temperature and feed moisture were insignificant on crispness scores of the extrudates ($p > 0.05$). Furthermore, no consistent variation trend was observed for crispness regarding extrusion conditions.

Instrumental texture results

Instrumental texture results were presented on Table 5 along with the descriptive sensory analysis results. Hardness is one of the most used quality criteria for extruded snacks. Hardness of the extrudates which were made of unprocessed IRGF was higher than that of the extrudates made of IR stabilized IRGF ($p < 0.05$). This result might be related with gelatinization of starch during IR stabilization process. Gat and Ananthanarayan (2015) investigated the effect of pregelatinized rice flour and extrusion conditions on the physicochemical properties of expanded snacks and found that use of pregelatinized rice flour decreased hardness of the extrudates. The authors pregelatinized rice before extrusion at temperatures ranged between 80 and 120 °C and found that hardness of the pretreated rice flour extrudates decreased as the extent of the gelatinization increased, while uncooked rice flour extrudates showed maximum hardness. Moreover, samples extruded at 130 °C showed harder texture compared to the samples extruded at 150 °C especially when the feed moisture content is high. Hardness is also notably associated with expansion behavior of the extrudates. As discussed above, samples which were extruded at higher exit-die temperature with a lower feed moisture had significantly higher expansion index which is inversely proportional with hardness. In other words, the higher the expansion index, the lower the hardness. Gat and Ananthanarayan (2015) also showed a significant and negative correlation ($R = -0.908$, $p < 0.01$) between expansion and hardness in extruded rice-based snacks.

Adhesiveness and fracturability results ranged between 0.11–0.20 mJ and 488–601 g, respectively. The effects of type of raw material, exit-die temperature and feed moisture and their interactions were insignificant on adhesiveness and fracturability of the extrudates ($p > 0.05$).

Conclusion

Use of IRGF either “as it is” (unprocessed) or in IR stabilized form in extruded snack production was evaluated on several counts from physico-chemical, nutritional, sensorial and textural perspectives. It can be concluded that IRGF, which is a by-product of paddy milling process and generally evaluated as “feed” has the potential of being used as a nutritious “food” ingredient in extruded snack production. This under-valued by-product of milling process has superiorities over many other agricultural by-products since it comprises remarkable amounts of

bioactive compounds such as dietary fiber, tocopherols and γ-oryzanol due to being whole grain. Moreover, IRGF has a hidden potential of being used in gluten-free foods in place of broken rice or white rice. However, extrusion process conditions should be optimized, and / or additional precautions should be taken in order to prevent rancidity, minimize nutrient loss, and enhance flavor.

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