# Textural and Sensory Characteristics of Extruded Corn Snacks with the Addition of Zinc- and Selenium-Biofortified Wheat

# Teksturalna i senzorska svojstva ekstrudiranih kukuruznih snack proizvoda s dodatkompčenice obogaćane cinkom i selenom

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# TEXTURAL AND SENSORY CHARACTERISTICS OF EXTRUDED CORN SNACKS WITH THE ADDITION OF ZINC- AND SELENIUM-BIOFORTIFIED WHEAT

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**SUMMARY**

***The aim of this paper was to investigate the influence of Zn- and Se-fortified wheat flour addition to the corn grits at 90:10, 80:20, 70:30, 60:40 ratios on the hardness, fracturability, expansion ratio, bulk density, color, and sensory attributes of the extrudates. Extrusion was performed at three temperature profiles: 140/170/170 °C, 150/180/180 °C, and 160/190/190 °C. With an increase in the proportion of Zn- and Se- fortified wheat flour and temperature increase, all observed physical characteristics of extrudates decreased. The lightness of all the samples increased after the extrusion. The total color change increased with the addition of Zn- and Se-fortified wheat flour. Sensory characteristics showed that the samples with a lower percentage of added Zn- and Se-fortified wheat flour had better scores and acceptability, compared to the samples with a higher fortification ratio.***

***Keywords: extrusion, corn, fortified wheat, Zn, Se, texture, color, sensory attributes***

## INTRODUCTION

The extrusion process is mostly implemented to produce the snacks that are based on the cereal flour or starch. Corn grits are a major raw material for the production of extruded snack due to their high starch content, conditioning a good expansion characteristic to a ready-to-eat product (O'Shea et al., 2013). Cereals are the basis of the diet of a large part of the world's population, which is deficient in terms of nutrition due to the lack of zinc (Zn) and other essential nutrients. The occurrence of Zn deficiency in human nutrition is present in all world populations and is estimated to affect more than a quarter of the world population (Maret and Sandstead, 2006). One of the main reasons for the widespread occurrence of Zn deficiency in humans in the developing countries is a diet consisting of a high proportion of foods low in Zn (Gibson, 2006). Cereal biofortification is a potential solution to compensate for the lack of essential elements in human nutrition, as it represents the process of developing plants that have an increased content of bioavailable nutrients in their edible parts (Palmgren et al., 2008). The enrichment of food ingredients with a high content of Zn and selenium (Se) is also an effective way of achieving sufficient quantities on a daily basis (Tangjaidee et al., 2019). Many studies show the positive results of consumption of fortified cereals on micronutrient intakes in the diets of adults and children (Barr et al., 2013; Serra-Majem, 2001; Fulgoni and Buckley, 2015). In order to obtain the extrusion products

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with a good expansion rate, it is necessary to optimize some extrusion parameters (Huang and Liang, 2019).

Barrel temperature of the extruder and mixing ratio had an effect on the physical and sensory properties of cassava extruded snacks (Tumwine and Asiimwe, 2019). The obtained results of other studies also show the influence of different parameters on the sensory and textural characteristics of extruded products (Shirazi et al., 2020; Korkerd et al., 2016; Maskus and Arntfield, 2015).

The objective of this research was to investigate the influence of Zn- and Se-fortified wheat flour addition to the corn grits on textural and sensory attributes of expanded snacks produced at different extrusion conditions, which is a basic precondition for the acceptance of new products by consumers.

## MATERIAL AND METHODS

Corn grits (produced 2016) were obtained from the Žito Ltd, Osijek. Zn- and Se-fortified wheat (harvest 2015) was obtained from the Faculty of Agrobiotechnical Sciences Osijek. Wheat samples were ground by IKA MF 10 mill (Ika-Werke GmbH & Co., Germany) with a 2.0 mm sieve. Chemical compositions of raw materials were determined according to the standard methods for moisture content (ISO 6540), protein (ISO 5983-2), fat (ISO 6492) and ash (ISO 5984), while the carbohydrate contents were calculated by difference (Ačkar et al., 2018).

### Sample preparation

Corn grits were mixed with Zn- and the Se-fortified wheat flours in the same proportions, as follows: 90:10 80:20, 70:30, 60:40. After setting the total moisture of the mixtures to 15%, the mixtures were placed in the plastic bags and stored for 24 h at 4 °C, then brought to the room temperature prior to the extrusion. The extrusion was performed using a laboratory single-screw extruder (Brabender 19/20 DN, Duisburg, Germany). Extrusion parameters were as follows: temperature profiles: 140/170/170 °C, 150/180/180 °C; and 160/190/190 °C; screw compression ratio: 4:1; screw speed: 100 rpm; feed rate: 15 rpm. The extrudates were air-dried at ambient temperature and stored up to the analysis.

### Hardness and fracturability determination

The hardness and fracturability of extrudates were determined by the texture analyzer (TA.XT2Plus) and the *Texture Exponent 32* software (both from Stable Micro Systems, Godalming, United Kingdom), using the cut test by a Warner-Bratzler shear blade with the guillotine probe (Paula and Conti-Silva, 2014). The following settings were applied: Pre-Test Speed: 1.0 mm/s; Test Speed: 1.0 mm/s; Post-Test Speed: 10.0 mm/s; Distance: 30 mm, with standardization of samples to 3 mm length. The results were expressed as a mean value of the ten measurements for each sample.

### Expansion ratio

Expansion ratio (ER) was calculated according to Brnčić et al. (2008), as follows:

$$ER = \text{extrudate diameter (mm)/die diameter (mm)} \quad (1)$$

The results were expressed as a mean value of five measurements for each sample.

### Bulk density

Bulk density (BD) was determined according to method of Alvarez-Martinez et al. (1988):

$$BD\ (g/cm^3) = 4\ m/\varpi d^2 L \quad (2)$$

where *m* is mass (g) of a length *L* (cm) of extrudate with a diameter *d* (cm).

The results were expressed as a mean value of five measurements for each sample.

### Color

The color of non-extruded and extruded (milled) samples was measured according to Jozinović et al. (2016) using a Chroma Meter CR-400 (Konica Minolta, Japan) with a granular materials attachment and the measuring head with 2° observer and illuminant C. The instrument was calibrated using a white standard calibration plate, and the color was expressed by the CIE-Lab parameters as L* (whiteness/darkness), a* (redness/greenness), and b* (yellowness/ blueness). The total color change (ΔE) was calculated as follows:

$$\Delta E = \sqrt{(L - L_0)^2 + (b - b_0)^2 + (a - a_0)^2} \quad (3)$$

Subscript ‘0’ indicates initial color values of the corn grits. For each sample, five measurements were taken, and the results were expressed as a mean value.

### Sensory analysis

Sensory evaluation was performed according to the ISO 4121 guidelines by a panel comprised of ten trained panelists in the Sensory Analysis Laboratory of the Karolina Ltd. Osijek factory. Sensory evaluation of external appearance (uniformity, color), structure (porosity, crispness), consistency (chewing), odor, flavor, and overall quality was performed on the following samples: a control sample of corn grits, the samples with 10, 20, 30, and 40% of added Zn, and the Se-fortified wheat flour. The results were presented as the mean value calculated by the ten trained panelists.

### Experimental design and data analysis

Statistical significance of the regression coefficients was determined by analysis of variance (ANOVA), at 95% level. Sensory attribute results were analyzed by the *Statistica 13* software (StatSoft Inc., USA), using post hoc LSD at 95% level.

## RESULTS AND DISCUSSION

Observing the results of the chemical composition of raw materials (Table 1), it can be stated that Zn wheat and Se wheat have a significantly higher protein content (14.28 ± 0.76 and 12.00 ± 1.00) when compared to the corn grits (8.29 ± 0.13), as well as a higher ash content (1.90 ± 0.07 and 1.89 ± 0.00) when compared to the corn grits (0.18 ± 0.01).

**Table 1. Chemical compositions of raw materials.**

*Tablica 1. Kemijski sastav sirovina.*

| Sample / *Uzorak* | Moisture / *Vlažnost* (%) | Ash / *Pepeo* (%) | Fat / *Masti* (%) | Protein / *Proteini* (%) | Raw carbohydrates / *Sirovi ugljikohidrati* (%) |
|---|---|---|---|---|---|
| Corn grits | 11.94 ± 0.06 [c] | 0.18 ± 0.01 [a] | 1.69 ± 0.05 [b] | 8.29 ± 0.13 [a] | 89.85 |
| Wheat Zn | 7.17 ± 0.10 [b] | 1.90 ± 0.07 [b] | 1.66 ± 0.029 [a] | 14.28 ± 0.76 [b] | 82.17 |
| Wheat Se | 8.60 ± 0.24 [a] | 1.89 ± 0.00 [b] | 1.45 ± 0.02 [b] | 12.00 ± 1.00 [b] | 84.67 |
| Values with different letters in the same column are significantly different ($p < 0.05$)<br>*Vrijednosti s različitim slovima u stupcima statistički se značajno razlikuju ($p < 0,05$)* | | | | | |

Tables 2 and 3 show the results of the expansion ratio (EO) and bulk density (BD), as well as the hardness and fracturability of the extruded products. Analyzing the results, it can be seen that the hardness of the extrudates decreases with an increasing temperature of the extrusion, both in the case of corn grits and in the case of samples with different proportions of added Zn and Se-fortified wheat. Similarity was observed by Obradović et al. (2018), who found that extrudates obtained at higher temperatures have lower hardness at different levels of carrot powder and ascorbic acid. The high puncture force associated with the low extrusion temperatures is due to the fact that a proportion of the starch is not completely gelatinized resulting in a dense and hard product (Tumwine and Asiimwe, 2019). A decrease in hardness with an increase in temperature is related to a higher expansion at elevated temperatures (Kumar et al., 2010). Feed moisture content and barrel temperature were found to have the most significant effect on the extrudate expansion, bulk density, and hardness. Gelatinization, molecular degradation, and/or reassociation during extrusion influence the final textural and functional properties of the product (Korkerd et al., 2016). Observing the individual extrusion temperatures, it was found that the hardness of the extrudate increases with an increasing Zn and Se-fortified wheat content, at all three observed temperatures. Similarity was observed by Maskus and Arntfield (2015) during the extrusion of pea snack products and by Tumwine and Asiimwe (2019) during the extrusion of cassava snacks. Nevertheless, it is known that the addition of different ingredients with a higher protein and fiber content increases the hardness of the extrudates, it cannot be generalized (Ačkar et al., 2018). So, Obradović et al. (2018) and Huang and Liang (2019) have found that hardness of the extrudate decreases by supplementing with different additives.

According to the results for the hardness of the extrudates, the fracturability also decreases with an increasing extrusion temperature and increasing flour content. The results of reducing the fracturability were also reported by Jozinović et al. (2017), whereby the increase in the content of the defatted hemp cake reduced the fracturability of extrudates. Similarity was reported by Obradović et al. (2018) and Shruthi et al. (2019), whereby a decrease in extrudates fracturability was also observed with an increasing extrusion temperature.

Expansion ratio of extruded products decreased with an increase of temperature and Zn- and Se-fortified wheat ratio. The decrease in expansion of blends may be manifested due to an increase in the protein content, resulting in a decrease in the amount of starch, because the protein does not expand as extensively as the starch (Yagci and Gogus, 2009). The other authors have also reported a similar trend. Increasing the proportion of pumpkin flour decreased the expansion ratio of the extruded pellets (Norfezah et al., 2013). Maskus and Arntfield (2015) found that the expansion ratio of puffed pea snack product was increasing with a decrease in temperature. Ačkar et al. (2018) found that the expansion ratio decreased proportionally to the quantity of added by-products, with a slightly stronger impact with the addition of brewer's spent grain and the least impact with the apple pomace addition.

**Table 2. The effect of Zn-fortified wheat addition on expansion ratio, bulk density, and texture properties of corn extrudates**

*Tablica 2. Utjecaj dodatka pšenice obogaćene Zn na ekspanzijski omjer, nasipnu gustoću i teksturalne karakteristike kukuruznih ekstrudata*

| Sample / *Uzorak* | Expansion ratio / *Ekspanzijski omjer* | Bulk density / *Nasipna masa* (gcm$^{-3}$) | Hardness / *Tvrdoća* (N) | Fracturability / *Lomljivost* (mm) |
|---|---|---|---|---|
| Corn grits 170 °C | 3.06 ± 0.14 $^{d,e}$ | 0.13 ± 0.01 $^{d,e}$ | 3.27 ± 0.61 $^{f}$ | 9.44 ± 0.46 $^{e,f,g,h}$ |
| Corn grits 180 °C | 3.05 ± 0.16 $^{g}$ | 0.11 ± 0.01 $^{a,b,c}$ | 1.85 ± 0.39 $^{a}$ | 9.96 ± 0.37 $^{h}$ |
| Corn grits 190 °C | 2.96 ± 0.15 $^{e,f,g}$ | 0.11 ± 0.01 $^{a,b}$ | 2.00 ± 0.24 $^{a,b,c}$ | 9.38 ± 0.47 $^{e,f,g}$ |
| Corn:Wheat Zn 90:10 170 °C | 3.02 ± 0.14 $^{f,g}$ | 0.12 ± 0.01 $^{a,b,c,d}$ | 2.44 ± 0.51 $^{c,d}$ | 9.54 ± 0.77 $^{f,g,h}$ |
| Corn:Wheat Zn 90:10 180 °C | 2.88 ± 0.14 $^{b,c,d,e,f,g}$ | 0.12 ± 0.01 $^{a,b,c,d}$ | 2.38 ± 0.42 $^{c,d}$ | 9.13 ± 0.33 $^{d,e,f,g}$ |
| Corn:Wheat Zn 90:10 190 °C | 2.90 ± 0.07 $^{c,d,e,f,g}$ | 0.11 ± 0.01 $^{a}$ | 2.21 ± 0.39 $^{a,b,c}$ | 9.01 ± 0.60 $^{c,d,e,f}$ |
| Corn:Wheat Zn 80:20 170 °C | 2.95 ± 0.15 $^{d,e,f,g}$ | 0.13 ± 0.01 $^{d,e}$ | 2.15 ± 0.44 $^{a,b,c}$ | 9.66 ± 0.74 $^{g,h}$ |
| Corn:Wheat Zn 80:20 180 °C | 2.85 ± 0.20 $^{b,c,d.e.f}$ | 0.11 ± 0.02 $^{a}$ | 1.90 ± 0.23 $^{a,b}$ | 9.02 ± 0.46 $^{c,d,e,f}$ |
| Corn:Wheat Zn 80:20 190 °C | 2.83 ± 0.08 $^{a,b,c,d,e}$ | 0.11 ± 0.01 $^{a,b}$ | 2.09 ± 0.40 $^{a,b,c}$ | 8.38 ± 0.82 $^{a,b}$ |
| Corn:Wheat Zn 70:30 170 °C | 2.66 ± 0.06 $^{a}$ | 0.16 ± 0.02 $^{f}$ | 2.77 ± 0.42 $^{d,e}$ | 8.60 ± 0.60 $^{a,b,c,d}$ |
| Corn:Wheat Zn 70:30 180 °C | 2.81 ± 0.16 $^{a,b,c,d,e}$ | 0.13 ± 0.01 $^{c,d,e}$ | 2.41 ± 0.42 $^{c,d}$ | 8.90 ± 0.70 $^{b,c,d,e}$ |
| Corn:Wheat Zn 70:30 190 °C | 2.71 ± 0.08 $^{a,b}$ | 0.12 ± 0.01 $^{b,c,d}$ | 2.14 ± 0.35 $^{a,b,c}$ | 8.50 ± 0.45 $^{a,b,c}$ |
| Corn:Wheat Zn 60:40 170 °C | 2.76 ± 0.11 $^{a,b,c}$ | 0.14 ± 0.01 $^{e}$ | 2.87 ± 0.43 $^{e}$ | 8.25 ± 0.49 $^{a}$ |
| Corn:Wheat Zn 60:40 180 °C | 2.78 ± 0.05 $^{a,b,c,d}$ | 0.12 ± 0.002 $^{b,c,d}$ | 2.33 ± 0.64 $^{b,c}$ | 8.59 ± 0.75 $^{a,b,c,d}$ |
| Corn:Wheat Zn 60:40 190 °C | 2.71 ± 0.06 $^{a,b}$ | 0.13 ± 0.01 $^{d,e}$ | 2.27 ± 0.36 $^{a,b,c}$ | 8.20 ± 0.34 $^{a}$ |

Values with different letters in the same column are significantly different ($p < 0.05$)
170 °C – extrusion temperature profile: 140/170/170 °C; 180 °C – extrusion temperature profile: 150/180/180 °C;
190 °C – extrusion temperature profile: 160/190/190 °C
*Vrijednosti s različitim slovima u stupcima statistički se značajno razlikuju ($p < 0,05$)*
*170 °C – temperaturni profil ekstruzije: 140/170/170 °C; 180 °C – temperaturni profil ekstruzije: 150/180/180 °C; 190 °C – temperaturni profil ekstruzije: 160/190/190 °C*

**Table 3. The effect of Se-fortified wheat addition on expansion ratio, bulk density, and texture properties of corn extrudates**

*Tablica 3. Utjecaj dodatka pšenice obogaćene Se na ekspanzijski omjer, nasipnu gustoću i teksturalne karakteristike kukuruznih ekstrudata*

| Sample / *Uzorak* | Expansion ratio / *Ekspanzijski omjer* | Bulk density / *Nasipna masa* (gcm$^{-3}$) | Hardness / *Tvrdoća* (N) | Fracturability / *Lomljivost* (mm) |
|---|---|---|---|---|
| Corn grits 170 °C | 3.06 ± 0.14 $^{d,e}$ | 0.13 ± 0.01 $^{c,d,e}$ | 3.27 ± 0.61 $^{g}$ | 9.44 ± 0.46 $^{c,d}$ |
| Corn grits 180 °C | 3.05 ± 0.16 $^{d,e}$ | 0.11 ± 0.01 $^{a,b}$ | 1.85 ± 0.39 $^{a,b}$ | 9.96 ± 0.37 $^{e}$ |
| Corn grits 190 °C | 2.96 ± 0.15 $^{b,c,d}$ | 0.11 ± 0.01 $^{a,b}$ | 2.00 ± 0.24 $^{a,b,c}$ | 9.38 ± 0.47 $^{c,d}$ |
| Corn:Wheat Se 90:10 170 °C | 3.15 ± 0.26 $^{e}$ | 0.11 ± 0.02 $^{a}$ | 2.79 ± 0.52 $^{e,f}$ | 9.23 ± 0.48 $^{c,d}$ |
| Corn:Wheat Se 90:10 180 °C | 2.84 ± 0.08 $^{a,b,c}$ | 0.11 ± 0.01 $^{a}$ | 1.79 ± 0.28 $^{a}$ | 9.42 ± 0.54 $^{c,d}$ |
| Corn:Wheat Se 90:10 190 °C | 2.83 ± 0.10 $^{a,b}$ | 0.11 ± 0.01 $^{a,b}$ | 2.05 ± 0.44 $^{a,b,c,d}$ | 8.47±0.52 $^{a}$ |
| Corn:Wheat Se 80:20 170 °C | 3.03 ± 0.16 $^{c,d,e}$ | 0.12 ± 0.01 $^{a,b,c}$ | 2.28 ± 0.53 $^{c,d}$ | 9.54 ± 0.70 $^{d,e}$ |
| Corn:Wheat Se 80:20 180 °C | 2.71 ± 0.12 $^{a}$ | 0.11 ± 0.01 $^{a,b}$ | 2.01 ± 0.37 $^{a,b,c,d}$ | 8.59 ± 0.63 $^{a,b}$ |
| Corn:Wheat Se 80:20 190 °C | 2.68 ± 0.11 $^{a}$ | 0.13 ± 0.01 $^{b,c,d}$ | 2.26 ± 0.39 $^{b,c,d}$ | 8.43 ± 0.36 $^{a}$ |
| Corn:Wheat Se 70:30 170 °C | 2.79 ± 0.07 $^{a,b}$ | 0.11 ± 0.01 $^{e}$ | 2.43 ± 0.31 $^{d,e}$ | 9.13 ± 0.43 $^{c,d}$ |
| Corn:Wheat Se 70:30 180 °C | 2.87 ± 0.13 $^{a,b,c,d}$ | 0.12 ± 0.01 $^{a,b,c}$ | 2.13 ± 0.35 $^{a,b,c,d}$ | 9.13 ± 0.52 $^{c,d}$ |
| Corn:Wheat Se 70:30 190 °C | 2.73 ± 0.11 $^{a}$ | 0.12 ± 0.01 $^{a,b,c}$ | 2.13 ± 0.40 $^{a,b,c,d}$ | 8.54 ± 0.42 $^{a,b}$ |
| Corn:Wheat Se 60:40 170 °C | 2.81 ± 0.03 $^{a,b}$ | 0.14 ± 0.005 $^{d,e}$ | 2.94 ± 0.40 $^{f,g}$ | 8.33 ± 0.34 $^{a}$ |
| Corn:Wheat Se 60:40 180 °C | 2.84 ± 0.17 $^{a,b,c}$ | 0.12 ± 0.02 $^{a,b,c}$ | 1.82 ± 0.31 $^{a}$ | 8.99 ± 0.78 $^{b,c}$ |
| Corn:Wheat Se 60:40 190 °C | 2.75 ± 0.07 $^{a}$ | 0.12 ± 0.004 $^{a,b,c}$ | 2.38 ± 0.53 $^{c,d}$ | 8.10 ± 0.52 $^{a}$ |

Values with different letters in the same column are significantly different ($p < 0.05$)
170 °C – extrusion temperature profile: 140/170/170 °C; 180 °C – extrusion temperature profile: 150/180/180 °C;
190 °C – extrusion temperature profile: 160/190/190 °C
*Vrijednosti s različitim slovima u stupcima statistički se značajno razlikuju ($p < 0,05$)*
*170 °C – temperaturni profil ekstruzije: 140/170/170 °C; 180 °C – temperaturni profil ekstruzije: 150/180/180 °C; 190 °C – temperaturni profil ekstruzije: 160/190/190 °C*

Similar to other physical characteristics, bulk density also showed a decrease in value with increasing temperature and ratio of added Zn and Se-fortified wheat flour. The bulk density of the distillers dried grains with the soluble (DDGS) extrudates decreased as the temperature and screw speed of the extruder increased due to a greater expansion (Foley and Rosentrater, 2013). The response of expansion property on the barrel temperature is relative to the saturated vapor pressure and viscosity of extrudate during extrusion. A low bulk density product was obtained with a high temperature and a low screw speed. An increase in starch gelatinization with an increasing temperature resulted in an increase in volume and a decrease in the bulk density of extrudate (Ma et al., 2012). A lower bulk density is generally more desirable considering that it indicates a lighter, crisper final product (Maskus and Arntfield, 2015).

The Tables 4 and 5 show the effect of Zn and Se-fortified wheat addition on color properties of extruded products. With the addition of Zn and Se-fortified wheat flour to corn grits the lightness (L*) values decreased. The reason for this is that we used the flour from whole wheat grain in our study. The extrusion process caused the increase of lightness values in all samples. It is known that the main reasons which cause the color change during extrusion included Maillard reactions, caramelization, hydrolysis, and pigment degradation (Ačkar et al., 2018).

**Table 4. The effect of extrusion process and Zn-fortified wheat addition on color properties**

*Tablica 4. Utjecaj procesa ekstruzije i dodatka pšenice obogaćene Zn na promjenu boje*

| **Sample** / ***Uzorak*** | **Non-extruded samples** / ***Neekstrudirani uzorci*** | | | |
|---|---|---|---|---|
| | **L*** | **a*** | **b*** | **ΔE** |
| Corn grits | 64.92 ± 0.02 d | 1.47 ± 0.20 c | 36.13 ± 0.81 d | |
| Corn:Wheat Zn 90:10 | 62.56 ± 0.12 c | 1.45 ± 0.07 c | 34.30 ± 0.17 c | 2.99 |
| Corn:Wheat Zn 80:20 | 60.33 ± 0.49 b | 0.85 ± 0.18 a | 28.15 ± 0,.9 b | 9.23 |
| Corn:Wheat Zn 70:30 | 60.66 ± 0.17 b | 1.12 ± 0.16 b | 28.70 ± 0.53 b | 8.58 |
| Corn:Wheat Zn 60:40 | 59.55 ± 0.43 a | 1.04 ± 0.25 a,b | 23.29 ± 0.22 a | 13.93 |
| **Sample** / ***Uzorak*** | **Extruded 170 °C** / ***Ekstrudirani 170 °C*** | | | |
| | **L*** | **a*** | **b*** | **ΔE** |
| Corn grits | 65.09 ± 0.29 e | -2.45 ± 0.09 a | 35.34 ± 0.28 e | 4.00 |
| Corn:Wheat Zn 90:10 | 63.33 ± 0.20 d | -2.04 ± 0.05 b | 30.98 ± 0.08 d | 6.43 |
| Corn:Wheat Zn 80:20 | 62.18 ± 1.28 c | -1.33 ± 0.13 c | 27.05 ± 0.09 c | 9.89 |
| Corn:Wheat Zn 70:30 | 57.38 ± 0.13 a | -0.23 ± 0.07 d | 24.45 ± 0.25 b | 14.01 |
| Corn:Wheat Zn 60:40 | 59.69 ± 0.17 b | 0.06 ± 0.09 e | 20.84 ± 0.49 a | 16.22 |
| **Sample** / ***Uzorak*** | **Extruded 180 °C** / ***Ekstrudirani 180 °C*** | | | |
| | **L*** | **a*** | **b*** | **ΔE** |
| Corn grits | 64.43 ± 0.23 d | -2.58 ± 0.06 a | 35.07 ± 0.10 e | 4.22 |
| Corn:Wheat Zn 90:10 | 64.95 ± 0.11 e | -2.54 ± 0.04 a | 31.52 ± 0.22 d | 6.11 |
| Corn:Wheat Zn 80:20 | 61.88 ± 0.03 b | -1.25 ± 0.09 b | 26.75 ± 0.23 c | 10.23 |
| Corn:Wheat Zn 70:30 | 62.38 ± 0.07 c | -1.89 ± 0.09 c | 25.30 ± 0.17 b | 11.62 |
| Corn:Wheat Zn 60:40 | 59.16 ± 0.09 a | -0.67 ± 0.10 d | 21.29 ± 0.10 a | 16.07 |
| **Sample** / ***Uzorak*** | **Extruded 190 °C** / ***Ekstrudirani 190 °C*** | | | |
| | **L*** | **a*** | **b*** | **ΔE** |
| Corn grits | 67.15 ± 0.16 e | -2.52 ± 0.04 a | 34.51 ± 0.16 e | 4.86 |
| Corn:Wheat Zn 90:10 | 63.70 ± 0.52 d | -2.11 ± 0.12 b | 30.27 ± 0.06 d | 6.97 |
| Corn:Wheat Zn 80:20 | 63.08 ± 0.41 c | -1.53 ± 0.13 c | 23.16 ± 0.27 b | 13.43 |
| Corn:Wheat Zn 70:30 | 62.27 ± 0.33 b | -1.42 ± 0.14 c | 25.89 ± 0.06 c | 10.96 |
| Corn:Wheat Zn 60:40 | 60.04 ± 0.26 a | -0.83 ± 0.03 d | 20.55 ± 0.10 a | 16.49 |

Values with different letters in the same column are significantly different ($p < 0.05$)
170 °C – extrusion temperature profile: 140/170/170 °C; 180 °C – extrusion temperature profile: 150/180/180 °C; 190 °C – extrusion temperature profile: 160/190/190 °C
*Vrijednosti s različitim slovima u stupcima statistički se značajno razlikuju ($p < 0,05$)*
*170 °C – temperaturni profil ekstruzije: 140/170/170 °C; 180 °C - temperaturni profil ekstruzije: 150/180/180 °C; 190 °C – temperaturni profil ekstruzije: 160/190/190 °C*

**Table 5. The effect of extrusion process and Se-fortified wheat addition on color properties**

*Tablica 5. Utjecaj procesa ekstruzije i dodatka pšenice obogaćene Se na promjenu boje*

| **Sample /** ***Uzorak*** | **Non-extruded samples /** ***Neekstrudirani uzorci*** | | | |
|---|---|---|---|---|
| | **L*** | **a*** | **b*** | **ΔE** |
| Corn grits | 64.92 ± 0.02 [d] | 1.47 ± 0.20 [c] | 36.13 ± 0.81 [d] | |
| Corn:Wheat Se 90:10 | 62.81 ± 0.20 [d] | 1.70 ± 0.18 [b] | 33.85 ± 0.94 [c] | 3.11 |
| Corn:Wheat Se 80:20 | 62.49 ± 0.18 [c] | 1.64 ± 0.10 [a,b] | 33.09 ± 0.15 [c] | 3.90 |
| Corn:Wheat Se 70:30 | 59.55 ± 0.24 [b] | 2.22 ± 0.15 [c] | 27.38 ± 0.43 [b] | 10.29 |
| Corn:Wheat Se 60:40 | 57.90 ± 0.24 [a] | 2.84 ± 0.14 [d] | 24.52 ± 0.39 [a] | 13.63 |
| **Sample /** ***Uzorak*** | **Extruded 170 °C /** ***Ekstrudirani 170 °C*** | | | |
| | **L*** | **a*** | **b*** | **ΔE** |
| Corn grits | 65.09 ± 0.29 [e] | -2.45 ± 0.09 [a] | 35.34 ± 0.28 [e] | 4.00 |
| Corn:Wheat Se 90:10 | 63.32 ± 0.25 [c] | -2.27 ± 0.09 [b] | 32.00 ± 0.32 [d] | 5.79 |
| Corn:Wheat Se 80:20 | 63.02 ± 0.12 [c] | -1.85 ± 0.13 [c] | 30.12 ± 0.12 [c] | 7.13 |
| Corn:Wheat Se 70:30 | 59.96 ± 0.44 [a] | -1.15 ± 0.18 [d] | 27.51 ± 0.23 [b] | 10.28 |
| Corn:Wheat Se 60:40 | 61.59 ± 0.05 [b] | -1.12 ± 0.07 [d] | 24.41 ± 0.08 [a] | 12.45 |
| **Sample /** ***Uzorak*** | **Extruded 180 °C /** ***Ekstrudirani 180 °C*** | | | |
| | **L*** | **a*** | **b*** | **ΔE** |
| Corn grits | 64.43 ± 0.23 [d] | -2.58 ± 0.06 [a] | 35.07 ± 0.10 [e] | 4.22 |
| Corn:Wheat Se 90:10 | 63.21 ± 0.12 [c] | -1.62 ± 0.05 [b] | 31.27 ± 0.09 [d] | 6.01 |
| Corn:Wheat Se 80:20 | 62.95 ± 0.37 [b,c] | -1.34 ± 0.11 [c] | 27.91 ± 0.36 [c] | 8.90 |
| Corn:Wheat Se 70:30 | 62.70 ± 0.21 [b] | -1.25 ± 0.13 [c] | 26.12 ± 0.11 [b] | 10.71 |
| Corn:Wheat Se 60:40 | 60.34 ± 0.40 [a] | -0.39 ± 0.10 [d] | 24.28 ± 0.28 [a] | 12.84 |
| **Sample /** ***Uzorak*** | **Extruded 190 °C /** ***Ekstrudirani 190 °C*** | | | |
| | **L*** | **a*** | **b*** | **ΔE** |
| Corn grits | 67.15 ± 0.16 [e] | -2.52 ± 0.04 [a] | 34.51 ± 0.16 [e] | 4.86 |
| Corn:Wheat Se 90:10 | 64.37 ± 0.15 [d] | -2.26 ± 0.05 [b] | 30.74 ± 0.07 [d] | 6.58 |
| Corn:Wheat Se 80:20 | 63.86 ± 0.25 [c] | -1.75 ± 0.18 [c] | 28.33 ± 0.11 [c] | 8.50 |
| Corn:Wheat Se 70:30 | 62.47 ± 0.47 [b] | -1.52 ± 0.16 [d] | 26.38 ± 0.27 [b] | 10.49 |
| Corn:Wheat Se 60:40 | 60.96 ± 0.44 [a] | -0.63 ± 0.11 [e] | 22.91 ± 0.13 [a] | 13.96 |

Values with different letters in the same column are significantly different ($p < 0.05$)
170 °C – extrusion temperature profile: 140/170/170 °C; 180 °C – extrusion temperature profile: 150/180/180 °C; 190 °C – extrusion temperature profile: 160/190/190 °C
*Vrijednosti s različitim slovima u stupcima statistički se značajno razlikuju ($p < 0,05$)*
*170 °C – temperaturni profil ekstruzije: 140/170/170 °C; 180 °C - temperaturni profil ekstruzije: 150/180/180 °C; 190 °C – temperaturni profil ekstruzije: 160/190/190 °C*

The results obtained for the redness/greenness (a*) indicated that all of the non-extruded samples—that is, both with Zn and with Se addition, as well as a sample of Corn:Wheat Zn 60:40 at 170 °C after extrusion, were in the domain of red color. Subsequent to the extrusion, these values decreased in all samples. The reason for the decrease of the a* values after the extrusion process could be the destruction of heat sensitive pigments. In all samples, the extrusion process caused the decrease of yellowness (b*) values. The total color change (ΔE), ranged from 4.00 for the extruded corn grits to 16.49 for the extruded mixture with 40% of Zn-fortified wheat and to 13.96 for 40% of Se-fortified wheat. Similarly, all extrusion parameters, such as the composition, moisture, screw speed, and barrel temperature, affected the color coordinates of corn-honey, whereas the apple-incorporated extrudates within the experimental range the barrel temperature and the screw speed were the most important factors for all analyzed properties of extrudates (Nissar et al., 2017).

**Table 6. Sensory evaluation results for tested parameters of extrudates with Zn-fortified wheat addition**

*Tablica 6. Rezultati senzorskoga ocjenjivanja ispitivanih parametara ekstrudata s dodatkom pšenice obogaćene Zn*

| **Sample /** ***Uzorak*** | **External appearance (uniformity, color) /** ***Vanjski izgled (ujednačenost, boja)*** | **Structure, porosity, crispness /** ***Struktura, poroznost, prhkost*** | **Consistency (chewing) /** ***Konzistencija (žvakanje)*** | **Odor /** ***Miris*** | **Flavor /** ***Okus*** |
|---|---|---|---|---|---|
| Corn grits 170 °C | 4.6 ± 0.52 [e] | 3.8 ± 0.71 [a,b,c] | 4.0 ± 0.76 [a,b,c] | 4.8 ± 0.46 [a,b] | 4.6 ± 0.52 [d,e] |
| Corn grits 180 °C | 4.5 ± 0.53 [d,e] | 4.5 ± 0.53 [c] | 4.4 ± 0.52 [c] | 4.9 ± 0.35 [b] | 4.8 ± 0.46 [e] |
| Corn grits 190 °C | 4.7 ± 0.49 [a,b,c,d,e] | 4.7 ± 0.53 [a,b,c] | 4.3 ± 0.76 [a,b,c] | 4.7 ± 0.49 [a,b] | 4.7 ± 0.49 [a,b.c.d.e] |
| Corn:Wheat Zn 90:10 170 °C | 4.3 ± 0.71 [b,c,d,e] | 3.5 ± 0.53 [a,b] | 3.6 ± 0.52 [a,b,c] | 4.6 ± 0.52 [a,b] | 4.1 ± 0.64 [a,b,c,d,e] |
| Corn:Wheat Zn 90:10 180 °C | 4.5 ± 0.53 [d,e] | 4.0 ± 0.53 [a,b,c] | 3.8 ± 0.71 [a,b,c] | 4.6 ± 0.52 [a,b] | 4.3 ± 0.71 [b.c.d.e] |
| Corn:Wheat Zn 90:10 190 °C | 4.4 ± 0.52 [c,d,e] | 4.4 ± 0.52 [b,c] | 4.1 ± 0.64 [a,b,c] | 4.6 ± 0.52 [a,b] | 4.4 ± 0.52 [c,d,e] |
| Corn:Wheat Zn 80:20 170 °C | 4.0 ± 0.53 [a,b,c,d,e] | 3.6 ± 0.52 [a,b,c] | 3.8 ± 0.71 [a,b,c] | 4.4 ± 0.74 [a,b] | 3.9 ± 0.83 [a,b,c,d,e] |
| Corn:Wheat Zn 80:20 180 °C | 4.3 ± 0.46 [b,c,d,e] | 4.3 ± 0.46 [b] | 4.3 ± 0.46 [b,c] | 4.5 ± 0.76 [a,b] | 4.0 ± 0.76 [a,b,c,d,e] |
| Corn:Wheat Zn 80:20 190 °C | 4.1 ± 0.38 [a,b,c,d] | 4.0 ± 0.58 [a,b,c] | 3.9 ± 0.69 [a,b] | 4.3 ± 0.76 [a] | 4.0 ± 0.82 [a,b,c] |
| Corn:Wheat Zn 70:30 170 °C | 3.5 ± 0.53 [a,b,c] | 3.3 ± 0.71 [a] | 3.3 ± 0.71 [a] | 4.1 ± 0.83 [a,b] | 3.5 ± 0.53 [a,b,c] |
| Corn:Wheat Zn 70:30 180 °C | 3.9 ± 0.64 [a,b,c,d,e] | 3.9 ± 0.64 [a,b,c] | 3.6 ± 0.52 [a,b,c] | 4.4 ± 0.52 [a,b] | 3.8 ± 0.46 [a,b,c,d] |
| Corn:Wheat Zn 70:30 190 °C | 3.8 ± 0.46 [a,b,c,d,e] | 3.9 ± 0.35 [a,b,c] | 4.0 ± 0.53 [a,b,c] | 4.4 ± 0.52 [a,b] | 3.9 ± 0.64 [a,b,c,d,e] |
| Corn:Wheat Zn 60:40 170 °C | 3.3 ± 0.46 [a] | 3.3 ± 0.71 [a] | 3.3 ± 0.71 [a,b] | 4.1 ± 0.83 [a,b] | 3.4 ± 0.52 [a,b] |
| Corn:Wheat Zn 60:40 180 °C | 3.6 ± 0.74 [a,b,c,d] | 3.6 ± 0.74 [a,b,c] | 3.8 ± 0.71 [a,b,c] | 4.0 ± 0.76 [a,b] | 3.5 ± 0.53 [a,b,c] |
| Corn:Wheat Zn 60:40 190 °C | 3.4 ± 0.52 [a,b] | 3.5 ± 0.93 [a,b] | 3.5 ± 0.76 [a,b,c] | 3.9 ± 0.64 [a,b] | 3.3 ± 0.71 [a] |

Values with different letters in the same column are significantly different ($p < 0.05$)
170 °C – extrusion temperature profile: 140/170/170 °C; 180 °C – extrusion temperature profile: 150/180/180 °C;
190 °C – extrusion temperature profile: 160/190/190 °C
*Vrijednosti s različitim slovima u stupcima statistički se značajno razlikuju ($p < 0,05$)*
*170 °C – temperaturni profil ekstruzije: 140/170/170 °C; 180 °C - temperaturni profil ekstruzije: 150/180/180 °C; 190 °C – temperaturni profil ekstruzije: 160/190/190 °C*

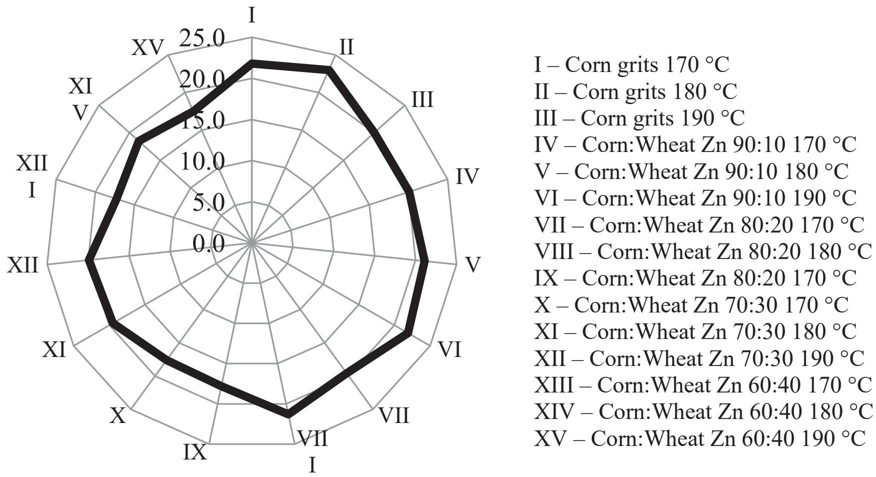
**Table 7. Sensory evaluation results for tested parameters of extrudates with Se-fortified wheat addition**

*Tablica 7. Rezultati senzorskoga ocjenjivanja ispitivanih parametara ekstrudata s dodatkom pšenice obogaćene Se*

| **Sample /** ***Uzorak*** | **External appearance (uniformity, color) /** ***Vanjski izgled (ujednačenost, boja)*** | **Structure, porosity, crispness /** ***Struktura, poroznost, prhkost*** | **Consistency (chewing) /** ***Konzistencija (žvakanje)*** | **Odor /** ***Miris*** | **Flavor /** ***Okus*** |
|---|---|---|---|---|---|
| Corn grits 170 °C | 4.6 ± 0.52 [c] | 3.8 ± 0.71 [a,b,c] | 4.0 ± 0.76 [a,b] | 4.8 ± 0.46 [a] | 4.6 ± 0.52 [b,c] |
| Corn grits 180 °C | 4.5 ± 0.53 [c] | 4.5 ± 0.53 [b,c] | 4.4 ± 0.52 [a,b] | 4.9 ± 0.35 [a] | 4.8 ± 0.46 [c] |
| Corn grits 190 °C | 4.7 ± 0.49 [b,c] | 4.7 ± 0.53 [a,b,c] | 4.3 ± 0.76 [a,b] | 4.7 ± 0.49 [a] | 4.7 ± 0.49 [a,b,c] |
| Corn:Wheat Se 90:10 170 °C | 4.5 ± 0.53 [c] | 3.8 ± 0.46 [a,b,c] | 3.8 ± 0.44 [a,b] | 4.6 ± 0.52 [a] | 4.4 ± 0.52 [a,b,c] |
| Corn:Wheat Se 90:10 180 °C | 4.5 ± 0.53 [c] | 4.8 ± 0.46 [c] | 4.5 ± 0.53 [b] | 4.8 ± 0.46 [a] | 4.8 ± 0.46 [c] |
| Corn:Wheat Se 90:10 190 °C | 4.5 ± 0.53 [c] | 4.5 ± 0.76 [b,c] | 4.3 ± 0.46 [a,b] | 4.8 ± 0.46 [a] | 4.6 ± 0.52 [b,c] |
| Corn:Wheat Se 80:20 170 °C | 4.3 ± 0.46 [b,c] | 3.4 ± 0.52 [a] | 3.4 ± 0.52 [a] | 4.5 ± 0.53 [a] | 4.0 ± 0.53 [a,b,c] |
| Corn:Wheat Se 80:20 180 °C | 4.4 ± 0.52 [c] | 4.8 ± 0.46 [c] | 4.4 ± 0.52 [a,b] | 4.6 ± 0.52 [a] | 4.4 ± 0.62 [a,b,c] |
| Corn:Wheat Se 80:20 190 °C | 4.4 ± 0.53 [a,b,c] | 4.4 ± 0.53 [a,b,c] | 4.0 ± 0.58 [a,b] | 4.7 ± 0.45 [a] | 4.6 ± 0.53 [a,b,c] |
| Corn:Wheat Se 70:30 170 °C | 3.9 ± 0.35 [a,b,c] | 3.6 ± 0.74 [a,b] | 4.0 ± 0.76 [a,b] | 4.4 ± 0.74 [a] | 4.0 ± 0.76 [a,b,c] |
| Corn:Wheat Se 70:30 180 °C | 3.9 ± 0.35 [a,b,c] | 4.0 ± 0.53 [a,b,c] | 4.5 ± 0.53 [b] | 4.6 ± 0.52 [a] | 4.4 ± 0.52 [a,b,c] |
| Corn:Wheat Se 70:30 190 °C | 4.0 ± 0.53 [a,b,c] | 4.3 ± 0.46 [a,b,c] | 4.4 ± 0.52 [a,b] | 4.4 ± 0.52 [a] | 4.1 ± 0.35 [a,b,c] |
| Corn:Wheat Se 60:40 170 °C | 3.4 ± 0.52 [a,b] | 3.4 ± 0.74 [a] | 3.5 ± 0.76 [a,b] | 4.3 ± 0.71 [a] | 3.6 ± 0.52 [a,b] |
| Corn:Wheat Se 60:40 180 °C | 3.8 ± 0.71 [a,b,c] | 3.9 ± 0.64 [a,b,c] | 3.9 ± 0.64 [a,b] | 4.0 ± 0.53 [a] | 3.8 ± 0.71 [a,b,c] |
| Corn:Wheat Se 60:40 190 °C | 3.6 ± 0.53 [a] | 4.1 ± 0.38 [a,b] | 4.3 ± 0.49 [a,b] | 4.6 ± 0.79 [a] | 3.9 ± 0.90 [a] |

Values with different letters in the same column are significantly different ($p < 0.05$)
170 °C – extrusion temperature profile: 140/170/170 °C; 180 °C – extrusion temperature profile: 150/180/180 °C;
190 °C – extrusion temperature profile: 160/190/190 °C
*Vrijednosti s različitim slovima u stupcima statistički se značajno razlikuju ($p < 0,05$)*
*170 °C – temperaturni profil ekstruzije: 140/170/170 °C; 180 °C – temperaturni profil ekstruzije: 150/180/180 °C; 190 °C – temperaturni profil ekstruzije: 160/190/190 °C*

The results for sensory attributes are given in Tables 6 and 7 and Figs. 1 and 2. It is evident from the obtained results that the highest rated samples were the ones with the lowest ratio of added Zn and the Se-fortified wheat flour, if compared to corn grits extrudates. The lowest scores were given to the samples with the added 40% of Zn and the Se-fortified wheat flour. It is known that the appearance of the corn snacks is connected with a proper expansion during extrusion (Ačkar et al., 2018), what is in accordance with the results obtained in this study. Namely, the addition of wheat flour caused the reduction of expansion, what resulted in a lower sensory score of the samples with the added wheat flour. However, all samples are within the acceptable range.

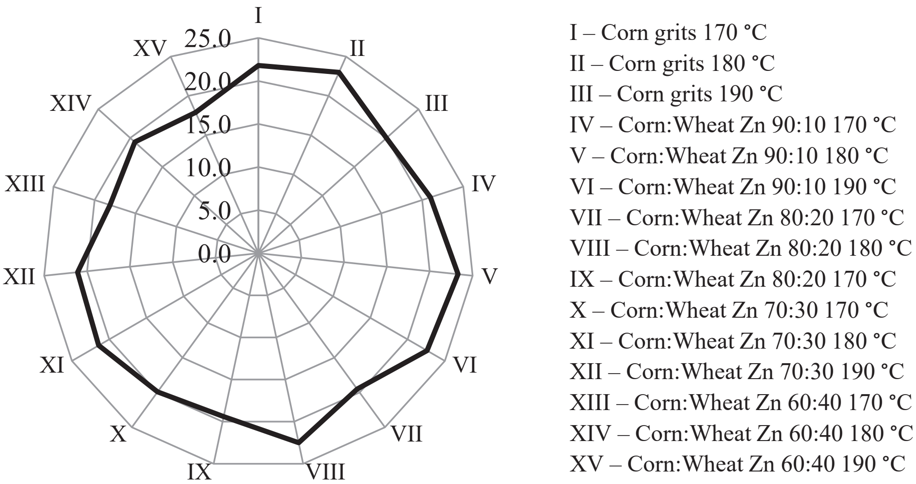



170 °C – extrusion temperature profile: 140/170/170 °C; 180 °C – extrusion temperature profile: 150/180/180 °C; 190 °C – extrusion temperature profile: 160/190/190 °*C*

*170 °C – temperaturni profil ekstruzije: 140/170/170 °C; 180 °C – temperaturni profil ekstruzije: 150/180/180 °C; 190 °C – temperaturni profil ekstruzije: 160/190/190 °C*

**Figure 1. Total sensory scores of corn snack products enriched with Zn-fortified wheat**

*Grafikon 1. Ukupna senzorna ocjena kukuruznih ekstrudata s dodatkom pšenice obogaćene Zn*




170 °C – extrusion temperature profile: 140/170/170 °C; 180 °C - extrusion temperature profile: 150/180/180 °C; 190 °C – extrusion temperature profile: 160/190/190 °*C*

*170 °C – temperaturni profil ekstruzije: 140/170/170 °C; 180 °C - temperaturni profil ekstruzije: 150/180/180 °C; 190 °C – temperaturni profil ekstruzije: 160/190/190 °C*

**Figure 2. Total sensory scores of corn snack products enriched with Se-fortified wheat**

*Grafikon 2. Ukupna senzorna ocjena kukuruznih ekstrudata s dodatkom pšenice obogaćene sa Se*

## CONCLUSION

Subsequent to research conducted on the extruded corn products with the addition of Zn and Se-fortified wheat flour, it can be concluded that the temperature and added different ratios of Zn and Se-fortified wheat flour have an impact on all investigated extrudate properties. As the temperature of extrusion and the ratio of Zn and Se-fortified wheat flour increased, all observed physical characteristics of extrudates deteriorated. Concerning the color, the lightness of all samples increased after extrusion, and total color change increased with the addition of Zn and Se-fortified wheat flour. Sensory characteristics showed that the samples with a lower percentage of added Zn and Se-fortified wheat flour had achieved the better scores and acceptability, compared to the samples with a higher fortification ratio.

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## TEKSTURALNA I SENZORSKA SVOJSTVA EKSTRUDIRANIH KUKURUZNIH SNACK PROIZVODA S DODATKOM PŠENICE OBOGAĆANE CINKOM I SELENOM


***SAŽETAK***

***Cilj ovoga rada bio je utvrditi utjecaj ekstruzije zamjesa kukuruzne krupice i pšeničnoga brašna obogaćenog Zn i Se, u omjerima 90:10, 80:20, 70:30, 60:40, na tvrdoću, lomljivost, ekspanzijski omjer, nasipnu masu, boju i senzorska svojstva. Ekstruzija je provedena na tri temperaturna profila: 140/170/170 °C, 150/180/180 °C i 160/190/190 °C. Povećanjem udjela pšeničnoga brašna obogaćenog Zn i Se i povećanjem temperature, vrijednosti svih fizikalnih svojstava su se smanjile. Svi uzorci su nakon ekstruzije posvijetlili. Ukupna promjena boje povećava se dodavanjem pšeničnoga brašna obogaćenog Zn i Se. Senzorska svojstva pokazuju bolju ukupnu ocjenu i prihvatljivost uzoraka s nižim postotkom dodanoga pšeničnog brašna u usporedbi s uzorcima s većim udjelima dodanoga pšeničnog brašna.***



***Ključne riječi: ekstruzija, kukuruz, Zn, Se, obogaćena pšenica, tekstura, boja, senzorska svojstva***

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