Effect of screw configuration, moisture content and particle size of corn grits on properties of extrudates

A. Jozinović[1], D. Šubarić[1], Đurđica Ačkar[1*], J. Babić[1], Mirela Planinić[1], Mariana Pavoković[1], Marijana Blažić[2]

[1]*Josip Juraj Strossmayer University of Osijek, Faculty of Food Technology Osijek, Franje Kuhača 20, HR-31000 Osijek, Croatia*
[2]*Karlovac University of Applied Sciences, Ivana Meštrovića 10, HR-47000 Karlovac, Croatia*

original scientific paper

Summary

Extrusion is a modern procedure for processing different types of raw materials and production of wide range of food products, where the corn grits are often used as main raw materials. Therefore the aim of this study was to determine the effect of screw configuration (4:1 and 1:1), moisture content (15% and 20%) and particle size of corn grits (>500 µm and <500 µm) on properties of extrudates. Samples were extruded in the laboratory single screw extruder Brabender 19/20 DN, at temperature profile 135/170/170 °C, using die with 4 mm diameter. Physical and rheological properties, digestibility and starch damage of the obtained extrudates were determined, and results were compared with control samples of non-extruded corn grits. Lower moisture content and usage of screw with compression ratio 4:1 increased expansion ratio and fracturability, but decreased bulk density and hardness of extrudates, regardless of granularity. After extrusion process water absorption index increased, but peak, hot and cold viscosity of all samples decreased, with more pronounced effect in grits extruded with lower moisture content and with screw 4:1. Extrusion caused a reduction of the resistant starch content and increase starch damage of all samples.

Keywords: extrusion, corn grits, particle size, moisture content, screw configuration

Introduction

Extrusion cooking of cereals is a very important process in food industry, since it regards a wide range of products such as snack-foods, baby-foods, breakfast cereals, noodle, pasta and cereals based blends (Semaska et al., 2010). Extruders minimize the operating costs and higher productivity than other cooking process, combining energy efficiency and versatility (Ficarella et al., 2004). Corn meal is a major ingredient for extruded foods, such as ready-to-eat breakfast cereals and snacks (Gujral et al., 2001). The effect of various process variables (moisture content, particle size, screw configuration) on extrusion behavior of corn grits and other flours have been extensively studied (Onwulata and Konstace, 2006; Delgado-Licon et al., 2009; Garber et al., 1997; Curic et al., 2009; Hood-Niefer and Tyler, 2010; Qi and Onwulata, 2011; Altan et al., 2009; Chuang and Yeh, 2004; Desrumaux et al., 1998; Carvalho et al., 2010). Rayas-Duarte et al. (1998) reported that samples prepared and extruded with the lowest moisture content have the largest water absorption and expansion index. Altan et al. (2009) investigated effect of screw configuration on properties of barley extrudates and reported that severe screw configuration produced more expanded product with low bulk density than that of medium screw configuration. Desrumaux et al. (1998) reported that increase in particle size for a given biochemical composition gave extrudates that were harder, with a modified expansion and lower cell density. Onwulata and Konstace (2006) reported that smaller particle size fractions exhibited increased solubility and significantly higher viscosity. Kebede et al. (2010) reported that increased barrel temperature, reduced feed moisture content and a higher screw speed showed a significantly (P<0.01) higher radial expansion, reduced bulk density and less compression resistance of teff flour extrudates. Carvalho et al. (2010) reported that extrudates produced with corn meal of higher particle sizes expanded more than extrudates produced with smaller particle sizes, and that increasing corn meal particle size decreased water absorption index (WAI) values.

The aim of this research was to determine the effect of screw configuration (4:1 and 1:1), moisture content (15% and 20%) and particle size of corn grits (>500 µm and <500 µm) on properties of extrudates – physical and rheological properties, digestibility and starch damage.

*Corresponding author: dackar@ptfos.hr

Materials and methods

Corn grits used in this study, with different particle size (>500 µm and <500 µm), were obtained from the mill „Đakovo“ of the „Žito“ Company Ltd. Osijek. Particle size of grits was determined by sifting grits through series of sieves on analytical sieve shaker model AS200, Retsch GmbH.

Moisture content of corn grits was set to 15% and 20%, and then samples were extruded in the laboratory single screw extruder Do-Coder, Brabender 19/20 DN, GmbH, Duisburg, Germany.

Extrusion parameters were as follows: screw: 4:1 and 1:1; die: 4 mm; temperature profile: 135/170/170 °C. Obtained extrudates were air-dried at ambient temperature over night to achieve moisture content 90±2%.

Extrudate diameter and *expansion ratio (ER)* were measured according to Brnčić et al. (2008), where expansion ratio was calculated as follows (Eq. 1):

ER = *extrudate diameter* (mm)/*die diameter* (mm) (1)

Bulk density (BD) of extrudates was measured according to Pan et al. (1998) and calculated according to Eq. 2:

BD = *extrudate mass* (g)/*extrudate volume* (cm^3) (2)

Texture analysis was performed on texturometer TA.XT2 Plus, Stable Microsystem using method „Measurement of the hardness and fracturability of pretzel sticks“ with following settings: Pre-Test Speed: 1.0 mm/s; Test Speed: 1.0 mm/s; Post-Test Speed: 10.0 mm/s; Distance: 3 mm; Trigger Type: Auto – 5 g.

Water absorption index (WAI) was determined according to Sosulski (1962).

Pasting properties of extrudates (10% d. m., 100 g total weight) were measured using a Micro Visco-Analyser (Model 803202, Brabender Gmbh & Co KG, Duisburg, Germany) according to standard method supplied with the apparatus. The flour suspensions were heated at 7.5 ºC/min from 32 to 92 ºC, held at 92 ºC for 10 min, cooled at 7.5 ºC/min to 50 ºC, and held at 50 ºC for 1 min.

Starch damage was determined according to AACC Method 76-31, and *resistant starch content* according to AOAC 2002.02 method.

Experimental data were analyzed by analysis of variance (ANOVA) and Fisher's least significant difference (LSD) with significance defined at P<0.05. All statistical analyses were carried out using software program STATISTICA 10.0 (StatSoft, Inc, USA).

Results and discussion

Effect of screw configuration, moisture content and particle size of corn grits on properties of extrudates is shown in Fig. 1. Extrudates prepared at lower moisture content and with screw configuration 4:1 were more expanded, regardless of corn grits granularity. These results are in accordance with other researches (Kebede et al., 2010; Onwulata and Konstance, 2006; Altan et al., 2009). The cross-sectional expansion index (SEI) was increased with a decrease in water injection rate and/or an increase in barrel temperature (Ryu and Ng, 2001). Extrudates produced with corn meal of higher particle sizes expanded more than extrudates produced with smaller particle sizes (Carvalho et al., 2010).

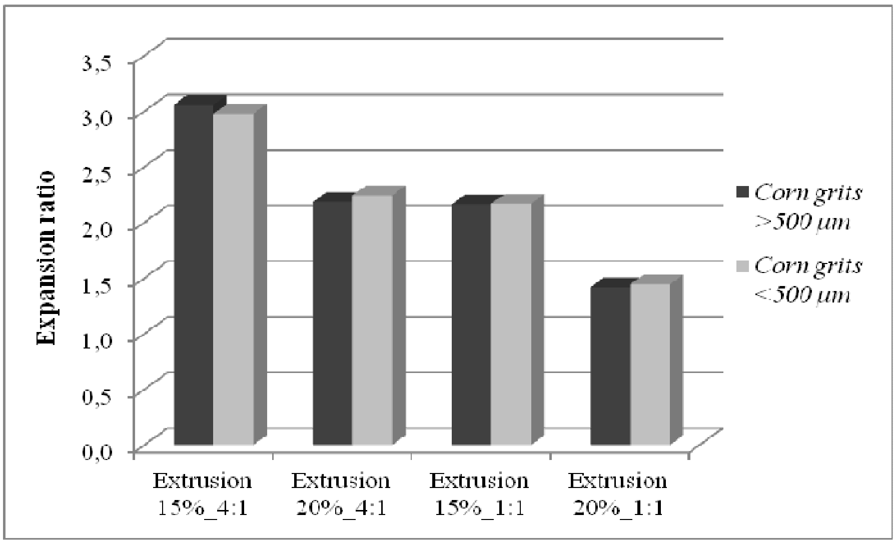

Fig. 1. Expansion ratio of corn grits extrudates

Bulk density (BD) of extrudates was higher when samples were extruded at higher moisture content and with usage screw configuration 1:1 (Fig. 2). The results obtained by measuring the bulk density are in accordance with the results of measurements of the expansion ratio i.e. extrudates with lower values of the diameter and expansion ratio had higher bulk density. The lowest BD value was obtained when rice flour was extruded at lower moisture contents and higher temperatures, whereas the highest value was obtained at higher moisture contents and lower temperatures (Hagenimana et al., 2006). Other researches also show the same trend, where is concluded that an increase of moisture content increased bulk density of extrudates (Ding et al., 2005, 2006; Thymi et al., 2005; Garber et al., 1997), which confirms the results obtained in this investigation.

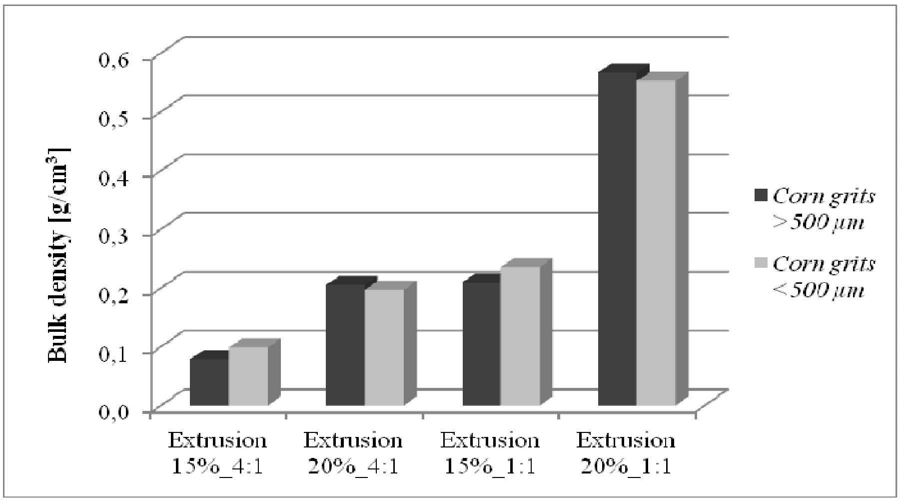

Fig. 2. Bulk density of corn grits extrudates

Texture properties of extrudates are highly influenced by expansion degree (Anton et al., 2009). This is in accordance with this research, since extrudates with lower expansion ratio had higher hardness and lower fracturability (Fig. 3, Fig. 4). Extrudates extruded at higher moisture content and with usage screw 1:1 had higher hardness and lower fracturability, regardless of corn grits granularity. Many studies have shown that the greatest impact on the texture of extrudates has moisture content (Brnčić et al., 2006; Petrova et al., 2010), but also other parameters (temperature, screw configuration, screw speed,...) are very important and were subjects of many papers (Lazou and Krokida, 2010; Mendonca et al., 2000; Saeleaw et al., 2012; Wu et al., 2007).

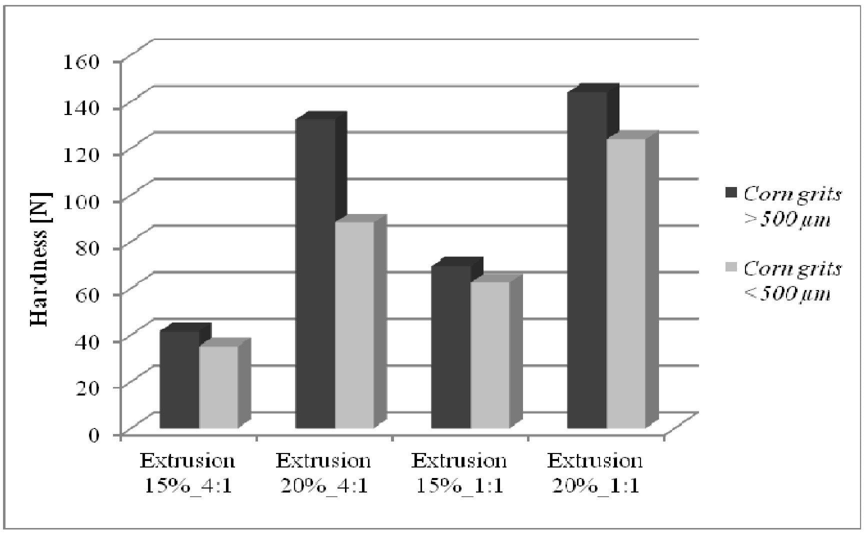

Fig. 3. Hardness of corn grits extrudates

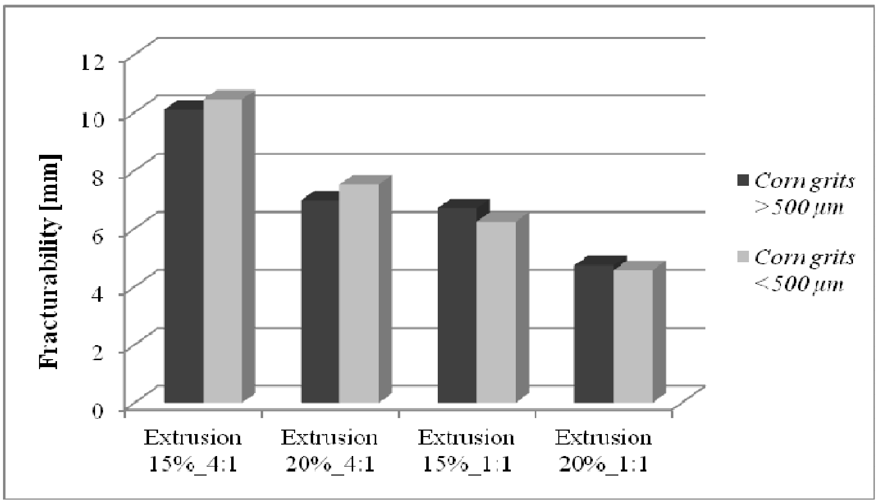

Fig. 4. Fracturability of corn grits extrudates

Water absorption index (WAI) values of all extruded samples were significantly higher compared to non-extruded corn grits, and the greater values were in more expanded extrudates (Fig. 5). Ding et al. (2005, 2006) concluded that the increase in moisture content results in extrudates with lower water absorption index values. Increasing corn meal particle size decreased WAI values (Carvalho et al., 2010). One more study, which is in accordance with the results obtained in this work, concluded that extrusion causes an increase in water absorption index (Larrea et al., 2005).

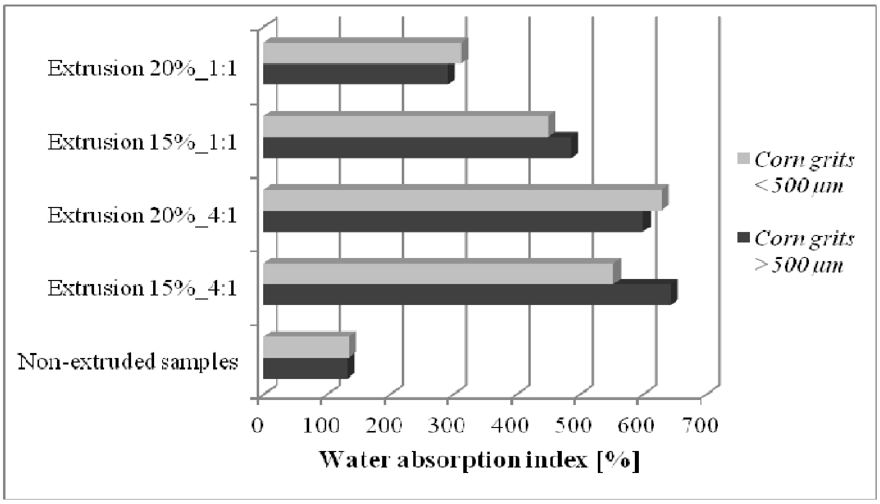

Fig. 5. Water absorption index (WAI) of non-extruded and extruded corn grits

In Table 1 pasting properties of non-extruded and extruded corn grits are shown. Extrusion resulted in decrease of peak, hot and cold viscosity of all samples. Decrease of peak viscosity is correlated to effect of extrusion on higher degradation and gelatinisation of starch (Hagenimana et al., 2006). Peak viscosity was lower at higher moisture content in extrusion using screw 4:1, but on the other hand, in extrusion using screw 1:1 peak viscosity was lower at lower moisture content. Gutkoski and El-Dash (1999) reported that initial viscosity of the paste increased with the increase of raw material moisture and extrusion temperature, while the maximum viscosity (at a constant temperature) decreased with the increase of temperature. Peak viscosity of corn grits with higher particle size was lower in non-extruded samples, but higher in all extruded samples. After heating and mixing on 92 °C viscosity of all samples decreased, and then after cooling on 50 °C viscosity of all samples marked increased, as a result of starch retrogradation during cooling. Viscosity values at 50 °C of non-extruded samples were higher in regards to all extruded samples. This is in accordance to other researches (Hagenimana et al., 2006; McPherson et al., 2000). Extrusion process partially damages starch granules, thus obtained gels of extruded products have lower viscosity than the initial grits (Dokić et al., 2009).

Table 1. Pasting properties of non-extruded and extruded corn grits

Sample	Peak viscosity [BU]	Viscosity at 92 °C [BU]	After mixing at 92 °C [BU]	Viscosity at 50 °C [BU]
Non-extruded samples				
Corn grits >500 μm	484.5 ± 18.5 [a]	112 ± 4.0 [a]	477.5 ± 21.5 [a]	809 ± 21.0 [a]
Corn grits <500 μm	502 ± 1.0 [a]	342.5 ± 1.5 [b]	475.5 ± 1.5 [a]	877 ± 2.0 [a]
Extrusion 15%_4:1				
Corn grits >500 μm	253 ± 36.0 [a]	154.5 ± 6.5 [a]	153 ± 9.0 [a]	242 ± 6.0 [a]
Corn grits <500 μm	230.5 ± 9.5 [a]	141 ± 3.0 [a]	137 ± 1.0 [a]	209 ± 4.0 [a]
Extrusion 20%_4:1				
Corn grits >500 μm	212 ± 18.0 [a]	191 ± 20.0 [a]	185 ± 3.0 [a]	293.5 ± 6.5 [a]
Corn grits <500 μm	181.5 ± 9.5 [a]	155 ± 2.0 [a]	165 ± 4.0 [a]	279 ± 4.0 [a]
Extrusion 15%_1:1				
Corn grits >500 μm	130 ± 5.0 [a]	107.5 ± 3.5 [b]	116.5 ± 7.5 [a]	172.5 ± 3.5 [b]
Corn grits <500 μm	128 ± 2.0 [a]	89 ± 0.0 [a]	91 ± 1.0 [a]	145 ± 2.0 [a]
Extrusion 20%_1:1				
Corn grits >500 μm	255.5 ± 1.5 [a]	213.5 ± 0.5 [a]	254.5 ± 1.5 [a]	474 ± 3.0 [a]
Corn grits <500 μm	250 ± 1.0 [a]	233 ± 2.0 [a]	246 ± 0.0 [a]	444 ± 1.0 [a]

Starch damage significantly increased and resistant starch (RS) content decreased after extrusion of all samples (Fig. 6, Fig. 7). This is in accordance to conclusion of Mendoza and Bresaani (1987) and Hagenimana et al. (2006). RS content was higher, before and after extrusion, in corn grits with higher particle size.

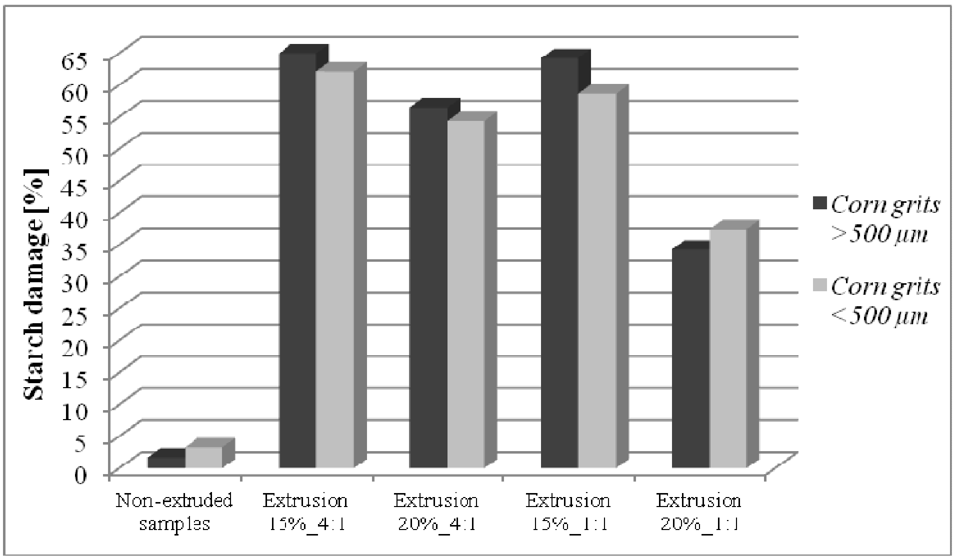

Fig. 6. Starch damage of non-extruded and extruded corn grits

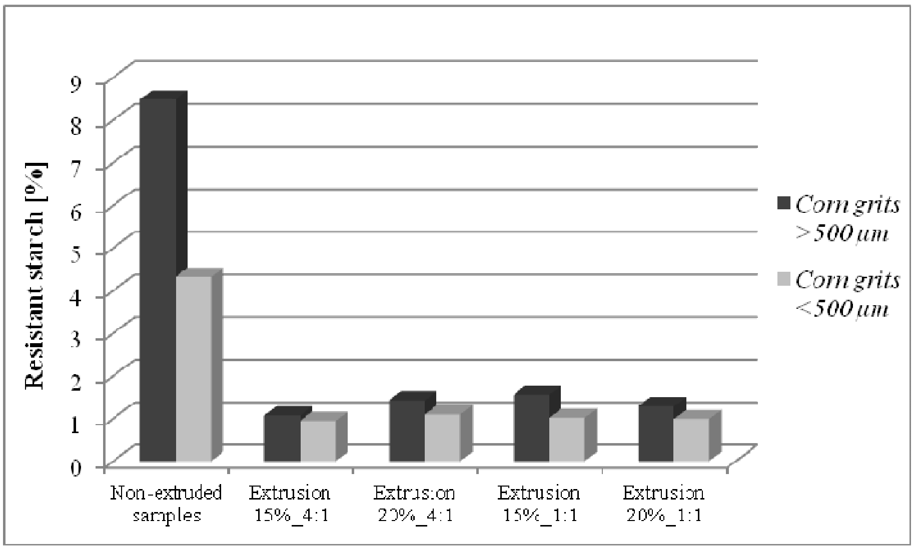

Fig. 7. Resistant starch content of non-extruded and extruded corn grits

Conclusions

This research was conducted to investigate the parameters of extrusion for preparation corn grits „snack“ products with desirable physical properties.

Extrudates prepared at lower moisture content and with screw configuration 4:1 were more expanded, regardless of corn grits granularity. The results for bulk density and texture properties are in accordance with the results of measurements of the expansion ratio i.e. extrudates with lower values of the diameter and expansion ratio had higher bulk density and hardness and lower fracturability. Water absorption index values of all extruded samples were significantly higher compared to non-extruded corn grits. Extrusion resulted in decrease of peak, hot and cold viscosity of all samples. Starch damage significantly increased and resistant starch (RS) content decreased after extrusion.

The results obtained in this research indicate that screw with compression ratio 4:1 and corn grits with higher particle size and with lower moisture content results in products with better physical properties in regardless to products obtained with screw 1:1 and with corn grits with smaller particle size and with higher moisture content.

Acknowledgments

Results shown have outcome from scientific project „Development of new modified starches and their application in food industry“ supported by the Ministry of Science, Education and Sports of the Republic of Croatia.

Literature

AACC 76-31, *Starch damage.* Official Methods of Analysis, of A.A.C.C. American Association of Cereal Chemists (AACC Method 76-31). The Association, St. Paul, MN.

Altan, A., McCarthy, K.L., Maskan, M. (2009): Effect of screw configuration and raw material on some properties of barley extrudates. *Journal of Food Engineering* 92, 377–382.

Anton, A.A., Fulcher, R.G., Arntfield, S.D. (2009): Physical and nutritional impact of fortification of corn-starch based extruded snacks with common bean (*Phaseolus vulgaris* L.) flour: effects of bean addition and extrusion cooking. *Food Chem.* 113, 989-996.

AOAC 2002.02, *Resistant starch in starch and plant materials*. Official methods of analysis of the AOAC international (18th ed.). Gaithersburg, Maryland: AOAC International.

Brnčić, M., Ježek, D., Rimac Brnčić, S., Bosiljkov, T., Tripalo, B. (2008): Utjecaj dodatka koncentrata proteina sirutke na teksturalna svojstva izravno ekspandiranog kukuruznog ekstrudata. *Mljekarstvo* 58 (2),131-149.

Brnčić, M., Tripalo, B., Ježek, D., Semenski, D., Drvar, N., Ukrainczyk, M. (2006): Effect of twin-screw extrusion parameters on mechanical hardness of direct-expanded extrudates. *Sadhana* 31 (5), 527-536.

Carvalho, C.W.P., Takeiti, C.Y., Onwulata, C.I., Pordesimo, L.O. (2010): Relative effect of particle size on the physical properties of corn meal extrudates: Effect of particle size on the extrusion of corn meal. *Journal of Food Engineering* 98, 103–109.

Chuang, G.C.C., Yeh, A. (2004): Effect of screw profile on residence time distribution and starch gelatinization of rice flour during single screw extrusion cooking. *Journal of Food Engineering* 63, 21–31.

Curic, D., Novotni, D., Bauman, I., Kricka, T., Dugum, J. (2009): Optimization of extrusion cooking of cornmeal as raw material for bakery products. *Journal of Food Engineering* 32, 294-317.

Delgado-Licon, E., Martinez Ayala, A.L., Rocha-Guzman, N.E., Gallegos-Infanate, J.A., Atienzo-Lazos, M., Drzewicki, J., Martínez-Sánchez, C.E., Gorinstein, S. (2009): Influence of extrusion on the bioactive compounds and the antioxidant capacity of the bean/corn mixtures. *International Journal of Food Sciences and Nutrition* 60 (6), 522-532.

Desrumaux, A., Bouvier, J.M., Burri, J. (1998): Corn Grits Particle Size and Distribution Effects on the Characteristics of Expanded Extrudates. *Journal of Food Science* 63 (5).

Ding, Q.B., Ainsworth, P., Plunkett, A., Tucker, G., Marson, H. (2006): The effect of extrusion conditions on the functional and physical properties of wheat-based expanded snacks. *Journal of Food Engineering* 73, 142–148.

Ding, Q.B., Ainsworth, P., Plunkett, A., Tucker, G., Marson, H. (2005): The effect of extrusion conditions on the physicochemical properties and sensory characteristics of rice-based expanded snacks. *Journal of Food Engineering* 66, 283-289.

Dokić, LJ.P., Bodroža-Solarov, M.I., Hadnađev, M.S., Nikolić, I.R. (2009): Properties of extruded snacks supplemented with amaranth grain grits. *Biblid* 40, 17-24.

Ficarella, A., Milanese, M., Laforgia, D. (2004): Numerical study of extrusion process in cereals production: Part I. *Fluid-dynamic analysis of extrusion system* 73, 103-111.

Garber, B.W., Hsieh, F., Huff, H.E. (1997): Influence of Particle Size on the Twin-Screw Extrusion of Corn Meal. *Cereal Chem.* 74 (5), 656–661.

Gujral, H. S., Singh, N., Singh, B. (2001): Extrusion behaviour of grits from flint and sweet corn. *Food Chemistry* 74, 303–308.

Gutkoski, L.C., El-Dash, A.A. (1999): Effect of extrusion process variables on physical and chemical properties of extruded oat products. *Plant Foods for Human Nutrition* 54, 315–325.

Hagenimana, A., Ding, X., Fang, T. (2006): Evaluation of rice flour modified by extrusion cooking. *Journal of Cereal Science* 43 (1), 38-46.

Hood-Niefer, S.D., Tyler, R.T. (2010): Effect of protein, moisture content and barrel temperature on the physicochemical characteristics of pea flour extrudates. *Food Research International* 43, 659–663.

Kebede, L., Worku, S., Bultosa, G., Yetneberek, S. (2010): Effect of extrusion operating conditions on the physical and sensory properties of tef (*Eragrostis tef* [Zucc.] Trotter) flour extrudates. *EJAST*, 1 (1) 27-38.

Larreaa, M.A., Changb, Y.K., Martinez-Bustos, F. (2005): Some functional properties of extruded orange pulp and its effect on the quality of cookies. *LWT* 38, 213–220.

Lazou, A., Krokida, M. (2010): Structural and textural characterization of corn–lentil extruded snacks. *Journal of Food Engineering* 100, 392–408.

McPherson, A.E., Bailey, T.B., Jane, J. (2000): Extrusion of cross-linked hydroxypropylated corn starches I. Pasting properties. *Cereal Chem.* 77 (3), 320-325.

Mendonca, S., Grossmann, M.V.E., Verhé, R. (2000): Corn Bran as a Fibre Source in Expanded Snacks. *Lebensm.-Wiss. u.-Technol.* 33, 2-8.

Mendoza, C.M., Bressani, R. (1987): Nutritional and functional characteristics of extrusion-cooked amaranth flour. *Cereal Chem* 64 (4), 218-222.

Onwulata, C.I., Konstance, R.P. (2006): Extruded corn meal and whey protein concentrate: Effect of particle size. *Journal of Food Processing and Preservation* 30, 475–487.

Pan, Z., Zhang, S., Jane, J. (1998): Effects of extrusion variables and chemicals on the properties of starch-based binders and processing conditions. *Cereal Chemistry* 75, 541-546.

Petrova, T., Ruskova, M., Tzonev, P., Zsivanovits, G., Penov, N. (2010): Effect of Extrusion Variables on the Hardness of Lentil Semolina Extrudates. In *7th International Conference of the Balkan Physical Union*, *AIP Conference Proceedings* 1203, 1031-1036.

Qi, P.X., Onwulata, C.I. (2011): Physical properties, molecular structures, and protein quality of texturized whey protein isolate: Effect of extrusion moisture content*. Journal of Dairy Science* 94 (5), 2231- 2244.

Rayas-Duarte, P., Majewska, K., Doetkott, C. (1998): Effect of Extrusion Process Parameters on the Quality of Buckwheat Flour Mixes. *Chereal Chemistry* 75 (3).

Ryu, G.H., Ng, P.K.W. (2001): Effects of Selected Process Parameters on Expansion and Mechanical Properties of Wheat Flour and Whole Cornmeal Extrudates. *Starch/Stärke* 53, 147–154.

Saeleaw, M., Dürrschmid, K., Schleining, G. (2012): The effect of extrusion conditions on mechanical-sound and sensory evaluation of rye expanded snack. *Journal of Food Engineering* 110, 532–540.

Semaska, C., Kong, X., Hua, Y. (2010): Optimization of Extrusion on Blend Flour Composed of Corn, Millet and Soybean. *Pakistan Journal of Nutrition* 9 (3), 291-297.

Sosulski, F.W. (1962): The centrifuge method for determining flour absorption in hard red spring wheat. *Cereal Chemistry* 39, 344-350.

Thymi, S., Krokida, M.K., Pappa, A., Maroulis, Z.B. (2005): Structural properties of extruded corn starch. *Journal of Food Engineering* 68, 519–526.

Wu, W., Huff, H.E., Hsieh, F. (2007): Processing and properties of extruded flaxseed-corn puff. *Journal of Food Processing and Preservation* 31, 211–226.

Received: November 11, 2012
Accepted: January 24, 2013