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THE EFFECT OF CORN DDGS ON EXTRUSION PROCESSING PARAMETERS AND PHYSICAL QUALITY OF EXTRUDED CATFISH FEED

UTICAJ KUKURUZNOG DDGS-A NA PROCESNE PARAMETRE EKSTRUDIRANJA I FIZIČKI KVALITET EKSTRUDIRANE HRANE ZA SOMA

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ABSTRACT

Four iso-nitrogenous European catfish (Silurus glanis) diets (protein content approximately 400 g/kg) with the inclusion of 0, 100, 200, and 300 g/kg of corn DDGS were formulated and processed by twin-screw extruder. The aim was to assess the influence that DDGS has on extrusion processing and the physical quality properties of sinking feed. All ingredients of the diets were finely ground at the hammer mill, mixed and steam conditioned to a temperature of 95 °C and moisture content of approximately 250 g/kg prior to the extrusion. The conditioned mixtures were processed by a twin-screw extruder in order to produce sinking pellets. The DDGS inclusion in catfish diets decreased specific mechanical energy during extrusion, which significantly ($p < 0.05$) decreased radial expansion of the product when DDGS was included at levels of 200 and 300 g/kg. The inclusion of corn DDGS at levels of 100 and 200 g/kg resulted in pellets with significantly higher hardness and durability ($p < 0.05$) and without significant changes ($p > 0.05$) in water stability compared with the control feed. Corn DDGS proved not just as a relatively cheap protein source in aquafeed but also as a techno-functional ingredient that reduces the cost of feed production while giving extruded fish feed of increased ability to withstand mechanical stress during transport, storage, and pneumatic feeding.

***Key words**: DDGS; catfish; extrusion; energy consumption; physical quality.*

REZIME

Za potrebe ovog istraživanja formulisane su četiri smeše za ishranu Evropskog soma sa istim sadržajem proteina (oko 400 g/kg) sa dodatkom 0, 100, 200 i 300 g/kg kukuruznog DDGS-a, koje su potom podvrgnute procesu ekstrudiranja dvopužnim ekstruderom. Cilj ovog istraživanja bio je da se ispita uticaj dodatka DDGS-a na parametre procesa ekstrudiranja, kao i na fizički kvalitet tonućih peleta. Svi sastojci smeše su fino samleveni mlinom čekićarem, potom umešani i kondicionirani dodatkom pare na temperaturu od 95 °C i do sadržaja vlage od oko 250 g/kg. Kondicionirana smeša je zatim ekstrudirana dvopužnim ekstruderom sa namerom da se proizvedu tonuće pelete. Dodatkom DDGS-a u hranu za soma smanjena je specifična mehanička energija ekstrudiranja, što je dovelo do značajnog smanjenja ($p < 0.05$) radijalne ekspanzije peleta pri dodatku DDGS-a u količini od 200 i 300 g/kg. Uključenje kukuruznog DDGS-a u recepturu od 100 i 200 g/kg za rezultat je imalo pelete sa značajno većom tvrdoćom i otpornošću na otiranje ($p < 0.05$) i bez značajnih promena ($p > 0.05$) u stabilnosti u vodi u poređenju sa kontrolnom smešom bez dodatka DDGS-a. Kukurzni DDGS se pokazao ne samo kao relativno jeftin izvor proteina u hrani za ribe, već i kao tehničko-funkcionalni sastojak koji može da smanji troškove proizvodnje dok istovremeno povećava kvalitet ekstrudirane hrane za ribe u pogledu otpornosti na mehanički stres prilikom transporta, skladištenja i pneumatskog doziranja.

***Ključne reči:** DDGS; som; ekstrudiranje; potrošnja energije; fizički kvalitet.*

INTRODUCTION

In 2020 annual production of fish by aquaculture reached 90.3 million tonnes with an estimated value of USD 141 billion. Global consumption of aquatic foods in 2020 was 20.2 kg per capita, which is more than double compared to 50 years ago. It is estimated that the total production of aquatic animals by aquaculture is going to reach 106 million tonnes in 2030 (*FAO, 2022*). The aquaculture industry makes an effort to develop successful sustainable models, as the problem of degradation of the environment becomes a subject of great importance. Therefore, sustainable aquaculture development remains critical in the ever-growing demand for aquatic foods (*FAO, 2022*). Alternative feed ingredients of plant origin that meet the nutritional requirements of the fish have the potential to enhance aquaculture production, therefore ensuring high-quality and safe products for human consumption with a minimal negative effect on the environment (*Kaur and Shah, 2017; Gatlin et al., 2007*). Also, there is great potential in the utilization of industry by-products that are often being discarded. In that manner, various wastes and by-products can become useful alternatives used as feed ingredients for aquaculture (*Caipang et al., 2019*). Distillers dried grains with solubles (DDGS) are becoming a promising protein source alternative (*Magalhães, 2013*). Distillers' dried grains with soluble (DDGS) remain the major by-product of ethanol production by yeast fermentation of starch from cereal grains. It is relatively high in protein (28−32%) and fat (10%) content and does not contain anti-nutritional factors found in most plant protein sources (*Lym and Yildirim-Askoy, 2008; Hardy, 2010*). The chemical composition of DDGS highly depends on the source and quality of grain used for ethanol production as well as the production process (*Lym and Yildirim-Askoy, 2008*). DDGS is proven as a prospective alternative protein feed ingredient in diets for tilapia (*Shelby et al., 2008*) and rainbow trout (*Cheng and Hardy, 2004; Stone et al., 2005*). The inclusion of 300 g/kg of corn DDGS as a partial replacement for soybean meal in the channel catfish diet resulted in increased feed consumption as well as feed conversion ratio compared to the soybean meal-based diet (*Li et al., 2010*). Production of commercial fish feed is mainly done by extrusion process, resulting in high energy products with high physical quality as well good nutritional value. Influence of DDGS inclusion in tilapia (*Kannadhason et al., 2010*), catfish (*Kannadhason et al., 2011*), rainbow trout (*Ayadi et al., 2011a*), and yellow perch (*Ayadi et al., 2011b*) diet on physical properties of pellets produced by a single screw and twin-screw extrusion process was investigated up to now. In this study, one control diet for European catfish (*Silurus glanis*) and three experimental diets were formulated with the inclusion of 100, 200, and 300 g/kg of corn DDGS and produced by a twin-screw extruder. The aim was to investigate the influence of corn DDGS on extrusion parameters (temperature and pressure at the die, specific mechanical energy) and physical quality of obtained feed (expansion ratio, bulk density, pellet hardness, durability and water stability).

MATERIAL AND METHOD

Four iso-nitrogenous European catfish (*Silurus glanis*) diets with approximately 400 g/kg of protein and 70 g/kg of fat were formulated as presented in Table 1. Experimental diets (DDGS-100, DDGS-200 and DDGS-300) were formulated with the inclusion of 100 g/kg, 200 g/kg and 300 g/kg of corn DDGS, respectively.

Table 1. Composition and calculated nutrient content in control and three experimental European catfish diets

Diets	DDGS-0	DDGS-100	DDGS-200	DDGS-300
Ingredients (g/kg)				
Corn DDGS[1]	-	100.0	200.0	300.0
Poultry meal[2]	250.0	205.0	160.0	120.0
Wheat[3]	249.5	188.9	127.5	66.7
Soybean flour[4]	210.2	220.0	230.0	235.0
Fish meal[5]	200.0	200.0	200.0	200.0
Yeast[6]	50.00	50.0	50.0	50.0
Soybean oil[7]	18.0	12.0	6.0	-
Fish oil[5]	15.0	15.0	15.0	15.0
Premix[3]	5.0	5.0	5.0	5.0
Salt[3]	0.8	1.5	3.0	4.0
Lysine[3]	0.6	1.5	2.2	2.8
Methionine[3]	0.4	0.6	0.8	1.0
Yttrium(III)-oxide[8]	0.5	0.5	0.5	0.5

1 Pannonia Gold, Dunaföldvár, Hungary
2 BRO-MK Processed animal protein, Brovis DOO, Visoko, Bosnia & Herzegovina
3 Purchased from the local fish feed producer − DTD Ribarstvo, Bački Jarak, Serbia
4 SOPRO-TB200, Sojaprotein, Bečej, Serbia
5 Sardina DOO, Postira, Brač, Croatia
6 Minimum 48% of protein, Biofood, Tambou, Russia
7 Victoriaoil, Šid, Serbia
8 Alfa Aesar, Thermo Fisher (Kandel) GmbH, Karlsruhe, Germany

Dry ingredients were ground by a hammer mill (ABC Inženjering, Pančevo, Serbia) equipped with the 1.0 mm sieve and then mixed in a double-shaft pedal mixer (model SLHSJ0.2A Muyang, Yangzhou, China). The mixture of soybean and fish oil was added directly into the mixer during the mixing of dry ingredients through nozzles that were positioned in the upper part of the mixer, above the mixing pedals. The material was preconditioned by the direct addition of steam and water in the aforementioned double-shaft mixer until the final temperature of the material reached 95 ºC. The targeted final moisture content of the material after preconditioning was approximately 250 g/kg. Preconditioned material was extruded using a co-rotating twin-screw extruder (Bühler BTCM30, 7 sections, length/diameter ratio = 28:1, Bühler, Uzwil, Switzerland) with 4 mm die opening and conical outlet (die open area of 12.56 mm^2). The screw configuration that was used is presented in Figure 1.

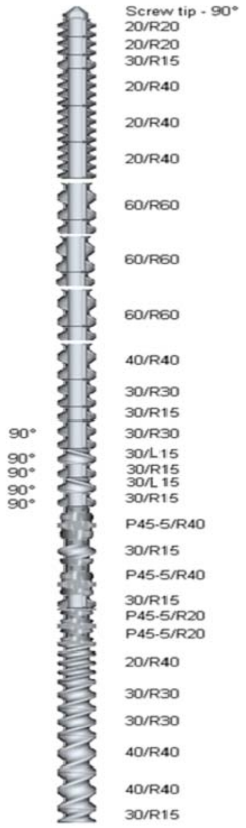

Fig. 1. Schematic view of used screw configuration and its screw segments

The feed rate was set at 25 kg/h and water temperature for jacketed heating of extruder barrel's sections 2-4 and 6-7 was set at 110 and 70 ºC, respectively. The moisture content of the material in the feeding section of the extruder barrel was targeted to be approximately 250 g/kg, as it was after conditioning, thus for the fine setting of moisture content water was needed to be added directly inside the barrel via cavity pump. Screw speed was set at 600 RPM. Temperatures of section 3 and section 6 of the extruder barrel were measured by sensors located in the extruder barrel. Sensors located before the die were used to measure die temperature and pressure. Specific mechanical energy (SME) and torque were read directly from the extruder's control panel. The six knives were used for cutting the final product at the die outlet, and the knife rotation speed was set at 1000 RPM. The subsequent drying of pellets was done by a vibrating dryer (FB 500x200, Amandus Kahl, Hamburg, Germany) at 80 ºC until the product reached a final moisture content of approximately 100 g/kg. The average pellet diameter was determined by measuring 20 randomly selected pellets using a caliper and the expansion ratio was calculated using the equation presented in the study by *Sørensen, Morken, Kosanovic, and Øverland (2011).* The bulk density (BD) of extruded feed was determined using a bulk density tester (Tonindustrie, West und Goslar, Germany). Pellet hardness was determined by a motor-driven KAHL pellet hardness tester (Amandus Kahl, Hamburg, Germany). The result of pellet hardness was an average of the ten replicates expressed in KAHL units. Pellet durability index (PDI) was determined using Holmen pellet tester (NHP100, Holmen Feed, Norfolk, UK) with the timer set at 120 s, according to the method described in the study of *Wolska et al. (2014).* The water stability index (WSI) was determined by the static method described in the work of *Banjac et al. (2017).* The nutrient leaching of feed was determined by the conductometric method previously proposed by *Banjac et al. (2017).* One-way ANOVA and Tukey honestly significant difference test were used to analyze variations of the results. Differences between the means with probability $P < 0.05$ were accepted as statistically significant. The level of confidence was set at 95% (STATISTICA 13.0, TIBCO Software, USA).

RESULTS AND DISCUSSION

Extruder process parameters are presented in Table 2.

Table 2. Processing parameters during extrusion of experimental European catfish feed diets

Diets	DDGS-0	DDGS-100	DDGS-200	DDGS-300
Conditioning				
Temperature[1] (°C)	95.0	95.0	95.0	95.0
Moisture content[2] (g/kg)	244.0	255.0	223.0	237.0
Extrusion				
Temperature[3] (°C)				
Section 3	101.5	102.1	195.7	102.0
Section 6	68.8	69.4	68.3	68.7
Die	107.0	111.0	106.0	107.0
Screw speed (RPM)	400	400	400	400
Throughput (kg/h)	25.0	25.0	25.0	25.0
Water throughput (kg/h)	0.0	0.0	1.2	1.1
Moisture[4] (g/kg)	244	255	258	269
Die pressure (bar)	0.8	0.7	0.9	0.9
SME[5] (Wh/kg)	108.9	88.5	86.5	89.9

1 Measured by the sensor located inside the conditioner.
2 Moisture content determined after conditioning by rapid moisture analyzer.
3 Measured by sensors located in the extruder barrel.
4 Total moisture content during extrusion that was calculated based on the moisture content of the material after conditioning, material throughput and water throughput in the extruder barrel.
5 Specific mechanical energy.

The temperature in section 3 of the extruder barrel ranged from 101.5 to 195.7 ºC and it increased from 101.5 (DDGS-0) to 195.7 (DDGS-200) and then dropped to 102.0 ºC (DDGS-300). An increase in DDGS content of the diet when the inclusion of DDGS was 100 g/kg resulted in a slight increase of the temperature at the die from 107.0 to 111.0 ºC. At the higher levels of the inclusion of DDGS temperature of the die slightly decreased to 106.0 ºC and 107.0 ºC. During the production of all four feeds, DDGS inclusion in European catfish diets did not significantly influence the pressure at the die during extrusion. This result was not in accordance with the one obtained by *Chevanan et al. (2010)* where an increase of DDGS in feed blends from 200 to 300 and 400 g/kg significantly decreased pressure at the die when single screw extrusion of feed was performed. The collision within these extrusion parameters perhaps was the result of great variety in DDGS quality (*Lym & Yildirim-Askoy, 2008*). The highest value of specific mechanical energy (SME) was obtained during the production of European catfish pellets with no presence of DDGS in diet composition (108.9 Wh/kg). SME decreased with the inclusion of DDGS in quantities of 100 g/kg, 200 g/kg and 300 g/kg to 88.5, 86.5 and 89.9 Wh/kg, respectively. On the contrary, in the study by *Chevanan et al. (2010),* the increase of DDGS content from 300 to 400 g/kg in the feed blend did result in significantly higher SME. Changes in DDGS content in European catfish diets influenced changes in the physical quality of extruded pellets. Analysis of physical quality in the course of the experiment is presented in Table 3.

Table 3. Physical quality parameters of extruded catfish feed samples

	DDGS-0	DDGS-100	DDGS-200	DDGS-300
Expansion ratio (%)	13.00 ± 3.50^b	12.75 ± 2.75^b	4.75 ± 3.62^a	5.00 ± 2.04^a
Bulk density (kg/m^3)	488.46 ± 2.81^b	485.64 ± 2.90^b	500.40 ± 3.83^c	466.84 ± 1.15^a
Hardness (KAHL unit)	1.62 ± 0.28^a	2.83 ± 0.54^b	2.56 ± 0.73^b	2.77 ± 0.59^b
PDI (%)	93.94 ± 0.12^a	95.05 ± 0.01^b	95.57 ± 0.14^c	94.68 ± 0.16^b
WSI (%)	84.08 ± 0.17^b	83.78 ± 0.53^b	83.69 ± 0.28^b	82.00 ± 0.67^a

Values with a different superscript within the same row are significantly different (P<0.05)
PDI - *pellet durability index*, WSI - *water stability index*

The highest level of radial expansion ratio (13.00%) was obtained for the feed DDGS-0. With the inclusion of 100 g/kg of DDGS expansion ratio slightly decreased and with an increase of DDGS content to 200 g/kg and 300 g/kg expansion ratio significantly decreased ($p < 0.05$) to the levels of 4.75% and 5.00%, respectively. Obtained results were in accordance with the results of studies by *Chevanan et al. (2007), Kannadhason et al. (2010),* and *Kannadhason et al. (2011)* but not with the results obtained by *Ayadi et al. (2011b)* where no significant differences of pellet expansion were recorded when DDGS content in yellow perch feed was changed from 100 to 500 g/kg. No significant changes occurred in bulk density with the inclusion rate of 100 g/kg of DDGS. Samples DDGS-200 and DDGS-300 had significantly lower ($p < 0.05$) bulk density compared with the control feed. The bulk density of the extrudates is affected by the volume of pores formed inside the extrudates as expansion occurs during extrusion processing, as well as void spaces formed during the filling of the pellets into containers of a specific size during testing *(Chevanan et al., 2007)*. The lowest bulk density was obtained for the sample DDGS-300 (466.84 kg/m^3). This feed formulation possessed a lower level of radial expansion compared to DDGS-0 and DDGS-100 diets, and it was expected to have higher bulk density. The possible explanation for this occurrence was that the greater DDGS inclusion in the diet caused greater longitudinal than radial expansion of the pellets. According to *Chevanan et al. (2007)*, greater longitudinal expansion can result in forming a more porous structure of the pellets and could create more void spaces due to the geometry of filling a one-liter cup, thus resulting in a lower bulk density. Pellet hardness is defined as the maximum force needed to crush a pellet and pellet resistance to the crushing force is important physical property for storage in a silo or bin or screw conveying *(Kaliyan and*

Morey, 2009). The inclusion of DDGS significantly influenced ($p < 0.05$) pellet hardness resulting in harder pellets. There were not any significant differences in pellet hardness between experimental diets when DDGS was included. This result was in accordance with the results of *Ayadi et al. (2011a)* where 100−500 g/kg inclusion of DDGS in rainbow trout feed significantly increased ($p < 0.05$) compressive strength of the pellets. With the inclusion of DDGS at all levels, it was observed a significant increase ($p < 0.05$) in PDI values compared with the DDGS-0 sample. WSI significantly differed only in sample DDGS-300 and it had the lowest value out of all of the samples (82.00%). This result indicates that WSI significantly decreases with the inclusion of DDGS above. WSI corresponded well with the results of nutrient leaching, which can be approximated based on the conductivity curves presented in Figure 2. The conductivity of water increases as the nutrients, fat, and minerals from feeds leaches into water right after their immersion *(Ighwela et al., 2013).* The control feed and feeds with 100 and 200 g/kg of DDGS included has almost the same curves with a linear rate of nutrient leaching during the 24-hour period of soaking in water. The conductivity curves of those three feeds showed that practically, there was no difference in their nutrition leaching, just as there were no significant differences in their WSI. On the contrary, the conductivity curve for feed DDGS-300 shows that there was a high rate of nutrient leaching in the first three hours of soaking after which the loss of nutrients started in a constant mode. Also, the conductivity values for feed DDGS-300 were higher compared with the conductivity values of the other three samples, supporting the results of WSI, and leading to the conclusion that the inclusion of corn DDGS above 200 g/kg results in extruded fish feed with deteriorated water stability and tendency for higher nutrient leaching.

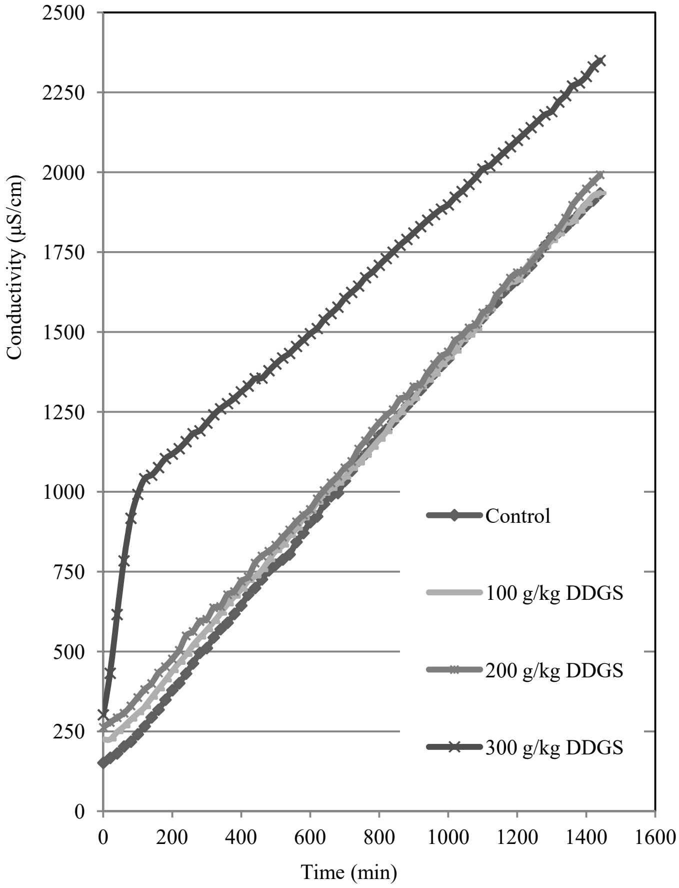

Fig. 2. Water conductivity during 24 h long soaking of four tested European catfish feeds

CONCLUSION

The inclusion of corn DDGS in the European catfish diet reduced specific energy consumption during twin-screw extrusion processing. The inclusion of 200 g/kg and 300 g/kg of corn DDGS negatively affected radial product expansion but promoted longitudinal expansion which led to a decrease in bulk density. The inclusion of DDGS at all rates contributed to significantly higher hardness and durability of pellets. However, the inclusion of corn DDGS above 200 g/kg in fish feed negatively affected the water stability of pellets and caused higher nutrient leaching. The obtained results showed that the usage of corn DDGS in fish feed formulations may reduce the cost of feed production while giving extruded fish feed of increased ability to withstand mechanical stress during transport, storage, and pneumatic feeding.

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