TEKA. COMMISSION OF MOTORIZATION AND ENERGETICS IN AGRICULTURE – 2012, Vol. 12, No. 1, 185–189

Influence of process conditions on quality and energy consumpion during extrusion-cooking of carp feed

Tomasz Oniszczuk[1], Leszek Mościcki[1], Agnieszka Wójtowicz[1], Marcin Mitrus[1], Andrzej Rejak[1], Kazimierz Zawiślak[2], Paweł Sobczak[2], Jacek Mazur[2], A. Oniszczuk[3]

[1]Department of Food Process Engineering, University of Life Sciences in Lublin; [2]Department of Food Engineering and Machinery, University of Life Sciences in Lublin; [3]Department of Inorganic Chemistry, Medical University in Lublin, e-mail:tomasz.oniszczuk@up.lublin.pl

Summary. The paper presents the results of influence of the extrusion-cooking process conditions on the energy requirement and water stability of carp feed. The feed was obtained from standard mixtures of raw materials having various initial moisture content (25%, 27% and 29%, respectively), with the application of baro-thermal treatment using a single screw extrusion-cooker type TS-45. The results of the examinations showed that higher moisture content of raw materials influenced the decrease of the specific mechanical energy SME. The efficiency of the extrusion process increased both with the higher screw speed and higher moisture content of raw materials. The highest water stability was obtained for the carp feed produced from the mixture of 25% m.c. processed at 80 rpm.

Key words: extrusion-cooking, specific mechanical energy, water stability, single screw extrusion-cooker.

INTRODUCTION

The development of freshwater fish farming in Poland requires that more attention should be paid to the process of fish nutrition and more efficient use of fish feed. It pertains to different age groups and species of reared fish. In order to implement a suitable fishery management, the knowledge of biology, fish dietary needs, nutrition methods and quality of feed ingredients is required [2, 3, 6, 9].

Cost-effectiveness of fish rearing and the specificity of carp feeding depend to a large extent on the stability of feed in the water. Feeding fish with less stable feed containing expensive, wholesome components that may undergo lixiviation or dilution, leads to severe losses in the aquatic environment, mainly due to the deterioration of oxygen balance in ponds and increased load of organic matter. Due to constant technological progress, the feed industry offers more efficient and nutritious feed.

A variety of production processes is applied in the manufacture of aquatic feed. In the past dry or wet pelleting was the most popular method [18,19]. Since the quality of pellets for the fish is not suitable due to low water stability and limited nutritional effects, the recent years have seen the replacement of such a feed type by extruded one [7, 10, 11,14]. Extrusion technique allows to introduce various types of components that still have not been used in the production of fish feed. These components have a significant impact on the improvement of physical properties of feed, the efficiency of rearing as well as death rate and health of fish. To understand the basic physical properties of extruded fish feed with different additives, it is necessary to perform a series of measurements that will help identify the main utility characteristics of extrudates and implement appropriate adjustments to the manufacturing parameters in order to obtain high quality products [4, 11, 13, 16, 21].

The aim of this study was to examine the influence of process conditions on functional properties of the extrusion-cooked carp feed as well as the consumption of energy during processing.

MATERIALS AND METHODS

A standard mixture of carp feed was used in the experiment (Table 1). The basic raw materials and components were delivered by Animex Grupa Drobiarska S.A., Zamość, Poland. The balancing of feed recipe and the production technology were developed on the basis of commonly available nutritional standards, computer program, as well as following the recommendations of the personnel of the of Department of Food Engineering and Machinery, Lublin University of Life Sciences. The feed was produced by extrusion-cooking on a single screw extrusion-cooker TS-45 (polish design), fitted with a plasticizing unit of L/D ratio of 16/1.

Table 1. The composition of the mixture

Component	Percentage content [%]
Maize	12.0
Wheat	19.0
Soybean	32.0
Fishmeal	20.0
Fodder yeast	5.0
Rapeseed oil	9.0
II-calcium phosphate	0.8
Chalk Fodder	1.2
Premix[1]	1.0

[1]Premix (1kg): VITAMIN A - 4 400.00 IE, VITAMIN D3 – 680.00 IE, VITAMIN E – 6.00 mg, VITAMIN B1 – 0.60mg, VITAMIN B2 – 1.20mg, BIOTIN – 40.00mcg, VITAMIN B6 – 0,8mg, VITAMIN B12 – 6000.00mcg, VITAMIN K – 0.8mg, NIACIN – 20.00mg, FOLIC ACID – 0.16mg, Ca PANTOTHENATE – 4.00mg, Mn – 16mg, Zn – 20mg.

Raw materials used in the production of the carp feed were grinded with a hammer mill H-111/3 type, using sieves with the openings of 2 mm. 10 kg of the sample was prepared and mixed for 10 minutes in a ribbon mixer. After mixing the ingredients, their moisture content was tested. The mixtures were once again placed in the mixer and moistened by adding water to the final moisture content of 25%, 27% and 29% d.m. The moisture content was determined by a drying method according to PN-76/R-64752.

During the production of feed, the following process parameters were adopted: heat treatment temperature from 110°C to 140°C (various in different extruder sections), the degree of screw compression 1:3, screw speed 80, 100 and 120 rpm, rotational speed of the knife: 1200-1500 rpm, die with 3 holes of 2.5 mm diameter each [12].

The final stage of production was vacuum coating of feed with soybean oil, in which the premix had been dissolved. Fat liquidation was performed in a vacuum mixer of the authors' own construction equipped with a stirrer. Oil and the premix were injected inside by a spray nozzle at 0.08 MPa. The process of fat liquoring and stirring lasted 10 minutes.

The examination of extrusion-cooker's efficiency was performed by determining the mass of the extrudates obtained in 5 minutes for all the applied mixtures of raw materials and process parameters. The measurements were carried out six times for each series of tests, the results being the average of the measurements. The efficiency was expressed in $kg{\cdot}h^{-1}$ according to the formula:

$$Q = \frac{m}{t} \cdot [kg \cdot h^{-1}], \qquad (1)$$

where:
Q – extruder's efficiency,
m – weight of extrudate obtained during, the measurement [kg],
t – measurement time [h].

The measurement of energy consumption was conducted by a standard wattmeter connected to the extrusion-cooker's motor unit. Taking into account the specifications of the engine installed in the extrusion-cooker TS-45, and determining the motor load and efficiency measured at consecutive attempts, the values were converted into the value of specific mechanical energy (SME) according to the formula [1, 5, 8, 10, 15, 17, 20]:

$$SME = \frac{N \cdot O \cdot P}{N_m \cdot 100 \cdot Q}[kWh \cdot kg^{-1}], \qquad (2)$$

where:
N - screw speed [rpm],
N_m - max. srew speed [rpm],
P - power [kW],
O - motor load [%],
Q - process efficiency $[kg{\cdot}h^{-1}]$.

The examination of water stability of carp feed

Water stability of the obtained carp feed was assessed using the Hastings-Hepher method in own modification. The aim of the research was to determine the loss of the extrudate mass during the bath at temperature similar to water temperature in the pond, simultaneously stimulating water movements which caused the fall of feed onto the bed. The device equipped with base, electric engine, electric regulator of rotations and two containers with water, where containers with the examined samples were immersed, was used for the experiment. The extrudate was weighed to 0.01 g twice. The weighed samples were placed in two containers made of wire net with the mesh diameter of 0.1 x 0.1cm and 3x6x9cm linear size. One liter of water at temp. 20°C, 22°C and 24°C was placed to each of the containers. The containers with feed were suspended and the device put into motion with the frequency of 1 rotation of the container per 8 seconds. The testing lasted 60 minutes, after which the containers were put away for draining and dried at the temperature of 110°C to obtain constant weight. Next, the weight of the samples was compared with the weight of the feed before testing. The obtained results were expressed as water stability measurement. The stability was calculated from the following formula:

$$S = \frac{m_g}{m_n} * 100[\%], \qquad (3)$$

and after:

$$m_w = \frac{m * W}{100}[g], \qquad (4)$$

$$m_n = m - m_w \, [g], \qquad (5)$$

where:
S – water stability [%],
m_g – sample mass after testing and drying [g],

m_n – dry granulate [g],
m_w – water mass in granulate used in testing [g],
m – granulate weight after soaking [g],
W – moisture [g].

All measurements were carried out in 6 replications [18,20].

RESULTS

All fish feeds were assessed in terms of their usefulness. Physical properties of these feeds, in particular their water stability and influence on aqueous environment contribute to the growth rate of fish and better living conditions in the pond. During the extrusion process, the influence of the initial moisture content of mixtures designed for the production of feed on their efficiency and the consumption of energy was observed [7]. It was proved that the efficiency of the extrusion process increased both with the higher extruders' screw speed and the growth of moisture content of the mixture. The highest efficiency of the extrusion process (30.5 kg·h^{-1}) was observed for the mixture of 29% of moisture content produced at 120 rpm, whereas the lowest efficiency was observed for the mixture of 25% of moisture content produced at 80 rpm^{-1}. Results are presented on the Fig. 1.

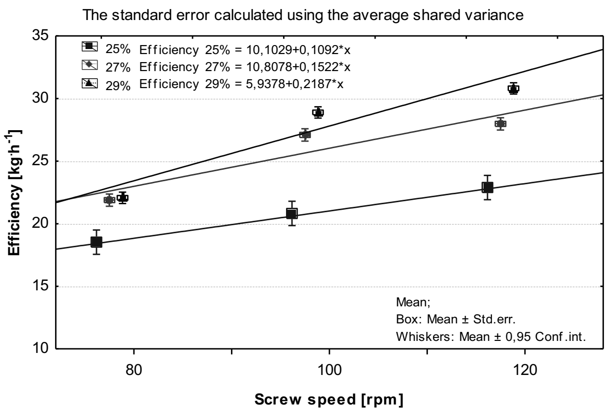

Fig. 1. The influence of the mixture moisture content and screw speed on the efficiency of the extrusion-cooking of carp feed

The application of extrusion techniques to the production of selected blends requires the determination of SME values, necessary to obtain a single mass of the product, which indicates whether the production is profitable. SME values depended on the changes of extrusion parameters, i.e. changes in screw speed and the moisture content of the mixtures. SME values decreased together with the growth of moisture content of raw mixtures.

The highest SME values (0.21 kWh·kg^{-1}) were observed at the extrusion of the mixture with 25% humidity, with the application of 120 rpm of screw speed. The lowest SME values (0.099 kWh·kg^{-1}) were observed at the extrusion of the mixture with 29% of moisture content with the application of 80 rpm screw speed of extruder (Fig. 2).

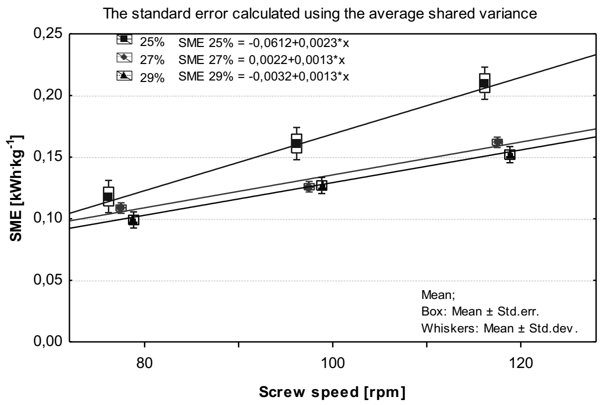

Fig. 2. The influence of the mixture moisture content and the screw speed on SME during the processing of carp feed

Sorensen et al. [18] observed that SME values ranged from 0.034 kWh·kg^{-1} to 0.039 kWh·kg^{-1} at the production of trout feed *(Oncorhynchusmykiss)*, where single screw extruder with conditioner was applied. Lower SME values observed by Sorensen were the result of the composition of feed, a higher content of fishmeal characterized by a limited number of fibers. The application of conditioner, which enables thermal processing of particular components, gives the possibility to dose more fat inside the conditioner. Water stability of the extrudates, which determines its quality, was another physical property measured. The experiment of the process of water stability of carp feed was carried out for water at 20°C, 22°C and 24°C. The extrudates produced at 80 rpm indicated the highest water stability, allowing for the whole range of moisture content of applied mixtures.

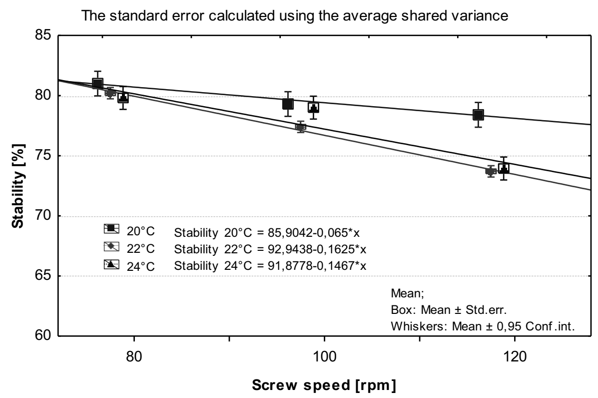

Fig. 3. The influence of the screw speed and pond's water temperature on the water stability of the extruded carp feed (mixture of 25% m. c.)

The growth of the screw rotations by 20 rpm caused the decrease of water stability by a few percent. The extrudates produced from mixtures of 25% humidity indicated the highest stability ranging from 78 to 81% (Fig. 3).

In the case of mixtures containing 25% of moisture content and processed at 80 rpm, the temperature of water applied for testing the feed slightly influenced water stability of carp feed.

The increase of the screw speed influenced the decrease of water stability in all the applied mixtures. The lowest water stability (67% – 70%) was observed at 120 rpm and the moisture content of mixtures at 27% and 29%, respectively (Fig. 4, 5).

The result may be considered satisfactory: the guarantees enough time for fish to eat the extrudate and contributes to smaller contamination of the reservoir. Pound's water temperature has important influence on the fish growth during intensive feeding, especially in summer. Fish belonging to the carp family have a tendency to feed together with the growth of temperature: the feed is eaten faster, which contributes to smaller contamination of the pond/reservoir.

Slightly lower values of water stability of the extrudates were observed for the mixtures tested at 24°C (the differences indicated approximately 2%). The mixtures containing 27% of moisture content and processed at the maximal speed of screw indicated the biggest difference (approximately 7%) depending on water temperature applied for testing.

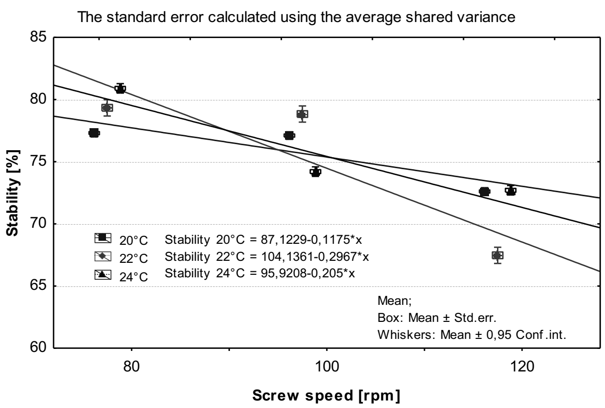

Fig. 4. The influence of pond's water temperature and the screw speed on water stability of the extruded carp feed (mixture of 27% m. c.)

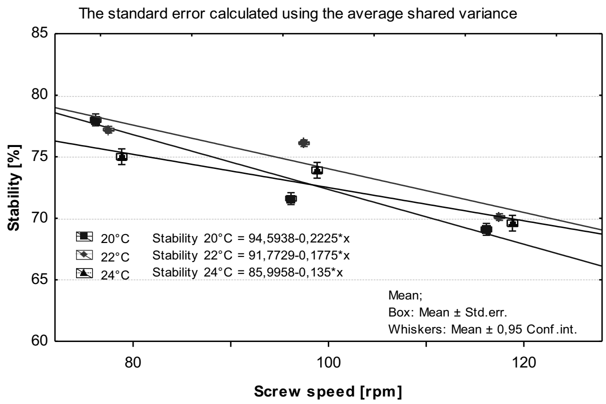

Fig. 5. The influence of the pond's water temperature and the screw speed on water stability of the extruded carp feed (mixture of 29% m. c.)

CONCLUSIONS

The efficiency of the extrusion-cooking of carp feed was higher when the mixture of raw materials with higher initial moisture content was processed at higher screw speed. However, an increase of the screw rpm usually resulted in higher energy consumption (SME) during extrusion-cooking, application of more water to the mixture (at softer level) can optimize the costs of processing and keeping proper level of the products quality. That has to be done on the compromise level.

The carp feed produced from the mixture with 25% of moisture content indicated the highest water stability. Water stability of extrudates decreased with the growth of screw speed. Pond's water temperature used during testing did not show substantial influence on the water stability of the extrusion-cooked carp feed.

REFERENCES

1. **Chung-Wen Su 2007.** Effects of eggshell powder addition on the extrusion behaviour of rice. Journal of Food Engineering, 79, p. 607-612.
2. **Dudkiewicz D. 2002.Technologia i** wyposażenie do produkcji ekstrudowanych pasz dla ryb. Magazyn Przemysłu Rybnego, 1, p. 5-9.
3. **Guziur J., Białowąs H., Milczarzewicz W. 2003.** Rybactwo stawowe. Oficyna Wydawnicza „Hoża", Warszawa.
4. **Harper J.M. 1981.** Extrusion of Foods. vol. 1, CRS Press Inc., USA.
5. **Janus P. 2002.** Metoda pomiaru energii użytecznej w procesie technologicznym przetwórstwa żywności oparta na stratach poszczególnych silnika elektrycznego i maszyny roboczej. Acta Scientiarum Polonorum. Technologia Alimentaria 1(1), p. 103-111.
6. **Koreleski J., Świątkiewicz S. 2006.** Zakaz stosowania antybiotyków – co dalej? Pasze Przemysłowe, 2/3, 22-29.
7. **Korol W. 2006.** Wymagania w zakresie zapewniania jakości handlowej w produkcji i obrocie pasz. Pasze Przemysłowe, 2/3, p. 29-35.
8. **Kulig R. 2007.** Effect of conditioning methods on energy consumption during pelleting. TEKA Commission of Motorization and Power Industry in Agriculture, 7a, p. 52-58.
9. **Lee K-J., Dabrowski K., Rinchard J., Gomez C., Guz L. 2004.** Supplementation of maca (*Lepidiummeyenii*) tuber meal in diets improves growth rate and survival of rainbow trout Oncorhynchusmykiss (Walbaum) alevins and juveniles. Aquaculture Research, 35, p. 215-223.
10. **Le Roux D., Vergnes B., Chaurand M., Abecassis J. 1995.** A thermomechanical approach to pasta extrusion. Journal of Food Engineering, 26, p. 351-368.
11. **Mościcki L., Mitrus M., Wójtowicz A. 2007.** Technika ekstruzji w przemyśle rolno-spożywczym. PWRiL, Warszawa.
12. **Mościcki L. 1998.** Produkcja karmy dla zwierząt domowych i ryb. Przegląd Zbożowo-Młynarski, 5.

13. **Mościcki L. 2000.** Technika ekstruzji w przetwórstwie rolno-spożywczym. Wyd. specjalne, Przegląd Zbożowo-Młynarski, Warszawa.
14. **Oniszczuk T. 2002.** Metodyka badań ekstrudowanych karm dla ryb. Inżynieria Rolnicza, 4(37), p. 257-263.
15. **Ryu G.H., Ng P.K.W. 2001.** Effects of selected process parameters on expansion and mechanical properties of wheat flour and cornmeal extrudates. Starch, 53, p. 147-154.
16. **Salah Mesalhy A. Mohamed Fathi M. George J. 2008.** Echinacea as immunostimulatory agent in Nile Tilapia (OreochromisNiloticus) via earthen pond experiment. 8TH International Symposium on Tilapia in Aquaculture.
17. **Singh N., Smith A.C. 1997.** A comparison of wheat starch, whole wheat meal and oat flour in the extrusion cooking process. Journal of Food Engineering, 34, p. 15-32.
18. **Sorensen M., Storebakken T., Shearer K.D. 2005.** Digestibility, growth and nutrient retention in rainbow trout *(Oncorhynchusmykiss)* fed diets extruded at two different temperatures. Aquaculture Nutrition, 11, p. 251-256.
19. **Szumiec J., Stanny L. 1975.** Ocena stabilności pasz granulowanych stosowanych w żywieniu karpi. Gospodarka Rybna, 12, p. 3-5.
20. **Szymanek M. 2008.** Energy-consumption at sweet corn threshing, TEKA Commission of Motorization and Power Industry in Agriculture, 8, p. 241-246.
21. **Thomas M., Van der Poel A.F.B. 1996.** Physical quality of pelleted animal feed 1. Criteria for pellet quality, Animalfeed Science and Technology, 61, p. 89-112.

WPŁYW WARUNKÓW PROCESU NA JAKOŚĆ I ENERGOCHŁONNOŚĆ EKSTRUDOWANEJ KARMY DLA KARPIA

S t r e s z c z e n i e. W pracy przedstawiono wyniki badań wpływu prędkości obrotowej ślimaka ekstrudera oraz wilgotności surowców na zapotrzebowanie energii jednostkowej oraz stabilność wodną karmy dla karpia w zależności od temperatury wody stosowanej w teście stabilności wodnej ekstrudatu. Karmę wytwarzano ze standardowych mieszanek surowcowych o zróżnicowanej wilgotności początkowej mieszanki (25%, 27% i 29%) oraz stosując obróbkę ciśnieniowo-termiczną przy użyciu zmodyfikowanego ekstrudera jednoślimakowego TS-45. W wyniku przeprowadzonych badań stwierdzono, że wzrost wilgotności mieszanek przeznaczonych do ekstruzji wpływał na spadek SME. Wydajność procesu ekstruzji zwiększała się wraz ze wzrostem prędkości obrotowej ślimaka ekstrudera oraz wraz ze wzrostem wilgotności mieszanki. Najwyższą stabilnością wodną charakteryzowała się karma wyprodukowana z zastosowaniem 80 obr.min-1 ślimaka ekstrudera przy wilgotności mieszanki surowcowej 25%.

S ł o w a k l u c z o w e: ekstruzja, właściwości fizyczne, stabilność wodna, ekstruder jednoślimakowy.