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PHYSICAL PROPERTIES AND ENERGY CONSUMPTION OF THE MANUFACTURE OF EXTRUSION-COOKED CARP FEED ENRICHED WITH ECHINACEA

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Summary. The paper presents the results of the study of an influence of an addition of Echinacea (priobiotic) on physical properties of extruded carp feed. The feed was obtained from standard mixtures of raw materials with an addition of a varied amount of ground and dried Echinacea root. The material was put to a baro-thermal treatment in a single screw extrusion-cooker type TS-45. The results of the examinations showed that the addition of a ground Echinacea root of up to 6% did not have any significant impact on the extrusion process, productivity, radial expansion ratio or bulk density of carp feed. It was noted that with an increasing content of Echinacea in the feed composition there was a growing demand per unit for the specific mechanical energy (SME); however, the study revealed a minor decline of the extrudates kinetic durability and stability in water.

Keywords: Echinacea, extrusion, physical properties, water stability, single screw extrusion-cooker.

INTRODUCTION

The development of freshwater fish farming in Poland requires that more attention 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 fisheries management, a knowledge is needed of fish biology, fish dietary needs, nutrition methods and quality of feed ingredients [Dudkiewicz 2002 Guziur et al. 2003, Koreleski, Świątkiewicz 2006]. According to veterinarians and zootechnicians, the addition of herbs such as maca (Lepidium meyenii) or echinaca (Echinacea purpurea) used in the manufacture of immunizing medicine to fish feed can reduce death rate, improve resistance to diseases and, in the case of maca, expand muscular tissue [Lee et al. 2004, Salah Mesalhy A. 2008]. This is particularly important at the initial stage of carp farming when the fry mortality is relatively high.

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, which may undergo lixiviation or dilution leads to severe losses in the aquatic environment by the deterioration of oxygen balance in ponds and an 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. A few years ago, the most popular method was dry or wet pelleting. Since the quality of pellets is not suitable for fish due to low water stability and limited nutritional effects, the recent years have seen the replacement of such a feed type by extruded feed [Korol 2006, Moscicki 1998, hum, Stanny 1975]. Extrusion technique allows for an introduction of various types of components that have not yet been used in the production of feed for fish. These components have a significant impact on improving the 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 quality products [Harper 1981, Moscicki 2000, Moscicki et al. 2007]. The aim of this study was to examine an influence of fragmented Echinacea root (Echinacea purpurea) on the functional properties of carp feed and on the energy consumption during the production process.

MATERIALS AND METHODS

Six different mixtures of varied material composition were used (Table 1 and 2). The basic raw materials and components were delivered by Animex Grupa Drobiarska SA, Zamość, Poland. Dried Echinacea root was obtained from the herb farm of Waldemar Lupa, Kolonia Dobryniów, Poland. The balancing of feed recipe and the production technology were developed on the basis of commonly available nutritional standards as well as following the recommendations of the scientists at the Department of Biology and Fish Diseases, University of Life Sciences in Lublin. The marking of the basic nutrients was performed in the Central Equipment Laboratory, University of Life Sciences in Lublin.

The feed was produced by extrusion on a single screw extrusion-cooker TS-45, fitted with a plasticizing unit of L/D ratio of 16/1.

Table 1. The content of feed components in the prepared blends (%)

Blend type Echinacea addition (%)	Metabolic energy (MJ/kg)	Protein general (%)	Raw fibre (%)	Raw fat (%)	Ca general (%)	P general (gP/100g))	N general (%)
A-6	14.93	38.95	7.51	9.35	1.42	0.69	6.23
B-3	14.72	37.98	7.54	9.82	1.42	0.70	6.03
C-2	14.71	37.96	7.33	9.38	1.40	0.71	6.00
D-1	15.26	38.55	6.21	9.48	1.39	0.70	6.17
E-0,5	15.34	38.91	6.08	9.66	1.38	0.74	6.22
F-0	15.16	38.67	6.67	9.52	1.49	0.72	6.18

Table 2. The composition of raw materials in individual compounds (%)

Balance component	Share in blends					
Wheat (%)	16	19	20	21	21	20.9
Yellow lupine (%)	10	10	10	10	10	10
Soybean (%)	30.9	30.9	30.9	30.9	31.4	32
Fishmeal[1] (%)	20	20	20	20	20	20
Fodder yeast (%)	5	5	5	5	5	5
Soybean oil (%)	9	9	9	9	9	9
II-calcium phosphate (%)	0.8	0.8	0.8	0.8	0.8	0.8
Chalk Fodder (%)	1.3	1.3	1.3	1.3	1.3	1.3
Premix[2] (%)	1	1	1	1	1	1
Echinacea (%)	6	3	2	1	0.5	0

[1] Crude protein-72%
[2] Premix (in 1kg of premix)- 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 feed were fragmented by a hammer mill H-111/3 type, using sieves with the openings of 2 mm. 20 kg of sample were prepared by mixing for 10 minutes in a drum mixer. After mixing the ingredients, their humidity was studied. The mixtures were once again placed in the mixer and moistured by adding water to a final humidity level of 25% d.m. The humidity was determined by the drying method according to PN-76/R-64752 [1976].

The blend obtained in such a way was stored in sealed polyethylene bags for 8 hours at ambient temperature in order to achieve a homogenous sample mixture. Thus, the prepared mixture was administered to a modified dispenser extruder subjecting them to working pressure - heat. The prepared mixture was fed into the modified extruder feeder and subject to heat and pressure treatment**.**

During the production of feed, the following process parameters were adopted:

- heat treatment temperature from 110ºC to 140ºC (varied in different extruder sections)
- the degree of screw compression 1:3,
- screw speed 100 rpm^{-1},
- rotational speed of the knife: 1200-1500 rpm^{-1},
- die with 3 holes of 2.5mm diameter each.

The obtained extrudates were dried in a drawer-type dryer with a forced circulation of air heated to 50ºC. The final stage of production was vacuum coating of feed with soybean oil, in which the premix had been dissolved. Fat liquoring was performed in a vacuum mixer own construction equipped with a stirrer. Oil together with the premix was 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 capacity was possible by determining the mass of the extrudate obtained in 5 minutes for all the applied mixtures of raw materials and the adopted process parameters. The measurement was carried six times for each series of tests, the result being the average of the measurements. The performance is expressed in kg/h according to the formula:

$$Q = \frac{m}{t} \text{ [kg/h]}, \tag{1}$$

where: Q – extruder's performance,
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 driving unit. Taking account of the specifications of the Shrage-type engine installed in the extrusion-cooker TS - 45, and after determining the engine load and performance measured at consecutive attempts, the values were converted into the unit of specific mechanical energy (SME) according to the formula proposed by Ryu [Chung-Wen Su 2007, Ryu, Ng 2001, Singh, Smith 1997, Le Roux et al.1995,]:

$$SME = \frac{N \cdot O \cdot P}{N_m \cdot 100 \cdot Q} \text{ [kWh/kg]}, \tag{2}$$

where: N – screw speed [rpm],
N_m – max. screw speed [rpm],
P – power [kW],
O – engine load [%],
Q – extrusion-cooker's performance [kg/h].

Another method of establishing the SME consumption per unit was proposed by Janus [Janus 2002]. The effective energy used in the technological process is shown in the following equation:

$$W_u = P_u \cdot t \text{ [kJ]}, \tag{3}$$

where: W_u – effective energy [kJ],
P_u - effective power [kW],
t – process time.

The SME indicator corresponding to the volume of material processed during the technological process is determined by the relation:

$$k = \frac{W_u}{m}, \tag{4}$$

where: k – indicator of SME consumption per unit [kJ/kg],
m – weight of the processed material during technological process [kg].

In order to determine the basic physical properties of the obtained extrudates, a standard methodology was used:

- the degree of radial expansion was measured as the ratio of the extrudate diameter and the diameter of the die [Harper 1981, Oniszczuk 2002],

- shaken density of extrudate according to PN-65/2-04003 [Thomas, Van der Poel 1996, Walczyński 2001, Oniszczuk 2002],
- bulk density of extrudate according to BN-87/9135-09 1987, [Thomas, Van der Poel 1996, Walczyński 2001, Oniszczuk 2002],
- slip angle of extrudate according to BN-87/9135-10 1987, [Thomas, Van der Poel 1996, Walczyński 2001, Oniszczuk 2002],
-durabilityof extrudate according to PN-R-64834 1998, [Thomas, Van der Poel 1996, Walczyński 2001, Oniszczuk 2002],
- the degree of water absorption according to WAI [AACC 5630 1995, Harper 1981, Oniszczuk 2002],
- the degree of water solubility-WSI [Harper 1981, Oniszczuk 2002].

All the measurements were made in 10 replications.

RESULTS

Depending on the purpose of feed (floating trout feed, sinking carp feed), the factors subject to assessment are essential properties such as usefulness, the possibility of feeding automation and the stability of water, influencing the quality of aquatic environment. The analysis of the extrusion-cooking processes was aimed to characterize the effect of addition of Echinacea on the performance of the process, its energy consumption and the physical features of the feed obtained in specific conditions [Korol 2006].

The measurement results of extruder's capacity showed that the addition of ground Echinacea root of up to 3% would improve the performance in question. However, in the case of a 6% Echinacea addition the performance was reduced. This is due to an increase of the fibre content and a decrease of wheat sharps in the mixture (Fig. 1).

When applying the extrusion-cooking technology for the manufacture of specialized feed mixtures, a very important factor to consider is the unit consumption of specific mechanical energy (SME) needed to obtain a unit weight of the product.

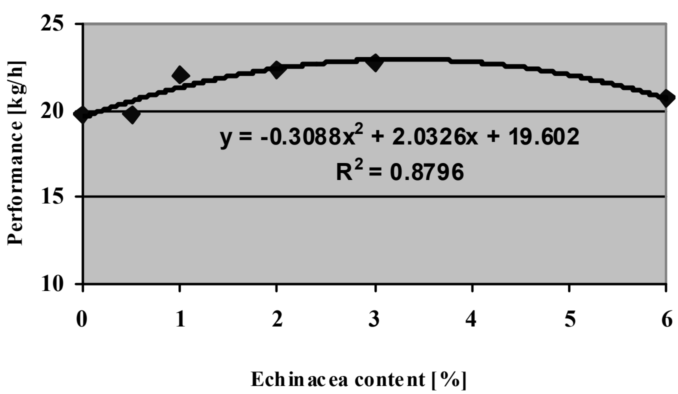

Fig. 1. The effect of Echinacea addition on the performance of extrusion-cooking of carp feed

These values were contingent upon changes in extrusion parameters, i.e. rotational speed of the screws, humidity of mixtures and temperature of extrusion. At the rotation of the extruder's screw of 100 r/min^{-1}, the load of the extruder's engine was 66%.

With an increase in the percentage of Echinacea in the mixture, the SME values decreased (Fig. 2). The exceeding of the critical value of Echinacea addition (above 3%) and consequently the increase in the fibre content in the mixture resulted in a surge of SME value.

Sorensen et al. [2005] found that in the production of feed for rainbow trout (Oncorhynchus mykiss), using a single screw extrusion-cooker equipped with a conditioner, the SME value varied between 0034kWh/kg and 0039kWh/kg. Lower values of SME reported by Sorensen primarily result from the material composition of feed, increased content of fishmeal, reduced content of fibre material, application of a conditioner in which the material is pre-thermally treated and the possibility of feeding greater quantity of fat directly inside. The rise in the extrusion temperature barely affected the reduction of the value of SME. Ryu [2001] used a twin-screw extrusion-cooker and reported that the SME value during extrusion of wheat flour and fragmented maize grains ranged between 0.067kWh/kg and 0293kWh/kg for flour and between 0074kWh/kg and 0343kWh/kg for maize grains.

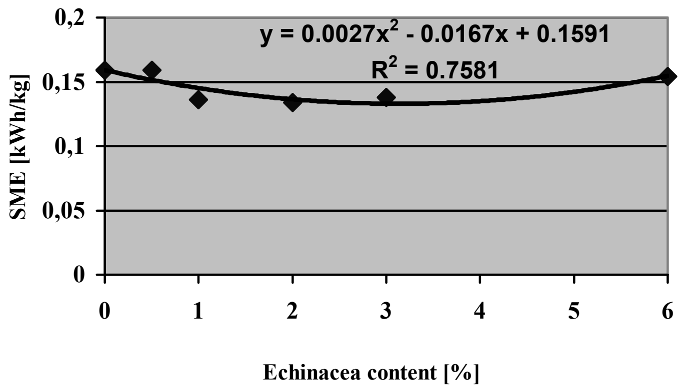

Fig. 2. The influence of Echinacea addition on the modification of unit demand for SME during extrusion of carp feed

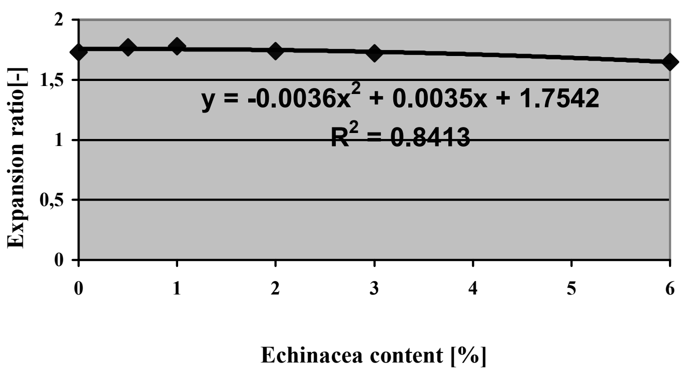

Fig. 3. The influence of Echinacea addition on the value of radial expansion ratio for carp feed

The measurements of the degree of radial expansion of the extrudates did not reveal significant differences among the feeds (Fig. 3). The difference in value between the lowest and the highest degree of expansion was only 0.1. It testifies to the fact that the addition of Echinacea did not significantly affect the product expansion.

Another physical property measured, indicating the quality of extrudate, was bulk density. Bulk density is essential for the calculation of the efficiency of the conveying and packaging machinery and in the choice of capacity of silos and flat storage [Walczyński 2001]. It was observed that the growing Echinacea content caused slight increase in bulk density. The average extrudate density was about 400 kg•m^{-3}. Because all the recipes used for the production had the same humidity and the extrusion processes was conducted at fixed technical parameters the range of results was not large (Fig. 4).

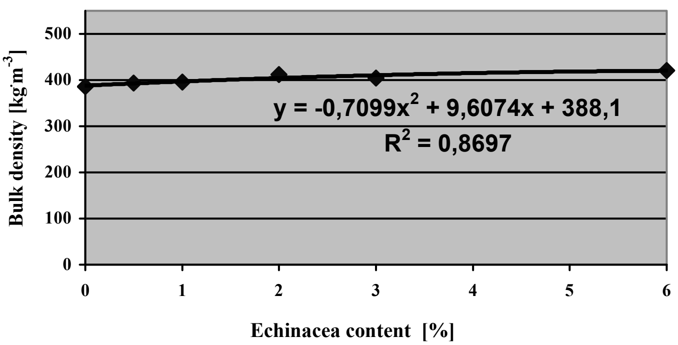

Fig. 4. The influence of Echinacea addition on bulk density of carp feed

The obtained results of the measurements of extrudates density demonstrate that the feed will be floating on the surface of water over a long period of time, which is not recommended when feeding carp which, in principle, feeds at the bottom of a reservoir. Hence, it is necessary to provide much greater density of material, which requires appropriate configuration of screws and the presence of the so-called degassing unit.

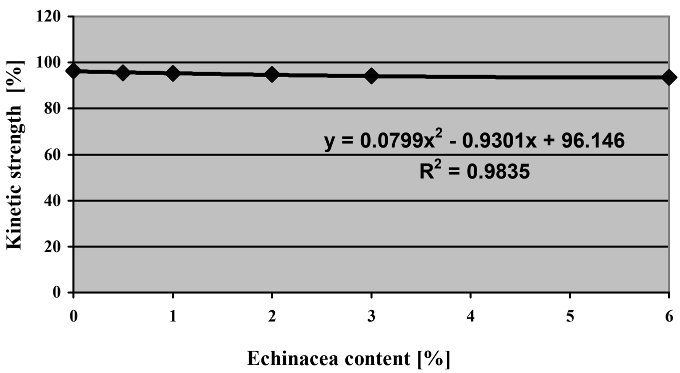

Fig. 5. The influence of Echinacea addition on kinetic strength of carp feed

The measurement of kinetic strength of extrudates was determined by means of a Pfost camera. The highest strength was reported for the feed without the addition of Echinacea (96.31%) and lowest for the feed containing 6% of Echinacea (93.43%) (Fig. 5). It's visible that even 1% addition of fibre in the mixture resulted in its capability to agglomeration. A more porous and fibrous structure, loss of wheat and an increased share of dust fractions with a growing content of Echinacea in the composition of the mixture reduces extrudates durability. This is caused by the weakening of the bond of extrudate structure, which translates onto a rising slip angle (see Fig. 6).

The lowest value of the slip angle was observed for the feed without the addition of Echinacea (27.6 º), and characterized by the highest value of the maximum amount of feed containing Echinacea (31.6º). The reason for poorer mixture was the reduced content of wheat sharps.

Water absorption, expressed by the WAI (water absorption index), is a vital feature of fish feed. Extensive water absorption may lead to the diminished water stability and less effective use of feed and, what follows, poses a threat of pollution to water reservoirs.

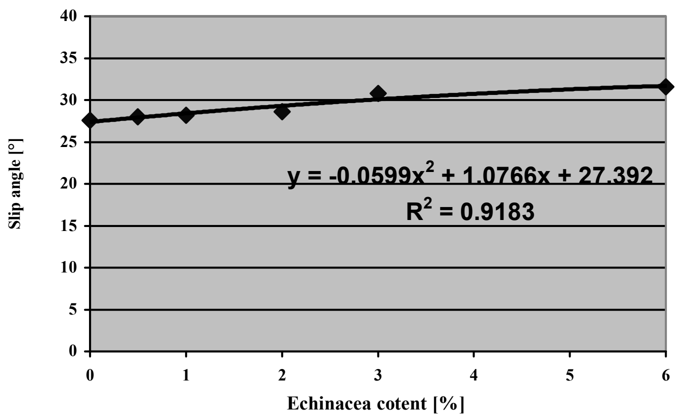

Fig. 6. The influence of Echinacea addition on slip angle of individual fish feed

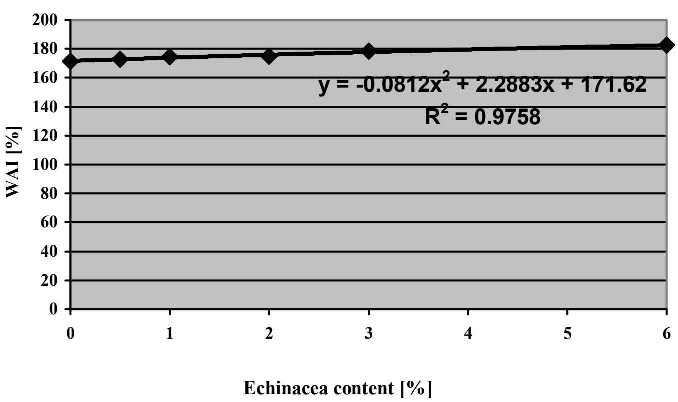

Fig. 7. The influence of Echinacea addition on water absorption index of carp feed

The examination of WAI showed that the obtained feed displayed water absorption capacity of 171.45% to 182.38% (Fig. 7), which should be regarded as a good result (differences not exceeding 10 percentage points). The most water was absorbed by the feed containing 6% of Echinacea addition, the least was absorbed by the feed with no additive. In previous studies, it had been reported that the feed containing the maximum amount of the additive was the most susceptible to damage in the Pfost's test, i.e. it had the least compact structure. This explains the propensity for water absorption.

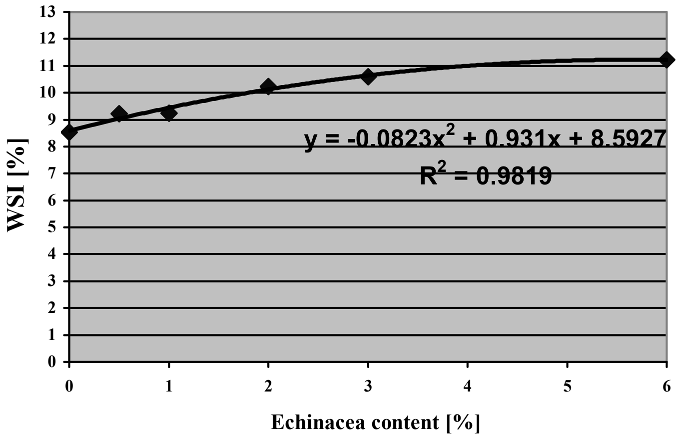

Fig. 8. The influence of Echinacea addition on water solubility of carp feed

The examined WSI for the obtained feed resembles the WAI. The most favourable WSI values were seen in the feed containing Echinacea. The loss of components in water was reported at 8.54%. The highest value of the WSI was observed for the feed containing 6% of Echinacea, which amounted to a loss of ingredients at 11.22%. It can be therefore concluded that this feed showed the least favourable quality parameters in terms of the WAI, WSI and durability. This does not disqualify the feed in terms of physical characteristics (reduced parameters). Due to health considerations, Echinacea appears to be a practical additive to recommend at the level of 3% of probiotic, which significantly protects both the quality and nutritional attributes.

CONCLUSIONS

1. The addition of Echinacea to carp feed mixtures had a varied impact on the quality of extruded feed, although, in the main, it did not cause a significant deterioration of its basic physical and utility properties. This applies especially to the degree of expansion, apparent density and the WAI for most samples.

2. Along with the increasing content of Echinacea in the mixtures, the extrusion-cooking efficiency was on the minor increase. The addition of 3% of Echinacea proved to be a critical value and, if exceeded, caused the process efficiency to diminish. A similar tendency was observed with regard to the per-unit consumption of energy (SME).

3. The feed with a much higher Echinacea content displayed lowered kinetic strength, due to a more fibrous structure and a greater dust fraction share, easily separated from the extrudate. It was also the reason for the growing slip angle for this feed.

4. The WAI for the examined extrudates ranged from 171.45% for the feed without Echinacea addition to 182.38% for the feed containing 6% of Echinacea, which was influenced by the porous structure of the extrudate. Despite the relatively high WAI, only minor amounts of soluble substances were lost (WSI from 8.54% for the feed containing Echinacea to 11.22% for the feed

containing 6% of Echinacea). Therefore, the degree of agglomeration of extrudates during extrusion-cooking is acceptable.

5. Carp feed should display a higher density, which is associated with the specific feeding habits of this fish. This feed should sink to the bottom of a reservoir. The extrusion-cooker used in our examination did not have the function of degassing of the mixture in the final section, which would have increased the degree of concentration of the granulated product. An alternative solution may be the application of ballast substance binding the product structure, such as betonite.

6. Considering the healthful properties of Echinacea and its impact on the physical characteristics of extruded carp feed, the optimum content of this ingredient should be maintained at 2 to 3%.

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WŁAŚCIWOŚCI FIZYCZNE I ENERGOCHŁONNOŚĆ WYTWARZANIA EKSTRUDOWANYCH KARM DLA KARPIA Z DODATKIEM ECHINACEA

Streszczenie. W pracy przedstawiono wyniki badań wpływ dodatku echinacea na właściwości fizyczne ekstrudowanej karmy dla karpia. Karmę wytwarzano ze standardowych mieszanek surowcowych dodając do nich zróżnicowane ilości wysuszonego, zmielonego korzenia echinacea oraz stosując obróbkę ciśnieniowo-termiczną przy użyciu zmodyfikowanego ekstrudera jednoślimakowego TS-45. W wyniku przeprowadzonych badań stwierdzono, że dodatek zmielonego korzenia echinacea w ilości do 6% nie wpłynął w sposób znaczący na przebieg procesu ekstruzji, jego energochłonność, wydajność, stopień ekspandowania promieniowego oraz na gęstość usypową karmy. Zauważono, że wraz ze wzrostem zawartości echinacea w składzie karmy wzrosło jednostkowe zapotrzebowanie energii mechanicznej SME, natomiast zmniejszyła się nieznacznie jej wytrzymałość kinetyczna i stabilność w wodzie.

Słowa kluczowe: echinacea, ekstruzja, właściwości fizyczne, stabilność wodna, ekstruder jednoślimakowy.