Ann. Anim. Sci., Vol. 22, No. 4 (2022) 1333–1340 *DOI: 10.2478/aoas-2022-0039*

sciendo

HOW POTENTIALLY SUSTAINABLE SOLUTIONS MAY BE UNSUSTAINABLE IN PRACTICE: CARROT POMACES IN COMMON CARP NUTRITION*

Joanna Kowalska[1], Natalia Homska[1], Lilianna Hoffmann[1], Mateusz Rawski[1], Grażyna Czyżak-Runowska[2], Piotr Konieczny[3], Bartosz Kierończyk[4], Jan Mazurkiewicz[1]♦

[1]Faculty of Veterinary Medicine and Animal Science, Department of Zoology, Laboratory of Inland Fisheries and Aquaculture, Poznań University of Life Sciences, Wojska Polskiego 71 c, 60-625 Poznań, Poland
[2]Faculty of Veterinary Medicine and Animal Science, Department of Small Mammals Breeding and Raw Materials of Animal Origin, Złotniki, 62-002 Suchy Las, Poland
[3]Faculty of Food Science and Nutrition, Department of Food Quality Management, Poznań University of Life Sciences, Wojska Polskiego 31, 60-624 Poznań, Poland
[4]Faculty of Veterinary Medicine and Animal Science, Department of Animal Nutrition, Poznań University of Life Sciences, Wołyńska 33,60-637 Poznań, Poland
♦Corresponding author: jan.mazurkiewicz@up.poznan.pl

Abstract

The aim of this study was to evaluate the effects of carrot pomaces dried at two temperatures as a feed component on growth performance, environmental sustainability, and meat quality in common carp (*Cyprinus carpio*). Three diets were developed: a control without pomace (CON); CPL with 15.5% carrot pomace dried at 40°C; and CPH with 23.6% carrot pomace dried at 120°C. A total of 240 two-year-old common carp (average body weight of individual: 1025 g) were randomly distributed into 12 tanks, four per treatment, including 20 fish per tank. The experiment was performed using an outdoor open flow aquaculture system. The growth trial lasted 60 days, after which fish samples were taken for analysis of meat quality parameters. There were no significant differences between groups in terms of the final body weight, protein efficiency ratio, and survival rate. However, in terms of weight gain, specific growth rate, and feed conversion ratio, fish fed the CPH diet exhibited significant worsening. Moreover, the fillets of fish from the CPH group exhibited a darker coloration compared to the CON diet. It is concluded that high temperature drying of carrot pomace added to carp diet negatively affected fish quality. It should be also emphasized that inclusion of the both carrot pomaces tested in this study significantly increased the usage of fish meal per kilogram of fish body weight gain. These results showed a reduced efficacy of using carrot pomace in practical and sustainable common carp nutrition.

Key words: common carp, carrot pomace, meat quality, sustainable aquaculture

The primary goal of modern aquaculture is to achieve sustainable resource use of aquafeeds while considering environmental and economic requirements. Suggestions for realizing this aim have included the use of agriculture by-products (Hall, 2015). Fish nutrition relies on the common use of ingredients such as soybean meal, fish meal, corn, wheat, rice, for which it competes in the marketplace with the terrestrial animal husbandry and direct demand for human consumption (Hardy and Kaushik, 2021). Moreover, in the last three decades, the prices of all these ingredients have doubled or even tripled, acutely impacting fish production economics (Rana et al., 2009). Recently, plant by-product uses, including bran rice meal (Lovatto et al., 2013), tomato pomace (Amirkolaie et al., 2015), and olive pomace (Yildirim and Guroy, 2015), have shown high potential for bioconversion in fish nutrition.

It was estimated by the United Nations Food and Agriculture Organization (FAO) that above thirty percent of the food produced in the world is wasted every year (FAO, 2018) and losses and waste of horticultural commodities are the highest among all types of foods, reaching up to 60% (Gustavsson et al., 2011). FAO (2018) revealed that the processing of fruits and vegetables is one of the main waste-generating factors in the developed parts of China, India, Philippines, and the United States produce approximately 55 MMT of fruit and vegetable waste (FVW). Kummu et al. (2012) noted that global agricultural losses

*This study was supported by the Poznań University of Life Sciences by the statutory funding of the Faculty of Veterinary Medicine and Animal Sciences and funds of the Experimental Station of Feed Production Technology and Aquaculture in Muchocin.

could be reduced by 47% and global consumption waste by 86%. One way to reduce food waste is the development of a circular economy, and part of it could be feed for fish from by-products of the food industry.

Common carp (*Cyprinus carpio*) culture is one of the largest aquaculture areas in the world in terms of volume and range of farming, ranking third among the top ten farmed freshwater fish (FAO, 2018). Due to its omnivorous character and the ability for utilising various fiber-rich feed components, carp frequently show high potential for sustainable application in animal nutrition as an element of waste into feed and energy strategies in a circular economy (Sirakov and Velichkova, 2018; Sobczak et al., 2021).

Poland is one of the largest producers of common carp and the third largest vegetable producer in the European Union (Nawirska and Kwaśniewska, 2005; EUMOFA, 2016). On the territory, the above-mentioned country is cultivating one of the most efficient carrot production which accounts for 18% total vegetable market of the EU (Kaniszewski and Cieslak-Wojtaszek, 2010). Plant processing volume, especially in the juice industry, has increased rapidly in recent decades and currently generates between 25% to 35% of fruit and vegetable by-products, mainly pomaces (Kruczek et al., 2016; Priyadarshini and Priyadarshini, 2018). Estimates suggest that 12% of plant by-products are wasted, yet a significant portion of these by-products could be used in fish nutrition. Vegetable pomaces are considered industrial residues with high nutritional value. Their main ingredients are carbohydrates (52.5–85.0%), although their protein content is low (6.3–21.5%), as shown by Serena and Knudsen (2007). Carrot pomaces contain residues of carotene and pectin, which are precursors to vitamin B (Schieber et al., 2001), as well as bioactive, functional, and health-promoting compounds (Sharma et al., 2012).

The use of pomaces in animal nutrition could reduce water and farmland use as well as competition between humans and animals for nutrients and energy sources. However, wet or even semiliquid forms of pomaces obstruct their practical application in animal diets, thus decreasing their usefulness. Thus, to achieve suitability for feed industry use (i.e., extrusion), drying must be performed. To date, the conditions and procedures of pomace processing have not been standardized, leaving unknown how various treatments affect the active compounds and nutritive value of dried materials. Considering the above-mentioned facts, the aim of this study was to evaluate the effect of carrot pomaces dried at high and low temperatures in diets for common carp to better understand how they affect growth performance and quality of meat as well as the environmental sustainability of fish aquaculture operations. It was assumed that the inclusion of the tested components could have a positive effect on the production parameters and meat quality of the common carp and improve the environmental sustainability of fish production.

Material and methods

Ethics Statement

This study was conducted in strict accordance with the recommendations of the National Ethics Commission (Warsaw, Poland). All procedures and experiments complied with the guidelines of the Local Ethics Commission of Poznań University of Life Sciences (Poznań, Poland) with respect to animal experimentation and care of animals, and all efforts were made to eliminate or minimize suffering. Prior to sampling, fish were euthanized by tricaine methane-sulfonate (MS-222) overdosing (Topic Popovic, 2012).

Carrot pomaces and experimental feed preparation

The carrot pomaces were dried at two temperatures and durations: a low temperature (40°C for 48 h) and a high temperature (120°C for 6 h) until they reached constant weight. Chemical analysis was performed in triplicate. Dried carrot pomaces compositions were determined in accordance with AOAC (2007) procedures including dry matter by drying in an oven at 105°C to a constant weight, crude protein by the Kjeldahl method (Kjel–Foss Automatic 16210 analyzer, AISN Foss Electric, Denmark), crude lipid by the Soxhlet method (Soxtec 1043 extraction unit, Tecator, Sweden), crude fiber (Fibretec System M 1020 Hot Concentrator, Tecator Flawil, Switzerland), and ash (550°C) for 12 h (furnace by Linn High Therm GmbH, Eschenfelden, Germany). The nutritional values of carrot pomaces are described in Table 1.

Table 1. Proximate composition and characteristics of carrot pomaces used in the experimental feeds

Parameter	CPL[1]	CPH[2]
Chemical composition (% as it is)		
Dry matter	86.66	90.86
Crude protein	7.42	6.47
Crude fiber	20.43	14.45
Crude fat	0.56	0.49
Ash	5.89	5.01
Nitrogen-free extract	52.36	64.44
Colorimetric parameters		
L[3]	54.50	64.00
a[4]	6.27	4.24
b[5]	16.70	18.70

[1]Carrot pomace (n=1) dried at low temperature (40°C); [2]Carrot pomace (n=1) dried at high temperature (120°C); [3]Lightness of color (+ = lighter, - = darker); [4]Saturation towards red (+ = redder, - = greener); [5]Saturation towards yellow (+ = yellower, - = bluer).

There were three experimental diets (Table 2): a control diet (CON) without pomace, the 2nd diet with 15.5% carrot pomace dried at a low temperature (CPL),

and the 3rd diet with 23.6% carrot pomace dried at a high temperature (CPH). The experimental diets were calculated as feeds meant for practical common carp nutrition with maximal possible contents of tested carrot pomaces, which resulted in various levels of those components incorporation. Therefore, the diets were calculated as isonitrogenous (30% crude protein) and isoenergetic (16.7 MJ kg^{-1}) with a 5% of crude fiber content (NRC, 2011). All experimental feeds were processed by extrusion using a single-screw warm extruder (Metalchem S-60 Gliwice, Poland). The extrusion conditions were as follows: a 90°C cylinder temperature in a zone of increasing pressure, a 100°C cylinder temperature in the zone of high pressure, a 110°C head temperature, a 52-rpm speed screw, and a 6-mm nozzle diameter.

Table 2. The composition of experimental diets

Ingredients (g kg^{-1})	Diet		
	CON	CPL	CPH
Fishmeal	147	173	184
Erythrocyte meal	80	80	80
Yeast	40	40	40
Soybean meal	40	40	40
Wheat	265	448	356
Wheat bran	370	0	0
CPL	0	155	0
CPH	0	0	236
Fish oil	20	26	26
Lecithin	5	5	5
Premix[1]	15	15	15
Vitamin mix[2]	1	1	1
Ground limestone	15	15	15
Choline chloride	2	2	2

[1]Polfamix W, BASF Polska Ltd. Kutno, Poland – containing per 1 kg: vitamin A 1 000 000 IU, vitamin D_3 200 000 IU, vitamin E 1.5 g, vitamin K 0.2 g, vitamin B_1 0.05 g, vitamin B_2 0.4 g, vitamin B_{12} 0.001 g, inositol 1.0 g, nicotinic acid 2.5 g, D-calcium pantothenate 1.0 g, choline chloride 7.5 g, folic acid 0.1 g, methionine 150.0 g, lysine 150.0 g, Fe 2.5 g, Mn 6.5 g, Cu 0.8 g, Co 0.04 g, Zn 4.0 g, J 0.008 g, carrier > 1000.0.

[2]Vitazol AD_3EC, BIOWET Drwalew, Poland – 1 kg contains vitamin A 50 000 IU, vitamin D_3 5 000 IU, vitamin E 30.0 mg, vitamin C 100.0 mg.

The chemical composition of the experimental feeds (Table 3) was determined according to the methods described above for carrot pomaces. Total amino acids in feeds were analyzed after hydrolyzation in 6 N HCl at a temperature of 106ºC for 24 h on an AAT 339 analyzer (Microtechna Prague, Czech Republic). Methionine and cystine were determined after they had been oxidized and fixed with formic acid. Tryptophan was determined using the colorimetric method. The gross energy of all feeds was calculated using energetic conversion factors for nutrients (kJ g^{-1}): 17.6 for carbohydrates, 23.9 for protein, and 39.8 for lipids (Bureau et al., 2002).

Table 3. Chemical composition, amino acid profile, and energetic value of experimental feeds

Parameter	Feed		
	CON	CPL	CPH
Nutrients (% of dry matter)			
Crude protein	30.01	30.01	30.07
Crude fat	6.19	6.15	6.13
Nitrogen-free extract[1]	41.72	42.41	43.16
Crude ash	7.81	8.11	8.38
Crude fiber	5.00	5.03	5.01
Gross energy (MJ kg^{-1})	16.64	16.75	16.88
Energy/Protein (kJ g^{-1})	34.58	34.76	35.06
Essential amino acids (g 100 g^{-1} of protein)			
Arginine	4.47	4.30	4.25
Histidine	2.76	2.67	2.64
Isoleucine	3.98	3.78	3.70
Leucine	6.87	6.50	6.37
Lysine	3.31	3.50	3.57
Methionine + Cystine	1.14	1.20	1.23
Phenylalanine + Tyrosine	5.44	4.96	4.79
Threonine	3.18	3.06	3.02
Tryptophan	1.08	1.00	0.98
Valine	5.11	4.86	4.77

[1]Nitrogen-free extract (NFE) = 100 – (crude protein + crude fat + crude ash + crude fiber).

In vivo experiment

The growth trial was conducted at the Experimental Station of Feed Production Technology and Aquaculture in Muchocin, Poland, using 240 two-year-old common carp (mean individual body weight 1023 ± 37 g). The fish were randomly allocated to 12 tanks (concrete walls and natural quartz sand on the bottom), and the capacity of each tank was 40 m^3 with 20 fish per tank. Each tank was equipped with an automatic band feeder allowing a continuous supply of feed for 12 hours per day. The experiment was conducted in four replications (four tanks per treatment). The calculated daily feed dose for each tank was given each day at 9:00 a.m., its consumption was controlled visually twice a day, and the rate was corrected if needed. The daily feed dose was restricted to ensure that all feed supplied was consumed. The feeding rate was calculated in consideration of fish biomass in each tank, which was corrected every 10 days based on the control weighing of all fish; measurements of the current average daily water temperature and feed consumption from the previous day were used for the additional correction. The trial lasted 60 days and was conducted in the summer (from June to August 2019). A constant flow of water throughout the experimental system was ensured by an open system with mechanical prefiltration. Prior to the trial, the experimental tanks were drained, plants and other organic matter were removed, and the tanks were whitewashed in order to improve sanitary conditions and fish disease prevention.

During the trial, the water temperature ranged from 16.3 to 25.0°C, and the dissolved oxygen in the water ranged from 3.60 to 4.46 mg O_2 dm^{-3} (ELMETRON, model CO-315), and the pH ranged from 7.0 to 7.2.

Fish growth and feed utilization parameters

All parameters were calculated from raw data on growth efficiency (body weight gain (BWG)), specific growth rate (SGR), feed conversion ratio (FCR), protein efficiency ratio (PER), and survival rate (SR) (Kesbiç et al., 2020). Four replications were used for each treatment. The mentioned parameters were calculated according to the following formulas:

$$BWG\ (g) = final\ fish\ weight\ (g) - initial\ fish\ weight\ (g)$$

$$SGR\ (\%/day) = [100 \times (\ln(final\ fish\ weight) - \ln(initial\ fish\ weight))\ days)]$$

$$FCR = feed\ intake\ (g) / body\ weight\ gain\ (g)$$

$$PER = (fish\ weight\ gain / feed\ intake\ (g) / protein\ level\ in\ the\ diet\ (\%))$$

$$SR\ (\%) = (final\ number\ of\ live\ fish / initial\ number\ of\ live\ fish) \times 100$$

Sampling and analysis of fish meat

All sampling was performed after the euthanasia procedure as described in the ethics statement section. The quality of meat filleted from the dorsal left side of 24 carp was analyzed, including the following parameters: pH, free water content, thermal drip, basic composition content, and color of muscle. The pH value (pH) was measured 15 min *post-mortem* ($pH_{15'}$) and after 24 h (pH_{24h}) with the use of a portable Handylab 2 apparatus (Schott Geräte Company, Mainz, Germany) with a glass-calomel electrode. For further analytical purposes (free water content, thermal drip, basic composition content, and meat color), skinless fillets were homogenized. The free water content was determined using a modified Pohja and Ninivaara method (1957). The color of the muscle tissue was determined after 24 h using a MINOLTA CR-5 colorimeter in the CIE $L^* a^* b$ system. L^* (lightness of color), a^* (saturation towards red), b^* (saturation towards yellow), C (chroma), and h (hue) were analyzed. The instrument was calibrated to a standard tile before analysis.

Environmental sustainability of experimental common carp production

Environmental sustainability parameters were calculated based on experimental diet compositions, fish growth performance, and feed utilization results obtained during the *in vivo* trial. The relative usage values of marine-derived feed ingredients – fish meal (FMU) and fish oil (FOU) – per kilogram of fish weight gain were calculated according to the following formulas:

$$FMU\ (g/1\ kg\ of\ fish\ biomass\ gain) = fish\ meal\ share\ in\ the\ diet\ (g/1\ kg) \times \frac{feed\ intake\ (g)}{body\ weight\ gain\ (g)}$$

$$FOU\ (g/1\ kg\ of\ fish\ biomass\ gain) = fish\ oil\ share\ in\ the\ diet\ (g/1\ kg) \times \frac{feed\ intake\ (g)}{body\ weight\ gain\ (g)}$$

The fish-in fish-out ratio (FIFO) was calculated as the quantity of live fish from capture fisheries required for each unit of farmed fish produced (Tacon and Metian, 2008; Naylor et. al, 2009), as follows:

$$FIFO = (+\ yield\ of\ fish\ oil\ from\ wild\ fish\ (g/1\ kg)) \times \frac{feed\ intake\ (g)}{body\ weight\ gain\ (g)}$$

where the yield of fish meal from wild fish was assumed to be 225 g per 1 kg of fresh fish weight and the yield of fish oil from wild fish was assumed to be 50 g per 1 kg of fresh fish weight (Crampton et al., 2010; Stejskal et al., 2020).

Statistical analysis

All the data obtained were assessed for normal distribution using the Kolmogorov–Smirnov test. Analysis of homogeneity of variance was conducted using Bartlett's test. One-way analysis of variance (ANOVA) was used to determine the occurrence of significant differences, and Duncan's multiple range test was used for comparisons between the groups. The significance level was determined at $P<0.05$. The calculations were evaluated using SAS 9.3 software. The following general model of ANOVA was used:

$$Y_i = \mu + \alpha_i + \delta_{ij}$$

where Y_i was the observed dependent variable; μ was the overall mean; α_i was the effect of carrot pomace inclusion; and δ_{ij} was the random error.

Results

The results of growth performance and feed utilization parameters for the 60-day trial are shown in Table 4. The final body weight, protein efficiency ratio, and fish survival rate were not affected by the dietary inclusion of carrot pomaces. However, body weight gain and specific growth rate exhibited significant differences in the fish fed the CPH diet, which presented the lowest values: for body weight gain 573 g (P=0.0119) and for specific growth rate 0.73 (P=0.0403). The feed conversion ratio in the CPH group was significantly (p=0.0212) worsened (2.11) in comparison to that in the CON (1.82) and CPL (1.78) groups.

The characteristics of fish fillets sampled at the end of the growth trial are shown in Table 5. The inclusion of carrot pomace into feeds did not affect the pH values (6.42–6.79), water (75.35–75.73%), protein (18.24–18.80%), or fat (4.19–4.69%) content (P>0.05), showing that carrot pomace did not influence the meat nutritional

properties. However, in the colorimetric values, there were significant differences in all the parameters measured. Fish that were fed the CPH diet presented the lowest (P=0.0143, P=0.0114) values in L* (61.76) and h-hue (56.11), while the values of these parameters in the CPL group were comparable to those in the CON and CPH groups. Moreover, fillets of fish from the CPH treatment exhibited the highest values (P=0.0189, P=0.0149) of C-chroma (17.58) and a* color (9.65). However, in those parameters, there were no significant differences between the CPL and CON groups.

Table 4. Growth performance and feed utilization parameters of common carp fed experimental feeds for 60 days of the trial

Parameters	Group			P value
	CON	CPL	CPH	
Final body weight (g)	1710 ± 58	1728 ± 96	1596 ± 23	0.1063
Body weight gain (g)	687 a ± 38	697 a ± 46	573 b ± 17	0.0119
SGR[1] (% d^{-1})	0.84 a ± 0.03	0.85 a ± 0.01	0.73 b ± 0.02	0.0403
FCR[2]	1.82 b ± 0.06	1.78 b ± 0.03	2.11 a ± 0.05	0.0212
PER[3]	1.83 ± 0.06	1.81 ± 0.12	1.58 ± 0.04	0.1051
Survival rate (%)	100 ± 0.0	98.3 ± 2.9	100 ± 0.0	0.4411

Values are mean ± standard deviation. Means designated with different letters differ significantly (P<0.05).

[1]Specific growth rate; [2]Feed conversion ratio; [3]Protein efficiency ratio.

Table 5. Characteristics of fish fillets sampled at the end of the growth trial

Parameter	Group			P value
	CON	CPL	CPH	
$pH_{15'}$	6.79	6.68	6.67	0.4673
pH_{24h}	6.50	6.42	6.42	0.3098
Water (%)	75.73	75.51	75.35	0.9667
Protein (%)	18.24	18.80	18.58	0.3315
Fat (%)	4.19	4.54	4.69	0.8364
Free water content (%)	31.70	32.06	31.74	0.9909
L*[1]	66.85 b	66.11 ab	61.76 a	0.0143
a*[2]	5.30 a	7.50 ab	9.65 b	0.0149
b*[3]	13.53	14.39	14.34	0.1181
C – chroma	14.59 a	16.26 ab	17.58 b	0.0189
h – hue	68.85 b	62.74 ab	56.11 a	0.0114

Means designated with different letters differ significantly (P<0.05).

[1]Lightness of color (+ = lighter, - = darker); [2]Saturation towards red (+ = redder, - = greener); [3]Saturation towards yellow (+ = yellower, - = bluer).

Table 6. Environmental sustainability of common carp production with the use of experimental feeds for 60 days of the trial

Parameter	Group			P value
	CON	CPL	CPH	
FMU[1]	267.6 c	310.7 b	388.5 a	< 0.0001
FOU[2]	36.4 c	46.7 b	54.9 a	< 0.0001
FIFO[3]	1.1 c	1.3 b	1.6 a	< 0.0001

Means designated with different letters differ significantly (P<0.0001).

[1]Relative fish meal use (g per 1 kg of fish weight gain); [2]Relative fish oil use (g per 1 kg of fish weight gain); [3]Fish-in fish-out ratio.

The parameters of environmental sustainability for the entire experimental period are shown in Table 6. Significant differences were observed in FMU, FOU, and FIFO among all groups (P>0.0001). The lowest FMU value was recorded in the control treatment (267.6), while the CPL diet increased it (310.7), and the highest value was observed in the CPH group (388.5). A comparable trend was observed for FOU: the lowest value for the CON group (36.4), higher value in the CPL group (46.7), and the highest in the CPH group (54.9). The third analyzed environmental parameter – FIFO – also recorded the lowest values in control treatment (1.10), higher in CPL group (1.3) and the highest in CPH group (1.6).

Discussion

The alternative components of feeds for aquatic animals whose application reduces the negative impact of animal production on the environment are one of the key elements positively influencing the development of sustainable aquaculture. Fish are able to adapt very quickly to changes in feed formulation, and the production of aquaculture is the most efficient way to convert by-products of the food market into a source of animal protein (Demirci et al., 2021). New ingredients applied in fish diets need also to be beneficial for animals, by promoting their health and growth performance, as well as ensuring high product quality (Cottrell et al., 2020; Nagarajan et al., 2021; Dawood, 2021). Another important aspect is the reduction of unsustainable feed material consumption, i.e. fish meal and fish oil (Rawski et al., 2021). Only the unification of the above-mentioned factors can practically improve the development of modern environmentally friendly aquaculture. One of the most frequently studied groups of alternative feed materials are by-products of the food industry, including pomaces from the production of juices (Pulgar et al., 2021; Hoseinifar et al., 2021).

The values of growth performance and feed utilization parameters observed in the present study show that the effects of carrot pomace dried at 40°C usages in common carp nutrition are comparable with the control group. Thus from a production efficiency point of view inclusion of that tested component can be justified. The possibility of using by-products of the food industry in common carp nutrition is also confirmed by studies on tomato pomace (Amirkolaie et al., 2015). Including this component to the level of 30% resulted in obtaining production parameters comparable to the control group. In turn, the use of olive pomace in feed for common carp without negative effects on fish growth is possible if the inclusion of that component does not exceed 6% of the diet composition (Kiapasha et al., 2019). Whereas, the supplementation diet of lemon pomace at the level of 5% improved performance and feed utilization (Laein et al., 2021), similar to the inclusion of tomato pomace at the level up to 10% (Amirkolaie et al., 2015). However, we

noticed that inclusion of 23.6% carrot pomace dried at 120°C in the tested fish diet has significant negative effects on growth performance and feed utilization. It was previously suggested that a temperature higher than 70°C significantly reduces the protein and carbohydrate contents of fruit pomace, thus affecting the final weight gain of the fish (Rawal and Masih, 2014). Limiting the use of alternative plant feed components may also result from reduced feed intake with too high inclusion of plant components in the extruded feeds, as with soy protein isolate (Slawski et al., 2011). The authors proved that the tested component could be used in common carp nutrition but a higher level than 33% replacement of fishmeal resulted in a deterioration of production parameters.

Feeds in the presented study were calculated in accordance with the nutritional requirements of the common carp (Webster and Lim, 2002). Crude protein content was in the range from 30.01 to 30.07%, crude fat from 6.13 to 6.19%, crude ash from 7.81 to 8.38%, nitrogen-free extract from 41.72 to 43.16%, and crude fiber from 5.00 to 5.03% of dry matter content. The levels of these nutrients in the experimental diets could not have a significant impact on production results. However, the drying process could affect not only growth performance, feed efficiency, and cost processing of them but also the amount of carrot pomace (for CPL 15.5 and for CPH 23.6% inclusion) in the experimental diet, as in the case of the inclusion of tomato pomace in fingerling carp (up to 30% inclusion), where the highest FCR and the lowest SGR and WG were reported in comparison to the rest of the diets with lower levels (Amirkolaie et al., 2015). In addition, the amount of fruit and vegetable pomaces included in fish diets could also be conditioned by the fiber content of those materials (Kaisangrsri et al., 2016). Crude fiber level was a main limiting factor for the inclusion of carrot pomace in the experimental diets. It must be emphasized that cyprinid fish in their natural environment efficiently utilize plant matter rich in fiber, which is degraded by a wide spectrum of cellulolytic bacteria, whose richness may exceed 250 taxa (Li et al., 2016). However, despite the above-mentioned situation, the high amount of dietary fiber may be the limiting factor in farm fish nutrition; thus, the maximal level of pomace use stands at approximately 20–25% of the diets. A higher addition of fruit pomace would generate too high a proportion of crude fiber in the feed.

The quality of fish fillets is one of the most important aspects for consumers, fish meat freshness parameters are widely analyzed in practice (Cheng et al., 2014). It has been shown that the diet is one of the most crucial factors influencing the nutritional value of carp fillets, their quality, and structure (Ljubojević, 2017). The results of the meat colorimetric analysis show that the dietary application of carrot pomace increased fish fillet pigmentation. This increase in pigmentation may be discussed as a consequence of high β-carotene levels present in carrot pomaces. This is confirmed by the results of Kaur et al. (2016), who reported that *Cypirnus carpio* absorbs β-carotene from a diet supplemented with dried carrot better than the synthetic form. This better absorption could be a positive aspect of using carrot pomace in common carp nutrition to improve fillet pigmentation. Moreover, Rashidnejad et al. (2018) showed that the addition of β-carotene to the carp diet can extend the shelf life of fillets by reducing lipid and protein oxidation. It should be emphasized that the method of carrot processing has a significant impact on the content of not only β-carotene but also other substances with antioxidant and health-promoting properties (Patras et al., 2009). These data are consistent with the results of the described experiment. The use of carrot pomace dried at a lower temperature (40°C) resulted in comparable effects in feed conversion ratio and specific growth rate compared to the control group. Whereas, fish which were fed diet containing pomace dried at a higher temperature (120°C) showed a statistically significant deterioration of these production parameters.

Alternative plant components such as tomato pomace, grape pomace, olive pomace, pumpkin, or lemon pomace can be used in common carp nutrition without adversely affecting the production parameters (Amirkolaie et al., 2015; Alashaab et al., 2017; Kiapasha et al., 2019; Sezgin and Aydin, 2021; Laein et al., 2021). However, in the case of these ingredients it has not been established whether their use could have a significant impact on the development of sustainable aquaculture. To determine whether the use of alternative feed materials is suitable in terms of environmental protection, it seems necessary to analyze the results of the mentioned studies in the context of the sustainability parameters analyzed in our research. It seems equally important to determine the cost-effectiveness of the applied solutions in the case of alternative feed ingredients.

It should be emphasized that the comparable effect on production parameters should not be the only variable determining the applicability of alternative feed ingredients in aquaculture. Their application should positively affect the environmental sustainability of fish production. Our research has shown that using carrot pomace in a common carp diet requires an increased amount of marine-derived components in both experimental diets to reach the nutritional requirements of the fish. The most widely used parameter for assessing the sustainability of fish production (Tacon and Metian, 2008; Jackson, 2009), FIFO (fish-in fish-out), was significantly higher in both experimental groups compared to the control. Moreover, the FIFO value was significantly higher in the CPH group compared to the CPL group. This value may be related to the low protein level in carrot pomace and the lowering of the nutritional value of high-temperature dried carrots, as mentioned earlier. The addition of both carrot pomaces, due to their low energetic value, caused a 30% increase in the amount of fish oil in the experimental diets. The addition of carrot pomaces resulted in a fish meal content increase of 17.7% in the CPL diet and 25.2% in the CPH diet. Therefore, the results of our re-

search show that the addition of by-products from carrot juice production does not positively affect the environmental sustainability of carp production.

The results of our study have shown that the use of carrot pomaces in carp nutrition is not justified, despite the impact on fillet color and the lack of a negative impact on production parameters. Thus, it must be emphasized that the use of food industry by-products in the nutrition of fish does not always contribute to sustainable aquaculture.

Acknowledgment

The authors would like to thank Krzysztof Florczyk and Jan Banaszak for their contribution to experimental feed preparation and help in care for fish during the growth test.

References

Alashaab M.N.A.N., Al-Shawi S.A., Mutter H.A., Collage D. (2017). Effect of using dried grape pomace juice on the total apparent digestibility coefficient, apparent protein digestibility coefficient and chemical body composition of common carp (*Cyprinus carpio*. L). Al-Anbar. J. Vet. Sci., 2: 116–122.

Amirkolaie A.K., Dadashi F., Ouraji H., Khalili K.J. (2015). The potential of tomato pomace as a feed ingredient in common carp (*Cyprinus carpio* L.) diet. J. Anim. Feed Sci., 24: 153–159.

AOAC (2007). Official Methods of Analysis. 18th edition. Arlington, Virginia, USA.

Bureau D.P., Kaushik S.J., Young Cho C. (2002). Bioenergetics. In: Fish Nutrition, Kaushik S.J., Halver J.E. (eds.). Academic Press, 3rd ed., San Diego, California, USA, pp. 1–59.

Cheng J.H., Sun D.W., Han Z., Zeng X.A. (2014). Texture and structure measurements and analyses for evaluation of fish and fillet freshness quality: a review. Compr. Rev. Food Sci. Food Saf., 13: 52–61.

Cottrell R.S., Blanchard J.L., Halpern B.S., Metian M., Froehlich H.E. (2020). Global adoption of novel aquaculture feeds could substantially reduce forage fish demand by 2030. Nat. Food., 1: 301–308.

Crampton V.O., Nanton D.A., Ruohonen K., Skjervold P.O., El-Mowafi A. (2010). Demonstration of salmon farming as a net producer of fish protein and oil. Aquac. Nutr., 16: 437–446.

Dawood M.A.O. (2021). Nutritional immunity of fish intestines: Important insights for sustainable aquaculture. Rev. Aquac., 13: 642–663.

Demirci B., Terzi F., Kesbic O.S., Acar U., Yilmaz S., Kesbic F.I. (2021). Does dietary incorporation level of pea protein isolate influence the digestive system morphology in rainbow trout (*Oncorhynchus mykiss*)? Anat. Hist. Embr., 50: 956–964.

EUMOFA, European Market Observatory for Fisheries and Aquaculture Products (2016). Case study: Price structure in the supply chain for fresh carp in Central Europe.

FAO (2018). The State of World Fisheries and Aquaculture, Rome.

Gustavsson J., Cederberg C., Sonesson U., van Otterdijk R., Meybeck A. (2011). Global food losses and waste: extent, causes and prevention. Rome, Italy: Food and Agriculture Organization of the United Nations.

Hall G.M. (2015). Impact of climate change on aquaculture: the need for alternative feed components. Turkish J. Fish. Aquat. Sci., 15: 569–574.

Hardy R.W., Kaushik S.J. (2021). Editors. Fish Nutrition. Academic Press: Cambridge, MA, USA.

Hoseinifar S.H., Rashidian G., Ghafarifarsani H., Jahazi M.A., Soltani M., Doan H.V., Paolucci M. (2021). Effects of apple (*Malus pomila*) pomace-derived pectin on the innate immune responses, expressions of key immune-related genes, growth performance, and digestive enzyme activity of rainbow trout (*Oncorhynchus mykiss*). Animals, 11: 2117.

Jackson A. (2009). Fish in–fish out ratios explained. Aquac. Eu., 34: 5–10.

Kaisangrsri N., Kowalski R.J., Wijesekarab I., Kerdchoechuena O., Laohakunjita N., Ganjyalb G.M. (2016). Carrot pomace enhances the expansion and nutritional quality of corn starch extrudates. Food Sci. Technol., 68: 391–399.

Kaniszewski S., Cieslak-Wojtaszek W. (2010). Vegetable production in Poland. World Carrot Museum.

Kaur S., Kaur V.I., Holeyappa S.A., Khairnar S.O. (2016). Effect of dietary supplementation of synthetic and natural β-carotene on survival, growth and pigmentation in freshwater ornamental koi (*Cyprinus carpio* L.) carp. Indian J. Anim. Nutr., 33: 448–455.

Kesbiç O.S., Parrino V., Acar Ü., Yilmaz S., Paro G.L., Fazio F. (2020). Effects of Monterey cypress (Hartw) leaf essential oil as a dietary supplement on growth performance and haematological and biochemical parameters of common carp (*Cyprinus carpio* L.). Ann. Anim. Sci., 20: 1411–1426.

Kiapasha F., Khoshkholgh M., Falahatkar B. (2019). Effect of replacement of different levels of dietary olive pomace on growth blood indices of common carp fingerling (*Cyprinus carpio*). J. Anim. Environ., 11: 179–186.

Kruczek M., Drygaś B., Habryka C. (2016). Pomace in fruit industry and their contemporary potential application. WSN, 48: 259–265.

Kummu M, de Moel H., Porkka M., Siebert S., Varis O., Ward P.J. (2012). Lost food, wasted resources: global food supply chain losses and their impacts on freshwater, cropland, and fertiliser use. Sci. Total Environ,. 438: 477–489.

Laein S.S., Salari A., Shahsavani D., Baghshani H. (2021). Effect of supplementation with lemon (*Citrus lemon*) pomace powder on the growth performance and antioxidant responses in common carp (*Cyprinus carpio*). J. Biol. Environ. Sci., 15: 47–54.

Li H., Wu S., Wirth S., Hao Y., Wang W., Zou H., Li W., Wang G. (2016). Diversity and activity of cellulolytic bacteria, isolated from the gut contents of grass carp (*Ctenopharyngodon idellus*) (Valenciennes) fed on Sudan grass (*Sorghum sudanense*) or artificial feedstuffs. Aquac. Res., 47: 153–164.

Ljubojević D., Đorđević V., Ćirković M. (2017). Evaluation of nutritive quality of common carp, *Cyprinus carpio* L. IOP Publishing. In IOP Conference Series: Earth Environ. Sci., 85: 012013.

Lovatto N.D.M., Goulart F.R., Correia V., Ferreira C.C., Silva L.P.D., Radünz Neto J. (2013). Inclusion of different sources of starch in diet for jundiá (*Rhamdia quelen*): metabolic and biochemical parameters. Cienc. Anim. Bras., 14: 299–304.

Miyatake H. (1997). Carp. Yoshoku, 34: 108–111.

Nagarajan D., Varjani S., Lee D.J., Chang J.S. (2021). Sustainable aquaculture and animal feed from microalgae – nutritive value and techno-functional components. Renew. Sust. Energ. Rev., 150: 111549.

Nawirska A., Kwaśniewska M. (2005). Dietary fibre fractions from fruit and vegetable processing waste. Food Chem., 91: 221–225.

Naylor R.L., Hardy R.W., Bureau D.P., Chiu A., Elliott M., Farrell A.P., Nichols P.D. (2009). Feeding aquaculture in an era of finite resources. PNAS, 106: 15103–15110.

NRC (2011). The National Academies Press: Washington, DC, USA. Nutrient Requirement of Fish and Shrimp. Animal Nutrition Series.

Patras A., Brunton N., Da Pieve S., Butler F., Downey G. (2009). Effect of thermal and high pressure processing on antioxidant activity and instrumental colour of tomato and carrot purées. Innov. Food Sci. Emerg. Technol., 10: 16–22.

Pohja M.S., Niinivaara F.P. (1957). Die Bestimmung der Wasserbindung des Fleisches mittels der Konstantdrückmethode. Fleischwirtschaft, 9: 193–195.

Priyadarshini A., Priyadarshini A. (2018). Market dimensions of the fruit juice industry. In: Fruit Juices, G. Rajauria, B.K. Tiwari (eds). Academic Press, 15–32.

Pulgar R., Mandakovic D., Salgado P., Venegas L., Ortiz D., Peña-Neira Á., Wacyk J. (2021). Micro-encapsulated grape pomace extract (MGPE) as a feed additive improves growth performance,

antioxidant capacity, and shifts the gut microbiome of rainbow trout. Aquaculture, 544: 737129.
Rana K.J., Siriwardena S., Hasan M.R. (2009). Impact of rising feed ingredient prices on aquafeeds and aquaculture production. FAO Fisheries and Aquaculture Technical, Rome, Italy, 541.
Rashidnejad A., Shahsavani D., Baghshani H. (2018). Investigation of the protective effect of β-carotene in the prevention of lipid and protein oxidation in carp meat during different storage times. J. Aquat. Food Prod. Technol., 27: 870–875.
Rawal R., Masih D. (2014). Study of the effect on the quality attributes of apple pomace powder prepared by two different dryers. IOSR-JAVS, 7: 54–61.
Rawski M., Mazurkiewicz J., Kierończyk B., Józefiak D. (2021). Black soldier fly full-fat larvae meal is more profitable than fish meal and fish oil in Siberian sturgeon farming: The effects on aquaculture sustainability, economy and fish GIT development. Animals, 11: 604.
Schieber A., Stinzing F.C., Carle R. (2001). By-products of plant food processing as a source of functional compounds – recent developments. Trends Food Sci. Technol., 12: 401–411.
Serena A., Knudsen K.E.B. (2007). Chemical and physicochemical characterisation of co-products from the vegetable food and agro industries. Anim. Feed Sci. Technol., 139: 109–124.
Sezgin A., Aydın B. (2021). Effect of replacing dietary soybean meal with pumpkin (*Cucurbita pepo*) seed cake on growth, feed utilization, haematological parameters and fatty acid composition of mirror carp (*Cyprinus carpio*). Aquac. Res., 52: 5870–5881.
Sharma K.D., Karki S., Thakur N.S., Attri S. (2012). Chemical composition, functional properties and processing of carrot – a review. J. Food Sci. Technol., 49: 22–32.
Sirakov I., Velichkova K. (2018). The influence of aquaponically grown duckweed (*Lemna minuta* Kunth) used for composition of sustainable diets on hydrochemical and technological parameters in carp (*Cyprinus carpio* L.). Turkish J. Fish. Aquat. Sci., 18: 1037–1044.
Slawski H., Adem H., Tressel R.P., Wysujack K., Koops U., Schulz C. (2011). Replacement of fishmeal by rapeseed protein concentrate in diets for common carp (*Cyprinus carpio* L.). Isr. J. Aquac., 6: 1–6.
Sobczak M., Panicz R., Eljasik P., Sadowski J., Tórz A., Żochowska-Kujawska J., Marques A. (2021). Nutritional value and sensory properties of common carp (*Cyprinus carpio* L.) fillets enriched with sustainable and natural feed ingredients. Food Chem. Toxicol., 112197.
Stejskal V., Tran H.Q., Prokesova M., Gebauer T., Giang P.T., Gai F., Gasco L. (2020). Partially defatted *Hermetia illucens* larva meal in diet of Eurasian perch (*Perca fluviatilis*) juveniles. Animals, 10: 1876.
Tacon A.G., Metian M. (2008). Global overview on the use of fish meal and fish oil in industrially compounded aquafeeds: Trends and future prospects. Aquaculture, 285: 146–158.
Takeuchi T., Satoh S., Kiron V. (2002). Common carp, *Cyprinus carpio*. In: Nutrients requirements and feeding of finfish for aquaculture, Webster C.D., Lim C.E. (eds.). CABI Publishing, Oxon, UK, pp. 245–261.
Topic Popovic N., Strunjak-Perovic I., Coz-Rakovac R., Barisic J., Jadan M., Persin Berakovic A., Sauerborn Klobucar R. (2012). Tricaine methane-sulfonate (MS-222) application in fish anaesthesia. J. Appl. Ichthyol., 28: 553–564.
Yildirim O., Guroy D. (2015). Effects of dietary olive pomace meal levels on growth performance, feed utilization and bio-economic analysis of juvenile tilapia (*Tilapia zillii*). Rom. Biotechnol. Lett., 20: 10982–10987.

Received: 16 I 2022
Accepted: 10 V 2022