



# The influence of expansion control device used during production of different extruded sea bass feeds on pellets quality

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**ABSTRACT.** In this study, the effects of expansion control devices (ECD) used in the production of extruded fish feed pellets were investigated. Five types of experimental sea bass feed with different pellets diameter (3, 4, 5, 6 and 9 mm for S3, S4, S5, S6 and S9, respectively) based on commercial formulations (lower total vegetable ingredients but higher starch and protein amount in S3 feed) were produced without or with the usage of ECD during extrusion process. The pellets quality was compared based on: pellets diameter size, pellet hardness, pellet durability, sink rate, after-extruder density, after-cooler density, moisture, loss quantity measurements and physical appearance. The obtained results showed that the pellets produced with ECD had lower diameters except for S3 feeds. The sink rate, and after-extruder and after-cooler densities were higher, and loss quantity was reduced in pellets produced with ECD regardless pellets size. There were less dusty and cracked pellets in feeds produced with ECD. It can be concluded that the ECD could be successfully used in the production of extruded fish pellets contributing to lower production costs.

## Introduction

The high-temperature-short-time (110–204 °C/ 10–20 s) extrusion cooking technology is usually used in the production of the aquaculture feeds (Hardy and Barrows, 2002; Glencross and Hawkins, 2007; Sørensen et al., 2009). The advantages of such thermal treatment as extrusion comprise: achievement of a desired physical form, inactivation of some antinutritional factors (Melcion and van der Poel, 1993), prolonged shelf-life, increased nutrient digestibility and enhanced palatability. In addition, the starch is gelatinized during the extrusion and in effect becomes more digestible for enzymes of carnivore fish (Bergot and Breque, 1983; Murray et al., 2001).

In the extrusion system, raw feed ingredients are exposed to the high temperature and pressure on mechanical shear tension in the screw-barrel assembly. The feed ingredient which is extruded takes shape from the die of end of the extruder's barrel. However, the expansion is seen while passing from the high pressure inside the barrel to the atmospheric pressure. This effect causes such alterations in the feed as: changes in bulk density, affected sink rate, differentiation of feed size, changes in feed hardness, endurance to the water and decreased stability. For example, the diameter of the pellets changes due to the expansion effect. For this reason, these pellets, which are larger than the fish mouths, can't be eaten. On the other hand, sinking pellets which are not consumed

and remain at the bottom of the tank lead to environmental pollution and economical waste.

The expansion on the exit of extruder machine affects also the bulk density. There is an inverse ratio between the expansion and bulk density. Expansion also affects the floating/sinking relationship of extruded feed ingredient. According to the Rout and Bandyopadhyay (1999), the ratio of expansion is inversely proportional to the density and sink rate of feed as feeds produced with the low expansion range had the highest density. Therefore, it is necessary to keep the low rate of expansion in the feed production process. ECD are used for this purpose. Using such device, the pressure outside the mould is under control and so, the lower expansion ratio is gained.

The ratio of the expansion inside the barrels is affected by other factors and is also changed according to the liquidity degree. The amount of soluble protein and starch in feed ingredients exerts positive influence on the expansion process, whereas the amount of fat – negative (Onwulata et al., 2001; Chang and El-Dash, 2003; Rokey and Plattner, 2004; Glencross and Hawkins, 2007; Sørensen, 2007). Various plants products, such as soyabean meal, maize and wheat flour, are used during the production of fish feed as protein sources. So, almost all studies are focused on soyabean (*Glycine max*) meal – the most commonly used plant protein in aquaculture feeds (Kaushik et al., 1995; Robaina et al., 1995; Kissil et al., 2000; Refstie et al., 2001). Starch, which is a major constituent of cereal grains, is the main energy source for animals. During the extrusion, starch gelatinization is crucial since it affects feed digestibility and expansion volume and also contributes to water stability. Thus, starch may have binding properties in pelleted feeds. The role of extrusion process variables on the expansion volume of cereals or starches has been already investigated (Faubion et al., 1982; Meuser et al., 1982; Launay and Lisch, 1983; Owusu-Ansah et al., 1983; Chinnaswamy and Hanna, 1988; Lai and Kokini, 1991; Jeong et al., 1991; Arhaliass et al., 2009).

Understanding the relationships between the feed ingredients, process parameters, equipment design and operation system is necessary to achieve the product of desired quality and to create the possibility to develop new products (Noel et al., 1990; Aguilera and Stanley, 1999; Rosentrater et al., 2009).

The aim of this study was to determine the effects of ECD usage on the quality of the fish feed pellets obtained in the extrusion process. Five types

of experimental sea bass feed with different pellet diameter sizes (3, 4, 5, 6 and 9 mm for S3, S4, S5, S6 and S9, respectively) based on commercial formulations (lower total vegetable ingredients but higher starch and protein amount in S3 feed) were produced without or with the usage of ECD during extrusion process.

## Material and methods

### Production of experimental diets

Five types of sea bass feed with different sizes (S3 – 3 mm, as starter feed for juvenile; S4 – 4 mm; S5 – 5 mm; S6 – 6 mm; S9 – 9 mm, as grower feeds for breeders) based on commercial formulations were examined. In S3 type feed, which is dedicated for juvenile, the amount of total vegetable ingredients was 31.9% and starch – 6.9%. In other feed types the amounts were 42% and 9.49%, respectively (Table 1). During production of all feeds, the same process stages were used with ECD or without such device (normal, N). The obtained feeds were examined to measure the physical quality differences.

**Table 1.** Formulation and chemical composition of examined feeds

Indices	Feed type <sup>1</sup>				
	S3	S4	S5	S6	S9
Ingredients, %					
wheat meal	9.5	9.5	9.5	9.5	9.5
wheat gluten meal	2	1.5	1.5	1.5	1.5
steam dried fish meal	49	40	40	40	40
full-fat soyabean meal	4.7	7.8	7.8	7.8	7.8
maize gluten meal	9.4	9.1	9.1	9.1	9.1
soyabean meal	6.3	-	-	-	-
soyabean meal solvent (48% protein)	-	14.1	14.1	14.1	14.1
fish oil	14	14	14	14	14
vitamin-mineral premix <sup>2</sup>	5.1	4	4	4	4
Total vegetable ingredient, %	31.9	42	42	42	42
Chemical composition					
crude protein, %	47	45	45	45	45
crude fat, %	18	20	20	20	20
cellulose, %	2	2.5	2.5	2.5	2.5
starch, %	6.90	9.49	9.49	9.49	9.49
total energy, kcal	5000	5250	5250	5250	5250

<sup>1</sup> feed types according to particle size: 3, 4, 5, 6 and 9 mm, for S3, S4, S5, S6 and S9, respectively; <sup>2</sup> vitamin-mineral premix content per kg of diet: IU: retinol 15 000, calciferol 2000; mg: alpha tocopherol 300, menadion sodio bis 16.6, thiamin 12.5, riboflavin 12.5, Ca pantothenate 33.3, nicotinic acid 116.7, pyridoxine 8.3, folic acid 4.2, cyanocobalamin 0.04, biotin 0.5, ascorbic acid 250, inositol 250, cobalt sulphate 1.91, copper sulphate 19.6, iron sulphate 200, sodium fluoride 2.21, potassium iodide 0.78, magnesium oxide 830, manganese oxide 26, sodium selenite 0.66, zinc oxide 37.5; g: dicalcium phosphate 8.02, potassium chloride 1.15, sodium chloride 0.44

The production process took place in a commercial fish feed company. Extruder machine had 4 ton · h<sup>-1</sup> capacity and it was single screwed type. The used parameters were as follows: 80 kg · h<sup>-1</sup> steaming in the preconditioner, and 400 kg · h<sup>-1</sup> water in the barrels. So, the pressure at the last barrel was 8–10 bars. The ECD used in the test had 0.8–1 bar air pressure and 7 kW motor power.

### Analysis of feed

**Physical appearance.** The features of extruded feed such as outer surface appearance, shape of feed, homogeneity, crumbling, broken-fracture pellets, colour, smell, dust and size/length balance were controlled.

**The diameter size of pellets** was measured with the electronic calipers (Starret EC799A-6/15, Athol, MA, USA) with 0.05-mm sensitivity. The values are expressed as the average of 60 pellets for each feed.

**The hardness** was measured in a pellet crusher (Amandus Kahl GmbH & Co. KG, Reinbek, Germany). Twelve pellets of different sizes were placed individually in a pellet crusher and the pressure that disintegrated pellets was recorded. Sixty pellets of each feed were examined.

**Durability** was measured in a Holmen Pellet Tester (Borregard Lignotech, Hull, UK). About 100 g of sieved pellets was hold on the quickly circulating air. At the end of the process, the proportion between amounts of the pellets which remain their form to the whole weight of sample at the beginning was calculated as durability level (Winowski, 1995). The analysis was conducted in triplicate for each feed type. The results are expressed as %.

**Moisture** was measured with the use of the moisture analyser (MA150, Sartorius, Göttingen, Germany). The feeds samples were squeezed and about 5 g was placed in the analyser. The process was done in triplicate for each feed and the values are expressed as %.

**Sink rate.** Sixty pellets of each feed were cooled and placed in water with 12% salinity and 4 °C temperature. The number of pellets which sank during 15 s was determined. The analysis was done in triplicate for each type of feed. The result is expressed as %.

**Bulk density.** The feed samples collected from the extruder die were cooled and placed in the 1-litre cylindrical cup to measure density in the precise analytical balance (TE64, Sartorius Göttingen, Germany). The process was done in triplicate for each feed and the values are expressed as g · l<sup>-1</sup> (Sørensen et al., 2009).

**The amount of loss.** At the beginning of the process, the weight of all raw materials to be used in feed production was measured. Then feed particles and dusts were collected from the extruder outlet, sieves, conveyor belts and their weights were measured (TE64, Sartorius, Göttingen, Germany). Particles and dust weight was removed from the initial raw material weight. The result was divided into the production tonnage of the extruder system and loss ratio is expressed as %. Samples were collected after the production of each feed group.

### Statistical analysis

Separately for each feed type (S3, S4, S5, S6 and S9) the results obtained for normal process and process with ECD were compared with the use of Student t-test.

For the comparison between feed types (separately for ECD and normal process) either ANOVA or Kruskal-Wallis test was used. Selection of the test was conditional upon the fulfilment of the ANOVA test assumptions. Normal distribution of all data was determined by the Kolmogorov-Smirnov test. The homogeneity of all data was tested with the Levene test. After this step, homogeneity and normality were only seen in feed loss so this parameter was tested with ANOVA. Transformed to provide normality and homogeneity for other variables, but no assumptions were met. Therefore, other variables were tested with the Kruskal-Wallis test.

All the statistical analyses were conducted using Statistical Package for Social Science (SPSS for Windows, ver 15.0; IBM, Armonk, NY, USA) and differences were considered statistically significant at  $P < 0.05$ .

## Results

**Physical appearance.** According to the visual physical analysis, the product gained from the production with ECD had no breaks or fractures. Such pellets had shiny appearance. In case of normal production, pellets were generally dusty, mat, with breaks and fractures.

**Pellets diameter size.** Outer diameters of all sample feeds were suitable for the assumed size of pellets. However, the usage of ECD in the production positively affected size of feeds reducing pellets diameter size in groups S4, S5, S6, and S9 ( $P < 0.05$  for all these groups, Student t-test). Only in group S3 such effect was not observed (Table 2).

Table 2. The physical parameters of extrude fish pellets produced using the expansion control device (ECD) and normally (N)

Physical properties	Feed type <sup>1</sup>			S4			S5			S6			S9		
	ECD	N	(t; P)	ECD	N	(t; P)	ECD	N	(t; P)	ECD	N	(t; P)	ECD	N	(t; P)
Pellet size, mm	3.02 ± 0.90	3.07 ± 1.32	-0.465; 0.643	4.03* ± 2.34	4.2 ± 1.57	-5.150; 0.000	5.02* ± 2.20	5.3 ± 3.12	-7.494; 0.000	6.98* ± 2.10	7.81 ± 3.70	-3.628; 0.000	9.04* ± 1.78	9.10 ± 1.32	-3.994; 0.000
Pellet hardness, kg · cm <sup>2</sup>	1.55 ± 1.75	1.52 ± 2.53	0.363; 717	1.34 ± 1.12	1.21 ± 1.56	1.667; 0.098	2.62 ± 2.24	2.44 ± 2.63	4.382; 0.000	1.65 ± 2.34	1.57 ± 3.03	2.372; 0.019	1.50 ± 2.13	1.40 ± 2.0	1.526; 0.130
Pellet durability, %	94.7 ± 0.17	95.9 ± 0.12	-1.561; 0.127	98.7 ± 0.23	99 ± 1.48	2.236; 0.031	99 ± 1.67	98.5 ± 0.33	2.236; 0.031	98.5 ± 1.18	98.5 ± 1.45	0.000; 1.000	98.5 ± 1.27	98 ± 2.34	0.000; 1.000
Sink rate, %	90.1* ± 0.57	82.3 ± 1.09	15.645; 0.000	92.0* ± 0.21	87 ± 0.47	12.927; 0.000	94.7* ± 0.87	85.3 ± 0.66	14.005; 0.000	97.8* ± 0.54	88.0 ± 0.46	22.046; 0.000	99.5* ± 4.57	88.4 ± 5.34	21.337; 0.000
Bulk density after extruder, g · l <sup>-1</sup>	596* ± 2.01	532 ± 2.17	7.946; 0.000	592* ± 1.33	550 ± 1.85	19.597; 0.000	625* ± 1.43	578.1 ± 1.50	34.470; 0.000	598.5* ± 2.12	543.5 ± 1.57	30.185; 0.000	592.1* ± 2.78	538.1 ± 2.65	23.872; 0.000
Bulk density after cooler, g · l <sup>-1</sup>	712* ± 1.22	688 ± 1.04	14.847; 0.000	714* ± 1.67	690 ± 2.13	9.151; 0.000	742* ± 1.87	710.8 ± 2.01	14.793; 0.000	713.5* ± 1.23	687.6 ± 1.95	19.086; 0.000	689.9* ± 2.01	648.5 ± 2.21	19.205; 0.000
Loss amount, %	5.7* ± 0.13	14.8 ± 0.20	-39.740; 0.000	5.80* ± 1.43	13.2 ± 1.31	-35.596; 0.000	7.48* ± 0.63	17.20 ± 0.63	-41.658; 0.000	8.7* ± 1.12	15.9 ± 1.22	-36.043; 0.000	8.65* ± 1.78	18.5 ± 1.86	-39.946; 0.000
Moisture, %	8.0 ± 1.11	7.1 ± 0.55	6.05; 0.000	7.9 ± 1.44	7.1 ± 1.16	3.25; 0.000	8.1 ± 1.12	7.9 ± 1.45	0.71; 0.479	8.5 ± 1.64	8.2 ± 1.22	1.01; 0.316	7.7 ± 1.67	6.5 ± 1.38	4.76; 0.000

<sup>1</sup> see Table 1; \* - indicates that pellets produced using ECD are significantly different at  $P < 0.05$  from those produced normally; values for each feed type are presented separately according to Student t-test (t - t-test results, P - P-value)

**Hardness and durability of pellets.** There was observed no influence of ECD usage on pellets hardness and durability regardless pellets size. When different feed types produced with ECD usage were compared, the highest value of pellet hardness was found in group S5 ( $P < 0.05$ , Kruskal-Wallis test).

**Moisture.** Statistical comparison of the ECD and normal production processes reveals that the moisture content was decreased in groups S3, S4 and S9 ( $P < 0.5$  according to Student t-test), no such effect was found in group S5 and S6 (Table 2).

**Sink rate.** The introduction of ECD in the production process caused the increased sink rate regardless pellets size ( $P < 0.5$  for all groups, Student t-test) (Table 2).

**Bulk density.** According to the both measurements performed on pellets collected at the exit of the extruder and at the exit of the cooler, in all feed types the production process with ECD caused higher densities in comparison with the normal production ( $P \leq 0.05$  for all groups, Student t-test) (Table 2).

The highest density after cooling was found in 5 mm sea bass feed obtained in the production process with ECD ( $742 \text{ g} \cdot \text{l}^{-1}$ ). The lowest one was found in 9 mm sea bass feed obtained in the production process without ECD ( $648.5 \text{ g} \cdot \text{l}^{-1}$ ).

**Loss amount.** For each feed type, the production with ECD caused lower loss amount ( $P < 0.05$  for all groups, Student t-test) (Table 2).

## Discussion

According to many researchers the main factors affecting quality of the pellets in extruded fish feeds are colour, pellet dimension, bulk density, water absorption, hardness and durability of pellets, sink rate and loss amount (Hansen and Storebakken, 2007; Sørensen, 2007; Rosentrater et al., 2009). The physical appearance of the feed is an important feature that affects the customers. In the present study, the most important feature of feed produced with ECD was shiny colour of pellets.

Previous studies have also shown that feed diameter is related to the physical quality of the pellets. Vegetable ingredients contain starch that cause further expansion. This leads to an increase in feed diameters (Thomas and van der Poel, 1996; Chen et al., 1999; Sørensen et al., 2009). In the study by Rokey et al. (2010) it has been shown that expanded pet and aquatic feeds will often expand by more than 50% of the die opening. The degree of expansion is positively affected by the level of starch and soluble protein and negatively – by the level of fat in the formulation. The reason of the significant differences among the other

feed groups (S4, S5, S6 and S9), except for group S3, may be related to the amount of total plant protein content used in these feed groups. While the amounts of vegetable ingredient and starch in S3 feed were 31.9% and 6.90%, respectively, in other groups these values were 42% and 9.49%, respectively.

The hardness of fish pellets should be high to prevent dust formation and crushing during storage and transportation. The production of hard and durable pellets will reduce the amount of feed loss. Moreover, the stability of the feed in water depends on the pellet hardness. In this way, a high feed conversion ratio and efficiency of production are provided. It is claimed that hardness and durability of the pellets are parallel to the increasing level of cellulose in feed (Breen et al., 1977; Wood, 1987; Cavalcanti and Behnke, 2005; Hansen and Storebakken, 2007). Similarly, some findings indicate that usage of both toasted and untoasted soyabean in feed positively affects the durability and hardness of feed (Wood, 1987; Cavalcanti and Behnke, 2005). Also, reduction in particle size improves gelatinization ratio, increases pellet durability and water stability (Obaldo, 1998). For this reason, in this study, the amount of cellulose (2%) in the group S3 positively affected the durability and pellet hardness. In the case of other groups, although pellet diameter changes between 4–9 mm, 2.5% raw cellulose ratio provided the durability and hardness of the pellets. Therefore, the obtained results indicate that ECD has no effect on the durability of pellets. In comparison with normal production, ECD is considered to have statistically neutral effect on the cellulose content in feeds.

According to Pérez-Navarrete et al. (2006) moisture content depends on both the temperature reached during processing and raw material moisture. The second is vital when feed is not properly packed – the excessive moisture content can lead to fairly rapid deterioration. Huber (2001) reported the value of moisture content for expanded products as  $10\text{--}20 \text{ g} \cdot \text{kg}^{-1}$ . The results of present study show that the moisture content of S3, S4 and S9 groups produced by ECD is higher than in normal production. This result shows that the water content in the feed is reduced due to the high expansion rate during normal production operations.

Density in bulk affects floating and sinking capability of feed. The value for the bulk density in the sinking feed is  $1000\text{--}1200 \text{ g} \cdot \text{dm}^3$  and it is  $900\text{--}1000 \text{ g} \cdot \text{dm}^3$  for the floating feed (Lucht, 2001). To increase the density in bulk, increasing the oil level and feeding rate of extruder, decreasing thermal energy inputs and increasing the moisture level up to 26% are necessary (Lindley, 2005). Bulk density

changes depend on density of the used ingredients in the formulation. If the starch level increases, the density in bulks decreases. The sink ratio of feed produced with Press-Pellet technology is higher than of the feed produced with extruder technology. However, according to these study, bulk density and so sink rate of feed can be controlled by using ECD.

The expansion rate of the pellets is very important for the amount of feed loss. Pellets expanding above the desired ratio can be broken up at the exit of the extruder, in the conveyor belts or in the dryer. As a result, the feed production is carried out in lesser quantities than expected. This leads to both excessive energy usage and wear of machines. It was observed that the amount of loss for all feed groups fell when the production was made with ECD.

## Conclusions

The usage of expansion control device during fish feed production process was found to have a positive effect on feed quality. On the other hand, more experiments are needed with more diversified raw material composition to get more detailed answers concerning the best process conditions in the case of sea bass feed production.

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