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RESEARCH ARTICLE **ARAŞTIRMA MAKALESİ**

The effects of different starch levels on the physical quality of high-oil extruded fish feed

Farklı nişasta seviyelerinin yüksek yağlı extrude balık yemlerinin fiziksel kalitesi üzerine etkileri

Pınar Demir Soker[1] ● Aysun Kop[2*] ● Ali Yıldırım Korkut[2]

[1]Aquaculture Department, Graduate School of Natural and Applied Science, Ege University, 35100, Bornova, İzmir,Türkiye
[2]Aquaculture Department, Faculty of Fisheries, 35100, Bornova, Ege University, İzmir, Türkiye

*Corresponding author: aysun.kop.firat@ege.edu.tr

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Abstract: In this study, the effects of different starch levels (5%, 8% and 11%) on the physical properties of extruded fish feeds with high oil content (22%) were investigated. For this purpose, 3 types of extruded trout feed with different starch levels (S5, S8 and S11) were produced. Physical (moisture, feed diameter, bulk density and pellet durability) and chemical (lipid, starch, water absorption index, water solubility index and water stability) analyses of these feeds were performed in 3 repetitions on the samples taken from the extruder outlet, lubrication outlet and sieve outlet. An increase in the amount of starch in the feed caused an increase in feed diameter and durability of the pellets, while a decrease in bulk density was observed. According to the results of the chemical analysis, it was seen that the increase in the starch ratio had no effect on the crude oil and water solubility index values, the best water absorption index value was in the S8 feed, and the water stability values decreased from S5 to S11.

Keywords: Trout feed, extrusion technology, chemical analyses, water absorption index, water solubility index, bulk density

INTRODUCTION

The extrusion cooking technique has been used for many years to produce various types of animal feed and human food. It has been the main method used in the production of aquaculture feeds for the last three decades. The extruder machine consists of a section called the sleeve, in which one or two endlessly rotating screws are arranged one after the other, with varying tooth spacing from the inlet to the outlet. The process is based on the principle of generating heat (120-130°C) and mechanically cutting by applying high pressure 1-2 times (20-30 bar) to the feed mixture in the form of flour passing through the die (Sorensen, 2012; Khater et al., 2014). This process is also known as friction. The most important result of these processes is the gelatinization of starch granules in the feed mixture. Additionally, the presence of starch and a limited amount of oil in the feed mixture ensures that the pellet is water-resistant and hard (Yan et al., 2019).

When raw starch comes into contact with water without being exposed to heat, it absorbs 20-30% of water. However, starch is insoluble in cold water due to hydrogen bonds between molecules (Hongyuan et al., 2022). When the feed mixture is extruded at a humidity of 27-33% and a temperature of 115-140°C, these starch granules, which have the ability to absorb water, form gels. Due to the breaking of hydrogen bonds during gelatinization, starch granules are broken down, making it easier for water molecules to bind to hydroxyl groups. This leads to an increase in starch solubility (Cai and Diosady, 1993; Moscicki et al., 2013; Balakrishna et al., 2020). In a study using corn starch in a single-screw extruder, it was found that the water solubility of starch increases after extrusion (Chinnaswamy et al., 1990; Yan et al., 2019). While the solubility of raw starch in water before extrusion is 2.0%, this value increases to 28.8% after extrusion. Moreover, the water solubility reaches 35.4% in twice-extruded starches. The pellet acts as a binder during the process. In this process, the expansion rate increases with increasing cylinder temperature. The increased expansion rate allows the absorption of excess oil, which must be added for vacuum coating to create a high-energy feed (Sorensen, 2012).

Feeds with good physical properties maximize feed consumption and feed conversion rate in fish. This is because the feed should remain unchanged in terms of both physical and nutritional content until the fish consume it. Additionally, the feed encounters numerous stress factors that can cause breakage and dust throughout all stages, from shaping to the point of being provided to the fish. As a result, the presence of dust and small particles makes it difficult for the fish to consume the feed, leading to an increase in the feed conversion rate. Moreover, it is not desirable for the feed to be excessively hard. This is because, in such cases, the feed is not adequately broken down as it passes through the fish's gastrointestinal tract, preventing the nutritional content from reaching a suitable consistency for enzymatic degradation (Sorensen, 2012).

The physical suitability of extruded feeds is associated with functional properties such as solid density, water absorption index (WAI), water solubility index (WSI), water stability (WS), starch gelatinization, particle size, and powder. WSI is utilized to measure starch degradation and is defined as the amount of dry matter detected in the liquid phase of the gel formed during extrusion. A low WSI indicates minimal starch degradation, implying a lower amount of dissolved matter in extruded products (Hernandez-Diaz et al., 2007; Narbutaite et al., 2008). The high moisture content during the extrusion process reduces protein denaturation and starch gelatinization. One indicator of starch gelatinization is the water absorption index. WAI is expressed as the amount of gel obtained from a unit weight of dry matter. The cutting process applied during extrusion physically breaks down starch granules and accelerates water penetration into the starch granules. Extrusion operating conditions such as screw speed, geometry, temperature, and product properties such as amylose/amylopectin ratio and moisture content influence mechanical degradation and the amount of gelatinized starch (Lai and Kokini, 1990; Kokini et al., 1992). Various applications such as cutting, mixing, grinding, shaping and thermal treatment applied during extrusion cooking create the effect of gelatinization of the feed, protein denaturation, hydration, expansion of the feed, and texture change. In addition, the residence time of the feed mixture in the extruder is also important for the final product quality (Nwabueze and Iwe, 2010).

The aim of this study is to evaluate the effects of different starch levels on the physical quality of high-fat extruded fish feed, depending on the feed processing stages (extrusion, lubrication and final product).

MATERIALS AND METHODS

Experimental feed production

In this study, extruded trout feed containing 22% crude oil was produced with three different starch levels (5%, 8%, and 11%). The trial feeds were designated as S5, S8, and S11, and their formulations were prepared using the "Brill Formulation™" program (Version: 1.34.006). The formulation and experimental feed composition are presented in Table 1. In the feeds prepared iso-caloric (4.2 kcal/gr) and iso-proteic (40%), fish meal was used as the animal protein source, and a mixture of soybean meal and wheat flour was used as the plant protein source. The ratios of animal and plant protein sources in the feed were 20/60, 30/50, 40/40 (FM/SM). The experimental feeds were produced at a private commercial company using an EX 920 brand extruder machine. The vacuum coating method was employed during the lubrication stage. A standard feed was produced for approximately 1 hour until the extruder conditions stabilized. Once the extruder reached constant torque, pressure, and temperature conditions, the production of the trial feeds commenced. Molds with a diameter of 4.5 mm were utilized in the production of these feeds. For each trial feed, a total of 1 ton of production was conducted three times. In each production batch (1st, 2nd, and 3rd tons), 1 kg samples were collected from the extruder outlet, lubrication outlet, and sieve outlet. Physical and chemical analyses were performed three times for each sample group.

Table 1. Ration of trial feeds

	S5 (%)	S8 (%)	S11 (%)
Ingredients			
Fish meal	20.6	29.43	38.27
Soybean meal pulp	56.0	42.06	28.12
Wheat meal	3.34	9.24	15.14
Fish oil	19.74	18.95	18.15
Vitamin-Mineral	0.32	0.32	0.32
Total	100	100	100
Nutritional composition			
Crude protein (%)	40	40	40
Crude lipid (%)	22	22	22
Crude cellulose (%)	1.7	1.43	1.16
Starch	5.07	8.15	11.20
Total energy (kcal/kg)	4127	4171	4215
Vitamin A (KIU/kg)	10000	10000	10000
Vitamin.D_3	2000	2000	2000
Vitamin E	200	200	200
Vitamin K_3	11	11	11
Vitamin C	180	180	180

Analysis of the feed

Feed analyzes are examined under two headings: physical and chemical analyses.

Physical analyses

In this study, moisture content, feed diameter, bulk density and pellet durability were investigated as physical analyses.

As physical analysis, moisture content, feed diameter, bulk density and pellet durability were examined in the feeds.

Moisture content

The samples were ground to less than 1mm in Ika Brand MF 10 Basic (IKA-Werke GmbH & Co. KG) model mill. The moisture of the products was measured with a Sartarious brand MA 150 Model (Sartorius AG, Goettingen, Germany) moisture analyzer. Approximately 3 g of sample was weighed on the weighing pan of the device and dried with infrared rays, and moisture was calculated gravimetrically from percent weight loss.

Feed diameter

Diameter measurements were made with a caliper (Tesa IP67, Hexagon Switzerland) with a precision of 0.02 mm in 60 feeds taken from the extruder, lubrication and sieve outlets of 1,2 and 3 tons of production of each feed type. All measurements were performed in 3 repetitions.

Bulk density

The feed samples taken for analysis were poured into a 1 liter custom-made weighing container. After the weighing pan was filled to the top, its top surface was smoothed with a ruler. Then, Sartarious Brand GE 2102 (Sartorius AG, Goettingen, Germany) model with 0.01 g precision was weighed in a precision tailor). Analyzes were performed in triplicate (Figure 1).

Bulk density was calculated with the following formula;

Bulk Density (g/L) = Container Full Weight – Container Empty Weight / Container Volume

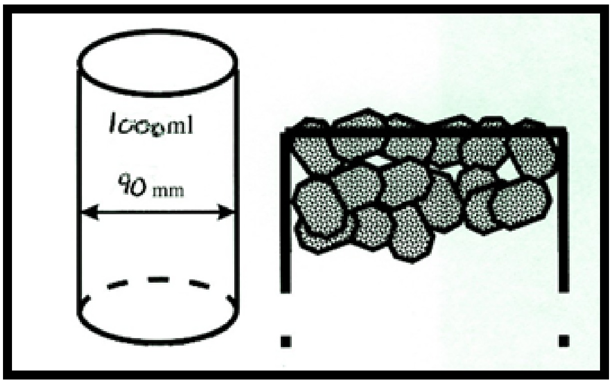

Figure 1. Bulk Density Determination

Pellet durability test

Pellet durability test was performed with DORIS (Durability on a Realistic Test) (Hendrix, Italy) testing device. Approximately 300 g of feed, cleaned of dust and broken pieces, was weighed on an analytical balance (M0) and poured from the inlet of the device. The device was run until all the bait samples had accumulated in the collection bottle. Then, the front cover was opened and the accumulated dust and broken pieces were added to the collection bottle. The collected product was passed through 1mm and 3.15 mm sieves. The amount of feed collected in the 1 mm sieve was weighed (Mb). The amount of dust collected at the bottom after passing through both sieves was also weighed (Ms). The durability value of the pellets was calculated according to the formula below. Analyses were performed in triplicate.

% Broken pieces= Mb/Mo x 100

% Dust = Ms/Mo x 100

DORIS value = % Broken piece + % Dust

Chemical analysis

As chemical analyses; lipid content, starch amount, water absorption index, water solubility (WSI) index and water stability (WS) of the feeds were determined.

Lipid content

Lipid analysis was performed by petroleum ether extraction process in FOSS brand Soxtec 2055 oil extraction device (FOSS Analytical, Denmark). The result of the analysis was calculated with the following formula;

Lipid% = (final sample weight - initial sample weight) / feed weight x 100

Analyzes were performed in triplicate.

Starch amount analysis

The amount of starch was investigated by measuring the optical rotation degree of the solute with HCl after removal of optically active solutes in the sample.

The degree of optical rotation of the samples was measured with MACHIMPEX Brand WXG-4 Model analog polarimeter (BANTE INSTRUMENTS CO., LTD.China). Analyzes were performed in triplicate. The result of the analysis was calculated with the following formula;

Starch = 2000 x P / $[\alpha]_D$

$[\alpha]_D$: Wheat Flour specific turning degree (degrees.mL/g.dm) = 182.7

$[\alpha]_D$: Specific degree of conversion of feed and soy (degrees.mL/g.dm) = 184

P: Polarimeter read value

Water absorption index (WAI)

The water absorption index is defined as the amount of gel obtained from a unit weight of dry matter. Analysis was done with modification of the method described by Anderson et al. (1969). The following formula was used to calculate WAI values.

WAI = Amount of Gel in Tube / Amount of Dry Matter of Sample x Amount of Sample

Results are given in g gel/g dry sample. Analyzes were performed in triplicate in all trials.

Water solubility index (WSI)

It is defined as the amount of dry matter detected in the liquid phase obtained in the water absorption index.

After determining the amount of liquid phase taken into tared drying containers, it was dried at 104 ^{0}C for 24 hours and the water solubility index per unit weight was calculated.

The following formula was used to calculate WSI values.

WSI = Amount of Dry Matter in Liquid Phase / (For example Amount of Dry Matter x Amount of Sample) x 100

Analyzes were performed in triplicate in all trials.

Water stability determination (WS)

A 10-g feed sample, whose dry matter amount was known in advance, was placed in a plastic container and filled with seawater to cover the feed by 1 cm. The tightly closed container was shaken in the incubator at 24°C and 1400 rpm for exactly 15 minutes. When shaking was completed, the container was weighed and dried in a tared conical flask in an oven set at 103°C for 24 hours. The samples coming out of the oven were brought to a constant weight in a desiccator and weighed.

Water stabilization was calculated according to the weight difference in dry matter with the following equation.

Loss in 10 g Feed (g) = [(Feed Amount(g) – Moisture (g)) – (Feed (Oven)]

All analyzes were performed in triplicate.

Statistical analysis

The data obtained as a result of physical and chemical tests were evaluated with the ANOVA parametric test using the Statistical Package for Social Science (SPSS for Windows; ver. 14.0, California, USA) program. At the same time, multi-factor ANOVA test was used to analyze the data, taking into account the levels of soybean meal and fish meal in the diet as the main factors. Some evaluations were made with the Independent Sample Test. Tukey test was used to find out which factors the difference depended on in cases where there was a difference between the factors as a result of the analysis of variance.

RESULTS

The results of the physical analysis can be viewed in Table 2.

Moisture

The moisture content of S5 feed at the extruder outlet was significantly higher than S8 and S11 feed ($p < 0.05$). This is due to the difficulties encountered during the pelletizing stage of S5 feed. Oil and water had to be added to the mixture to ensure that the feed adhered and held together. When the lubrication outputs of the feeds were analyzed, the moisture content of S5 feed was significantly higher than the other feed groups ($p<0.05$). Similarly, high moisture values were also observed in the sieve outlet of S5 feed. There was no statistical difference ($p>0.05$) between S8 and S11 feeds in terms of moisture content at all production stages (Table 2). When the results were analyzed according to raw materials, there was a statistically significant difference in the S5 (20/60) and S8 (30/50) feeds ($p<0.05$), while there was no difference in the S 11 ($p>0.05$) feed.

Feed diameter

Upon examining the samples taken at all stages of production (extruder, lubrication, and sieve exit), it was observed that the S5 feed had the smallest mean diameter, while the S11 feed had the largest diameter value (Table 2). However, when statistically analyzing the values, it was concluded that the difference between the S5 and S8 feeds was not significant ($p>0.05$). On the other hand, the diameter values of the S11 feed were found to be significantly different from the other two feeds ($p<0.05$).

When the results were analyzed according to raw materials, there was a statistically significant difference in the S5 (20/60), S8 (30/50) and the S 11 (40/40) feeds ($p<0.05$).

Bulk density

Based on the starch content of the S5, S8, and S11 feeds, a decrease in bulk density was observed at the extruder exit. There was no statistically significant difference in bulk density between the extruder outputs of the S5 and S8 feeds ($p>0.05$). However, the S11 feed group showed a significant difference compared to the other two feeds ($p<0.05$).

At the lubrication outlet, the S11 feed demonstrated a statistically significant difference ($p<0.05$) from the S5 and S8 feeds, similar to the extruder outlet. The density of the S11 feed was lower than that of the other two feeds. There was no statistical significance in the densities of the S5 and S8 feeds ($p>0.05$).

According to the sieve output data, an increase in starch content and a gradual decrease in bulk density were observed, which were considered statistically significant differences ($p<0.05$).

When the results were analyzed according to raw materials, there was a statistically significant difference in the S8 (30/50) and S 11(40/40) feeds ($p<0.05$), while there was no difference in the S5 (20/60) ($p>0.05$) feed.

Table 2. Physical analysis results

Physical analyses	Trial Feeds	Production Phase		
		Extruder outlet	Lubrication outlet	Sieve outlet
Moisture (%)±SD	S5	22.99a*±0.17	11.21a±0.10	13.26a±0.25
	S8	21.67b±0.19	6.65b±0.1	6.88b±0.14
	S11	21.65b±0.19	7.07b±0.05	6.98b±0.07
Feed Diameter(mm)±SD	S5	4.66b±0.02	4.78b±0.03	4.76b±0.03
	S8	4.76b±0.05	4.85b±0.04	4.85b±0.07
	S11	5.09a±0.08	5.19a±0.05	5.1a±0.04
Bulk Density (g/l)± SD	S5	498.13a±3.52	599.1a±5.43	608.71a±2.2
	S8	470.74a±5.05	589.05a±4.3	579.71a±3.13
	S11	422.60b±4.11	529.94b±2.56	538.98b±2.28
Pellet Durability (%)±SD	S5	NA	NA	NA
	S8	NA	9.73a±0.66	11.14a±0.29
	S11	NA	3.94b±0.60	3.04b±0.13

Values represent means ± SD
*Values in the same row with different letters were significantly different ($P<0.05$)
NA: Measurement could not be taken.

Pellet durability

Due to the low amount of starch in the S5 feed and as a result, the gelatinization process did not occur, the die was clogged and the product in proper pellet form could not be obtained. The pellet durability test, evaluated only in the S8 and S11 feeds, showed that the percentage of dust and broken pieces was higher in the S8 feed compared to the S11 feed ($p<0.05$) based on the results of the DORIS test conducted on the samples taken from the lubrication outlet. Similarly, in the samples taken from the sieve outlet, the highest amount of dust and broken pieces was obtained in the S8 feed, and a statistically significant difference was found when compared to the S11 feed ($p<0.05$)

When the results were analyzed according to raw materials, there was no difference statistically significant difference in the S8 (30/50) and S11 (40/40) feeds ($p>0.05$).

The results of chemical analyses are given in Table 3.

Lipid content;

Since fat is not added to the feed during the extruder stage, the values obtained are lower than the targeted values in the ration. The crude lipid analysis results in the samples taken from the extruder outlet did not show a statistically significant difference among the trial feeds group ($p>0.05$).

At the lubrication outlet, there was a decrease in the absorbed fat ratios due to the increase in the starch amount in the S5, S8, and S11 feed groups, and a statistically significant difference was observed ($p<0.05$).

When comparing the crude lipid analysis values of the sieve outlets of the S5, S8, and S11 feeds, there seemed to be a decrease in the absorbed fat ratio due to the increased starch amount. ($p<0.05$) (Table 3).

When the results were analyzed according to raw materials, there was a statistically significant difference in the S5 (20/60) and S8 (30/50) feeds ($p<0.05$), while there was no difference in the S 11 ($p>0.05$) feed.

The amount of starch;

The starch content in the samples collected from all production stages was found to be similar to the expected values based on the formulation. As a result, a statistically significant difference was observed between the measured starch content and the expected ratio values ($p<0.05$).

When the results were analyzed according to raw materials, there was a statistically significant difference in the S5 (20/60) feed ($p<0.05$), while there was no difference in the S8 (30/50) and S 11 ($p>0.05$) feeds.

WAI values;

Due to the high moisture content of the samples taken from the extruder outlets of the trial feeds, WAI, WSI and WS analysis could not be carried out in the samples.

The water absorption index was evaluated at the lubrication and sieve outlets of the trial feeds. In the samples taken from the lubrication outlet, it was determined that S5 had the lowest WAI value, while S8 had the highest WAI value. It was observed that the WAI values of the three feed types differed significantly at the $p<0.05$ level.

At the sieve outlet, the highest WAI value was obtained in S8, while the lowest WAI value was observed in the S5 feed among the three feed samples. There was no statistically significant difference between the groups ($p>0.05$).

In general, it can be concluded that for lubrication and sieve outlet, the WAI value was lower in S5 feed, while S8 and S11

Table 3. Chemical analysis results

Chemical analyses	Feed Types	Production Phase		
		Extruder outlet	Lubrication outlet	Sieve outlet
Lipid (%)	S5	3.73a±0.08	21.76a±0.27	21.41a±0.07
	S8	3.33a±0.06	20.36b±0.08	20.10a±0.22
	S11	3.81a±0.04	19.60c±0.16	19.85a±0.10
Starch (%)	S5	4.95a±0.41	4.96a±0.12	5.07a±0.17
	S8	8.81b±1.04	7.73b±0.24	7.95b±0.34
	S11	10.9c±0.84	10.93c±0.51	11.23c±0.49
WAI (g/g)	S5	NA	3.38a±0.06	3.55a±0.08
	S8	NA	4.12a±0.08	4.04a±0.04
	S11	NA	3.86a±0.03	3.8a±0.19
WSI (%)	S5	NA	1.98a±0.06	2.42a±1.04
	S8	NA	1.97a±0.14	2.15a±0.24
	S11	NA	2.01a±0.25	1.85a±0.07
WS (g/g)	S5	NA	1.22a±0.5	1.60a±0.34
	S8	NA	0.45b±0.19	0.16b±0.2
	S11	NA	0.27c±0.1	0.43c±0.05

Values represent means ± SD, and,
NA: Measurement could not be taken.

feeds were relatively similar and higher than S5. When the results were analyzed according to raw materials, there was a statistically significant difference in the S8 (30/50) and S 11 (40/40) feeds ($p<0.05$).

WSI values;

The water solubility index (WSI) was evaluated at the lubrication and sieve outlets. There was no statistically significant difference observed in the WSI values among the samples taken from the lubrication outlets ($p>0.05$). Similarly, no statistically significant difference was found in the WSI values at the sieve outlet for the three feed types ($p>0.05$).

When the results were analyzed according to raw materials, there was a statistically significant difference in the all trial feeds group ($p<0.05$).

WS values;

The water stability (WS) values of the feed samples taken from the lubrication outlet were evaluated, and statistically significant differences were observed ($p<0.05$). The WS values showed a decreasing trend from S5 to S11 feed samples. Similarly, significant differences were found in the WS values of all feed groups in the samples taken from the sieve outlet ($p<0.05$). The highest dry matter loss was observed in the S5 feed, while the least loss was observed in the S8 feed.

When the results were analyzed according to raw materials, there was a no statistically significant difference in the S5 (20/60) feed ($p>0.05$) while there was statistically significant difference in the S8 (30/50) and S 11 (40/40) feeds. ($p<0.05$).

DISCUSSION

Moisture

When comparing the moisture values, it is observed that the samples taken from the extruder outlet have higher moisture content compared to the samples taken from the lubrication and sieve outlet, even though the moisture content of all raw materials used in the formulation is consistent. This can be attributed to the addition of steam during the conditioning phase of the extrusion process, which increases the moisture content of the feed. This situation encountered during the extrusion phase shows a similar situation to the study that stated that in terms of feed technology, in wheat extrusion, the extruder machine did not work efficiently when extruding wheat with moisture addition below 20%, so the starting point was 20% (Adhikari and Adhikari, 2015). Additionally, the lower moisture values in the samples taken from the lubrication and sieve outlets can be attributed to the drying process that the products undergo after extrusion. However, since the dryer temperatures and residence time in the dryer were kept constant for all three feeds, the higher moisture values observed in the samples taken from the sieve and lubrication outlets of the S5 feed indicate an anomaly or deviation from the expected moisture level. Due to the high moisture content in the extruder stage, the incomplete gelatinization of the starch due to the low starch content of the S5 feed, and the fact that this feed contains a higher amount of soybean meal, the mold was clogged and pellets in proper form could not be obtained. It is also compatible with the results of other studies reporting that maximum gelatinization in extruded feeds occurs between 22-28% (Owusu-Ansah et al., 1983; Gomez and Aguilera, 1984; Case et al., 1992; Da Silva et al., 1996)

It is understood from the results obtained that the moisture content of the trial feeds varies depending on the feed production stages and starch sources. The high use of vegetable raw materials compared to fish meal has caused these results.

Feed diameter

When examining the feed diameter values, it was observed that the diameters increased with the increase in starch. The lowest diameter values were measured in the S5 feed, while the highest values were measured in the S11 feed. Due to the positive effect of wheat flour on gelatinization and expansion, in this production where the expansion control unit is also disabled, the diameter values of the S11 feed, which has the highest starch content, are higher than the others. In addition, the negative effect of soybean on expansion also supports this result and explains the fact that S5 feed with less starch and more soybean has the lowest diameter average and S11 feed with more starch and less soybean has the highest diameter average. Therefore, all results evaluated according to raw materials contain differences.

Bulk density

The expansion control unit (ECS) was not activated during production, as the effects of starch on expansion were also questioned in the experiments. When examining the Bulk Density values, it is observed that the volume of the feed changes with the expansion, which is positively influenced by the increase in starch. This, in turn, affects the density values. In our study, the inverse relationship between bulk density and the amount of starch is clearly evident, with statistical significance demonstrated at the $p<0.05$ level for the lubrication output. A decrease in bulk density was observed as the starch level increased. Although there is no difference in extruder outlet in terms of starch sources, it is seen that the difference increases as the usage rates of animal and vegetable origin raw materials approach each other.

Pellet durability

The low amount of starch contained in the S5 feed had a negative impact on pellet formation during the extrusion stage. The lubrication outlet of the third-ton production became clogged, resulting in distorted pellet shapes for the feed. This situation led to excessive waste in the feed, and an insufficient number of samples could be taken to determine pellet durability. In the case of the other group feeds, the durability of the pellets increased in parallel with the amount of starch. The use of raw materials of animal/vegetable origin in the ratios of 30/50 or 40/40, depending on the feed production stages, had no effect on pellet durability. According to researchers (Cheftel et al., 1985; Kannadhason et al., 2011), it has protein binding properties and therefore, as the protein ratio in the feed mixture increases, PDI values also increase. However, in this study, since the protein ratios of all trial feeds were similar, no differences were observed according to starch sources.

Lipid

In the study, there was a significant increase in the amount of absorbed oil with the increase in the starch content in the lubrication outlets of S5, S8 and S11 feeds (P<0.05). Since the effects of starch on expansion were also investigated in this study, the expansion control unit (ECS) was not used during feed production. Therefore, the density values of the trial feeds are lower (floating feed) than the densities of commercial feeds (sinking feed). For these reasons, S11 feed has a more porous and irregular structure. In this case, the S11 feed absorbed more oil because it was more porous than normal, but it also vomited more oil due to the irregularity in its structure.

The lowest intensity value of S11 compared to the others also supports this interpretation, as the expelled oil created voids, causing the feed to lose weight without changing its volume.

While the lipid contents of the trial feeds had a significant difference in the extruder and lubrication stages according to the raw metarials, no statistically significant difference was observed in the sieve outlet.

Starch

When the physical and chemical analysis results of samples taken at different production stages and tons from S5, S8, S11 feeds produced under the same production conditions with rations with different starch levels are compared, it is seen that the results are different from each other. The low amount of starch contained in the S5 feed negatively affected the pellet formation during the extrusion stage. The die started to clog and the amount of wastage increased. While the lipid contents of the trial feeds had a significant difference in the extruder and lubrication stages according to the raw materials, no statistically significant difference was observed in the product outlet.

WAI values

The lower amount of starch used in the S5 feed compared to the other feeds resulted in lower Water Absorption Index (WAI) values due to reduced gelatinization. Furthermore, the contribution of soy in the S5 feed had a negative impact on the WAI value Similarly, despite the high amount of starch, the high content of fish meal in S11 feed negatively affected gelatinization. As a result, the S8 feed, where the ratio of soybean to fish meal is more balanced, exhibited higher WAI values compared to the S5 and S11 feeds. Similarly, in the study by Kannadhason et al. (2011), increasing starch levels from 20% to 40% resulted in a decrease in WAI values by 15.4% - 4.30%.

WSI values

When the water solubility index (WSI) values were analyzed, the fact that there was no increase in WSI values despite the increase in starch amount suggests that other raw material inputs have an effect on these values. The fact that inputs other than fish meal, soybean and wheat flour were constant in all three feed groups explains the effects of soybean on WSI. According to Sorensen (2012), changes in protein sources can cause significant changes in expansion. For example, the addition of soy protein to pure starch leads to an increase in expansion. Since it is known that the increase in expansion is paralleled by an increase in gelatinization, the higher than expected gelatinization in feed S5 can be attributed to the higher soy content compared to other feeds. This suggests that soy compensates for the lack of gelatinization caused by starch deficiency. Similarly, feed S8 contained less starch but more soy than feed S11. This can be seen as a reason for the balance in WSI values. In feeds with lower starch content, the amount of soy is increased to balance the raw material, which positively affects the gelatinization of the feed. In feeds with high starch content, less soy and more fish meal are used to balance the raw material, which negatively affects gelatinization. Narbutaite (2008) investigated the effects of moisture on gelatinization value, WSI and water absorption index (WAI) values in different starch sources and found that increasing moisture significantly affected gelatinization in wheat flour. From this perspective, we can explain that the S5 feed, which is exposed to steam during the extrusion stage, undergoes more gelatinization and therefore has a higher WSI value compared to other feeds. In the study by Kannadhason et al. (2011), increasing starch levels from 20% to 40% resulted in a decrease in WSI values by 31.4% and 11.4%. The fact that there was a statistical difference in all processing steps according to raw metarials and that S11 feed showed the lowest WSI value is similar to this study.

WS values

When examining the Water Stability (WS) values, it is observed that the dry matter loss of the S5 feed is quite high compared to the other feeds. It is expected for the dry matter loss to be higher due to the binding effect of starch molecules. However, studies have reported that soy additives at 42% or higher significantly decrease WS values (Lim and Cuzon, 1994), while wheat flour additives increase the WS value (Hepher, 1969; Balazs et al., 1973). Also, clear relationship related to starch content was observed in terms of WS values between the S8 and S11 feeds.

CONCLUSION

When evaluating the findings obtained from the study, it is evident that the physical quality of the feed is influenced by various factors. These factors include not only the change in the amount of starch but also the type of starch source, its ratio in the ration, and the production process. Additionally, the other raw materials present in the ration, their interactions with each other, and their behavior during the process also play a significant role. It has been concluded that the amount of absorbed oil does not have an impact on the physical quality of the feed. According to this study, the S8 (30/50) group gave more positive results on feed quality.

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AUTHORSHIP CONTRIBUTIONS

All authors contributed to the idea and design of the study. Material preparation and investigation were performed by Pınar Demir. The writing/editing was carried out by Aysun Kop and Ali Yıldırım Korkut. All authors have read and approved the article.

CONFLICT OF INTEREST STATEMENT

The authors declare that there are no conflicts of interest or competing interests.

ETHICS APPROVAL

No specific ethical approval was necessary for this study

DATA AVAILABILITY STATEMENT

All relevant data is in the article.

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