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Single Screw Extrusion Processing of Soy White Flakes Based Catla Feed

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Abstract

An initial investigation into the inclusion of soy white flakes (SWF) and high protein distillers dried grains (HP-DDG) in catla (*Catla catla*) diet, belonging to the family Cyprinidae, was conducted using a single screw extruder. Three isocaloric (302 kcal/100 g) ingredient blends containing graded levels of SWF in combination with HP-DDG and other required ingredients were formulated to contain a net protein content of 31.5% (wet basis). Extrusion processing was then performed using three levels each of SWF content, moisture content, and temperature gradient keeping a constant screw speed and die diameter. Effects of these variables on extrudate physical properties including: color, pellet durability index, bulk density, water absorption index, water solubility index, unit density and expansion ratio were extensively analyzed. Increasing the level of SWF resulted in increase in water absorption index and unit density but decrease in expansion ratio. The interaction effect of SWF content, moisture content and temperature were significant for color, pellet durability index, bulk density and expansion ratio. All the extrudates showed relatively high pellet durability and inclusion of SWF produced less expanded and more compact textured extrudates.

Keywords: aquafeed, expansion ratio, extrusion, soy white flakes, water absorption index, water solubility index

1. Introduction

Extrusion is a versatile and very efficient technology that is widely used in food and feed processing including increasing numbers of ready-to-eat cereals, salty and sweet snacks, coextruded snacks, indirect expanded products, croutons for soups and salads, an expanding array of dry pet foods and fish foods, textured meat-like materials from defatted high-protein flours, nutritious precooked food mixtures for infant feeding, and confectionery products (Mercier et al., 1989). Extrusion cooking is a high-temperature, short-time process in which starchy and/or proteinaceous food materials are plasticized, cooked, and in some cases expanded by a combination of moisture, pressure, heating, and mechanical shear, resulting in molecular transformation and chemical reactions. It provides a continuous high throughput processing and can be controlled automatically. It can be used to produce products with various shape, color, texture and appearance.

Protein is the most important nutrient which promotes growth in fishes. Depending on the fish species, fish feed generally requires protein content of 26% to 50% (Lovell, 1989). Commonly, high amount of ground marine caught fish as fish meal, are used to meet the requirement of protein in fishes which contributes significantly to variable production cost in aquaculture industry. However, decreasing fishmeal supply relative to demand and increasing costs threaten the sustainability and growth of the aquaculture industry. Approximately two to six pounds of marine fish are needed for the production of only one pound of farm fish (Marine Aquaculture Task Force, 2007). As protein is the costliest among various ingredients in preparation of fish feeds, it is necessary to search for the alternative protein sources in order to reduce the cost of feeds (Renukaradhya & Varghese, 1986; FAO, 2004; Lunger et al., 2007). Hence, the goal is to minimize fish meal inclusion in fish feed by substituting appropriate alternative protein sources (Hardy & Masumoto, 1990). A number studies of have been done regarding the efficacy of plant feedstuffs as alternative protein sources in fish feeds (Hossain & Jauncey, 1989).

High protein distillers dried grains (HP-DDG) and soy white flakes (SWF) can be used as an alternative source of protein. Distillers Dried Grains (DDG) and Distillers Dried Grains with Solubles (DDGS), a co-product from corn-based dry grind fuel ethanol manufacturing, is a viable protein source. Typically, DDGS contains approximately 30% protein (Rosentrater & Muthukumarappan, 2006; Spiehs et al., 2002) whereas DDG contain

1.5 times more protein that of DDGS and less fat; hence, it is called HP-DDG (Robinson & Li, 2008). Moreover, HP- DDG provides higher available phosphorous content thus reducing the need for phosphorous supplementation and its nutritional values are much more consistent than those of DDGS (Robinson et al., 2008). Fallahi et al. (2013) reported that inclusion of HP-DDG up to 40% led to the production of more expanded and floatable extrudates compared to those extrudates containing DDGS for rainbow trout. Soy is one of the most important protein-rich plants and a source of protein for aquafeeds (Morris et al., 2005; Francesco et al., 2007; Karalazos et al., 2007). Use of soy products like full fatted soybean meal, defatted toasted soybean meal (SBM) and defatted untoasted soybean meal or white flakes (WF) is becoming common (Fallahi et al., 2012). Romarheim et al. (2005) found that extrusion of WF diet increased the digestibility of protein and all amino acids whereas fishmeal and SBM had no significant effect on amino acid digestibility. Dersjant-Li, (2002) reported that soy protein isolate can be used to replace 40-100% fish meal without negative impact on growth performance of shrimp. To date, however, no trials of partial or complete replacement of fishmeal with SWF and HP-DDG for fish feeds have been conducted.

Therefore, the objectives of this study were to produce feed pellets for catla (*Catla catla*) with SWF and HP-DDG inclusions and to examine the effect of various levels of SWF content, moisture content and extruder barrel temperature on physical properties of the extruded feeds.

2. Materials and Methods

SWF were kindly donated by South Dakota Soybean Processors (Volga, SD). Corn flour was purchased from Cargill Dry Ingredients (Paris, IL). HP-DDG was obtained from the Dakota Ethanol LLC (Wentworth, SD). Corn gluten meal (CGM) and fishmeal were purchased from Consumer Supply Distributing Co. (Sioux City, IA). Vitamin-mineral premix was obtained from Lortscher Agri Service, Inc. (Bern, Kansas, USA). Soybean oil was obtained from USDA (Brookings, SD).

2.1 Blend Formulation

Three isocaloric (302 kcal/100 g) blends were formulated to contain a net protein content of 31.5% (wet basis) and a target fat content of ~ 4.2%. The total energy content for each blend was determined based on the fraction of protein, fat and carbohydrate contributing to the dietary energy. The total energy content was calculated based on the energy content of fractions namely, 4.5 kcal/g for protein, 9.1 kcal/g for lipid and 4.1 kcal/g for carbohydrate. The different ingredients in the blends include SWF (42.5% protein), HP-DDG (42% protein and 4.5% fat), corn gluten meal, corn flour, fish meal, soybean oil, and vitamin & mineral mix (Table 1). The ingredients were mixed in a laboratory scale Hobart mixer (Hobart Corporation, Troy, Ohio, USA) for 10 minutes and stored overnight at ambient temperature (25 ^{o}C) for moisture stabilization. The moisture balancing of the blends was done by adding required quantities of water during mixing.

Table 1. Ingredient composition of feed blends

Feed ingredients	Mass of ingredients (g/100 g)		
	Blend I	Blend II	Blend III
SWF	10	20	30
HP-DDG	40	30	20
Corn gluten meal	7	7	7
Corn flour	35	35	35
Fish meal	5	5	5
Soybean oil	1	1	1
Vitamin & mineral mix	2	2	2
Total	100	100	100

2.2 Extrusion Processing

The extrusion processing was performed using a single screw extruder (Brabender Plasti-Corder, Model PL 2000, South Hackensack, NJ) which was powered by a 7.5 hp motor with an operating range of screw speeds from 0 to 210 rpm (0 to 22 rad/s). The extruder had a barrel with length-to-diameter ratio of 20:1 and a barrel diameter (D) of 19 mm. A uniform 19.05 mm pitch screw with compression ratio of 3:1 was used in the experiments. The clearance (H) between the inner wall of the barrel and screw at die section is 1.27 mm (0.05 in) and the clearance (3H) between the inner wall of the barrel and screw at feed section is 3.81mm (0.15 in). A typical screw of a single screw extruder is shown in Figure 1.

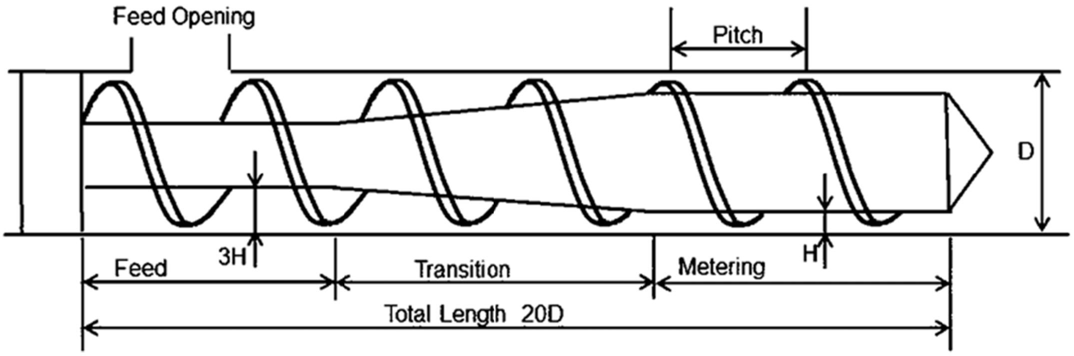

Figure 1. Schematic representation of screw in a single screw extruder

The length and diameter of the die nozzle was 17.5 mm and 3 mm (L/D: 5.83), respectively. The extruder barrel was equipped with external band heaters with provisions to control the temperature of all three zones: feed zone, transition zone/melting zone, and die sections (Figure 2).

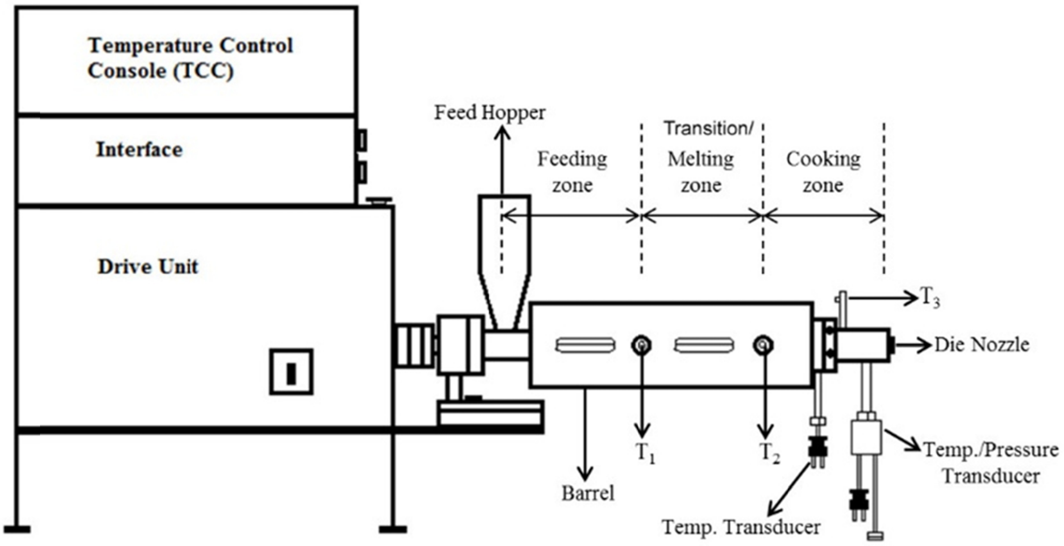

Figure 2. Schematic representation of laboratory extruder (Brabender Plasti-Corder, Model PL 2000)

The raw materials were fed in feeding zone of the extruder through feed hopper. It got gelatinized and plasticized under thermal and mechanical stresses generated by the rotation of screws in melting zone of the extruder. The gelatinized material then enters the cooking zone where the extruder barrel is fully filled due to pressure generated at die nozzle. When the process reached the steady state, samples were collected at the die. All samples were left to dry at ambient temperature (25 ºC) for 48 hours prior to further analysis. During the experiment the screw speed of extruder was maintained at 150 rpm.

2.3 Experimental Design and Analysis

Experiments were conducted using a full factorial, three-level design, with SWF content, moisture content, and barrel temperature gradient levels being the independent variables. This resulted in 27 unique extrusion trials for different combinations of three levels each of SWF content (10%, 20%, and 30%), moisture content (15%, 25%, and 35% db), and temperature gradient (T1-T2-T3) in the barrel (45-110-110 ºC, 45-140-140 ºC, and 45-170-170 ºC), hereafter referred as temperature of 110, 140 and 170 ºC. Each treatment was extruded once and three replicates were determined for all the extrudate physical properties, except unit density which was measured with ten replicates. All the collected data were analyzed with SAS v.9 (SAS Institute, Cary, NC). The Proc GLM procedure was used to determine the main, treatment and interaction effects using a Type I error rate (α) of 0.05. Post-hoc least significant differences (LSD) tests were used to identify where the significant differences occurred.

2.4 Measurement of Physical Properties

2.4.1 Color

A spectrophotometer (LabScan XE, HunterLab, Reston, VA) was used to determine extrudate color, where L* quantified the brightness/darkness, a* the redness/greenness and b* the yellowness/blueness of the extrudate samples.

2.4.2 Pellet Durability Index (PDI)

Approximately 100 g of extrudates from each blend were manually sieved (U.S.A. standard testing, ASTM E-11 specification, Daigger, Vernon Hills, IL) to remove initial fines, and then tumbled in a pellet durability tester (Model PDT-110, Seedburo Equipment Company, Chicago, IL) for 10 min. Afterwards, the samples were again sieved, and then weighed on an electronic balance (ASAE, 2004). PDI was calculated as:

$$PDI(\%) = \left(\frac{M_a}{M_b} \times 100 \right) \tag{1}$$

where, M_a was the mass (g) after tumbling and M_b was the sample mass (g) before tumbling.

2.4.3 Bulk Density (BD)

Bulk density was determined as the ratio of the mass of extrudates that they filled up to a given bulk volume and measured using a standard bushel tester (Seedburo Equipment Company, Chicago, IL) following the method recommended by USDA (1999).

2.4.4 Water Absorption Index (WAI) and Water Solubility Index (WSI)

Extrudates were ground to fine powders using a coffee grinder (Black & Decker ® Corporation, Towson, ML, USA). The ground extrudates (2.5 g) was suspended in distilled water (30 mL) in a tarred 60 mL centrifuge tube. The suspension was stirred intermittently and centrifuged at 3000 g for 10 min. The supernatant was decanted into a tarred aluminums cup and dried at 135 °C for 2 h (AACC, 2000). The weight of the gel remaining in the centrifuge tube was measured. The WAI and WSI were calculated by:

$$WAI(\text{unitless}) = \left(\frac{W_g}{W_{ds}} \right) \tag{2}$$

where, W_g is the weight of gel (g), and W_{ds} is the weight of dry sample (g).

$$WSI(\%) = \left(\frac{W_{ss}}{W_{ds}} \times 100 \right) \tag{3}$$

where, W_{ss} is the weight of dry solids of supernatant (g), and W_{ds} is the weight of dry sample (g).

2.4.5 Unit Density (UD) and Expansion Ratio (ER)

The extrudates were cut to a length of ~ 1 inch (25.4 mm) and weighed on an analytical balance (Adventurer™, Item No: AR 1140, Ohaus Corp. Pine Brook, NJ), then measured with a digital calliper (Digimatic calliper, Model No: CD-6"C, Mitutoyo Corp., Tokyo, Japan) to determine their diameter. The unit density (UD, g/cm^3) was calculated as the ratio of the mass M (g) to the volume V (cm^3) of each measured and weighed extrudate sample, assuming a cylindrical shape for each extrudate (Rosentrater et al., 2005):

$$UD(g / cc) = \left(\frac{M}{V} \right) \tag{4}$$

The radial expansion ratio of the extrudates was measured as the ratio of the diameter of the extrudates to the diameter of the die orifice.

3. Results and Discussion

3.1 Color

Change in color of extrudates can be an indication of nutrients degradation during extrusion processing (Bjorck & Asp, 1983). Increasing the SWF content from 10% to 30% resulted in 1.2% increase in L* value but 6.9% decrease in a* value and 3.5% decrease in b* value (Table 2). Change in a* value can be due to the difference in color of the raw material used before extrusion. Decrease in yellowness of extrudate was expected because raw DDG was yellowish in color; thus, decrease in DDG content or increase in SWF content (Table 1) resulted in a significant decrease in yellowness of the extrudate. Increasing the moisture content of ingredient blends from 15% to 35%, led to significant decrease in L* and b* values by 28.0% and 23.0%, respectively. Increasing moisture content in blends had significant effect on a* value but no particular trend was observed (Table 2). Likewise, increasing extruder barrel temperature from 110 ºC to 170 ºC resulted in significant change ($p<0.05$, Table 3) in L*, a* and b* values but no specific trends were discernible.

Table 2. Main effects of SWF content, moisture content of raw material and temperature profile (on extrudate physical properties) *

Variable	L* (-)	a* (-)	b* (-)	PDI (%)	BD (g/cc)	WAI (-)	WSI (%)	UD (g/cc)	ER (-)
SWF (%)									
10	41.93^{b}	6.20^{a}	15.45^{a}	88.01^{b}	0.36^{c}	3.98^{b}	14.03^{ab}	0.89^{b}	1.17^{a}
	(6.11)	(0.88)	(1.67)	(5.30)	(0.05)	(0.60)	(1.51)	(0.15)	(0.07)
20	42.06^{b}	5.99^{b}	15.17^{b}	85.73^{c}	0.39^{a}	4.07^{b}	13.66^{b}	0.92^{a}	1.13^{b}
	(6.25)	(0.89)	(1.89)	(6.37)	(0.05)	(0.67)	(1.27)	(0.16)	(0.12)
30	42.42^{a}	5.77^{c}	14.91^{c}	89.97^{a}	0.38^{b}	4.26^{a}	14.21^{a}	0.92^{a}	1.13^{b}
	(6.63)	(0.92)	(2.10)	(4.62)	(0.04)	(0.63)	(1.79)	(0.19)	(0.15)
MC (% db)									
15	48.93^{a}	5.19^{c}	16.61^{a}	89.28^{b}	0.42^{a}	3.39^{c}	15.39^{a}	0.95^{a}	1.15^{b}
	(3.29)	(0.80)	(0.36)	(2.30)	(0.02)	(0.29)	(0.59)	(0.14)	(0.12)
25	42.31^{b}	6.61^{a}	16.19^{b}	82.15^{c}	0.36^{b}	4.25^{b}	13.29^{b}	0.85^{b}	1.20^{a}
	(1.76)	(0.58)	(0.71)	(5.33)	(0.04)	(0.38)	(1.04)	(0.12)	(0.11)
35	35.17^{c}	6.16^{b}	12.72^{c}	92.27^{a}	0.35^{c}	4.66^{a}	13.21^{b}	0.94^{a}	1.09^{c}
	(2.87)	(0.67)	(0.91)	(3.08)	(0.06)	(0.39)	(1.64)	(0.21)	(0.10)
T (°C)									
110	40.58^{c}	6.30^{a}	15.20^{a}	88.99^{a}	0.41^{a}	3.81^{b}	13.81^{b}	1.07^{a}	1.10^{b}
	(7.24)	(1.21)	(2.09)	(5.77)	(0.02)	(0.60)	(1.50)	(0.12)	(0.08)
140	43.34^{a}	5.72^{c}	14.95^{b}	86.28^{c}	0.37^{b}	4.22^{a}	13.67^{b}	0.90^{b}	1.23^{a}
	(6.85)	(0.81)	(2.14)	(6.61)	(0.04)	(0.55)	(1.62)	(0.13)	(0.11)
170	42.49^{b}	5.94^{b}	15.37^{a}	88.44^{b}	0.36^{c}	4.28^{a}	14.41^{a}	0.77^{c}	1.11^{b}
	(4.13)	(0.47)	(1.37)	(4.25)	(0.07)	(0.67)	(1.44)	(0.09)	(0.11)

*Means with different letters in a column within each independent variable are significantly different ($p<0.05$) for that independent variable at $p<0.05$; values in parentheses are standard deviation. MC – Moisture content of the ingredients; T- Barrel temperature.

3.2 Pellet Durability Index (PDI)

Pellet durability indicates the mechanical strength of the extrudates. (Rosentrater et al., 2005). In fact, the extent of heat treatment, along with the level of starch transformation, protein denaturation, and water content, during the extrusion processing, influence the pellet durability quality of the extrudates (Rosentrater et al., 2009). The main effects of the independent variables on the extrudate pellet durability are presented in Table 2. The effect of changing the level of white flakes, moisture content and temperature on pellet durability of extrudates was found to be significant ($p<0.05$, Table 3) but no definite pattern was observed. As depicted in Table 2, increasing SWF inclusion from 10% to 20%, moisture content from 15% to 25% and temperature from 110 ºC to 140 ºC decreased PDI by 2.6%, 8% and 3.0%, respectively. Whereas, further increasing SWF content from 20% to 30%, increasing moisture content from 25% to 35% and increasing temperature from 140 ºC to 170 ºC resulted in a significant increase ($\alpha=0.05$) by 5%, 12.3% and 2.5% in PDI, respectively. Maximum and minimum values of PDI were observed as 89.97% and 85.73% at 30% and 20% SWF content in ingredient blends respectively, 92.27% and 82.15% at 35% and 25% moisture content of ingredients respectively and 88.99% and 86.28% at 110 ^{o}C and 140 ^{o}C respectively (Table 2). Interaction effect of all independent variables on PDI was significant, $p<0.0001$ (Table 3).

Table 3. Interaction results for SWF content, moisture content of raw material and barrel temperature on extrudate physical properties (p values)

Variable	L^* (-)	a^* (-)	b^* (-)	PDI (%)	BD (g/cc)	WAI (-)	WSI (%)	UD (g/cc)	ER (-)
SWF	0.02	<.0001	<.0001	<.0001	<.0001	0.0004	0.1046	0.0113	<.0001
MC	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
SWF×MC	0.0039	<.0001	0.0004	<.0001	<.0001	0.0431	0.008	<.0001	<.0001
T	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	0.0158	<.0001	<.0001
SWF×T	<.0001	<.0001	0.0153	<.0001	<.0001	0.0564	0.0016	0.0334	<.0001
MC×T	<.0001	<.0001	<.0001	<.0001	<.0001	0.4202	0.8013	<.0001	<.0001
SWF×MC×T	<.0001	<.0001	0.0526	<.0001	<.0001	0.714	0.2371	0.3335	0.0044

3.3 Bulk Density (BD)

Bulk density influences storage capacity required at the processing plant and during shipping. Increasing SWF content from 10% to 30% significantly changed ($p<0.05$, Table 3) BD of the extrudates but no particular trend was observed. Changing the level of moisture content from 15% to 35% resulted in a 17% decrease and increasing the barrel temperature from 110 ºC to 170 ºC resulted in a 12% decrease in BD. This may be due to the reason that when the melt exits the die nozzle at high temperature it expands more and have more volume than the extrudates exiting at low temperature.

3.4 Water Absorption Index (WAI) and Water Solubility Index (WSI)

Water absorption index indicates the amount of water immobilized by the extrudate, while water solubility index indicates the amount of small molecules solubilized in water (Mezreb et al., 2003). WAI is related to the water activity and influences the storage stability. Main effects of independent variables on WAI and WSI are shown in Table 2. When percentage of SWF in ingredient mix was increased from 10 to 30%, a significant increase of 7.0% in WAI was found. As the moisture content of ingredient was increased from 15% to 35% and barrel temperature was increased from 110 ºC to 170 ºC, WAI increased by 37.5% and 12.3%, respectively (Table 2). A similar trend was observed by Anderson et al (1969) with extruded sorghum grits. No significant change was observed for WSI as SWF content was increased from 10% to 30% in ingredient blends (Table 2). When moisture content was increased from 15% to 35% and barrel temperature was increased from 110 ºC to 170 ºC a decrease of 14% and an increase of 4.3% in WSI were observed, respectively (Table 2). This may be due to the reason that as the temperature increased, the extent of starch gelatinization increased. According to Harper (1981), WSI of the extrudate is directly related to the extent of starch gelatinization that occurs inside the extruder.

3.5 Unit Density (UD)

Unit density influences the floatability of the extrudates. As depicted in Table 2, a significant increase of 3.4% in UD of the extruded products was observed when level of SWF was raised from 10% to 30%. The maximum and minimum unit density values were 0.95 g/cm^3 and 0.85 g/cm^3 observed at 15% and 25% ingredient moisture content, respectively. The apparent viscosity of the ingredient melt inside the barrel and die is inversely proportional to the extruder barrel temperature (Harper et al., 1981; Bhattacharya & Hanna, 1986). When the ingredient melt having lower viscosity exits through the die, the produced extrudates tend to expand more, and thus have reduced UD. Increasing the barrel temperature from 110 ºC to 170 ºC resulted in a 28% decrease in UD (Table 2).

3.6 Expansion Ratio (ER)

Changes in the level of SWF content, moisture content of ingredient mix and temperature had a significant effect on ER of extrudates (Table 3) but no particular trend was observed. Changing the level of SWF content from 10% to 20%, a significant decrease of 3.4% in expansion ratio was observed; further increasing of the SWF inclusion to 30% had no effect on ER of the extrudates (Table 2).

4. Conclusions

The goals of this study were to produce fish feed pellets with HP-DDG and SWF inclusions and to examine the effect of various levels of SWF, moisture content and extruder barrel temperature on physical properties of the extruded feeds. Changing the level of SWF significantly affected extrudate color, pellet durability, bulk density, water absorption index, unit density and expansion ratio ($p<0.05$). Increasing the level of SWF from 10% to 30%, significantly increased the value of WAI from 3.98 to 4.26 and UD from 0.89 g/cm^3 to 0.92 g/cm^3 but decreased the value of ER from 1.17 to 1.13 ($\alpha=0.05$). Also changing the level of moisture content and temperature had significant effect ($p<0.05$) on all physical properties. Increasing moisture content from 15% to 35% resulted in a 37.5% increase in WAI and 17% and 14% decrease in bulk density and WSI, respectively. As temperature increased from 110 to 170 °C, WAI and WSI increased by 12.3% and 4.3%, respectively. But there was a decrease in BD by 12% and UD by 28%. The interaction effect of SWF content, moisture content and temperature (SWF×MC×T) were found to be significant for color, PDI, BD and ER. All the extrudates showed relatively high pellet durability, which is important to retaining their physical structure during transportation and storage. This indicates that utilization of combined SWF and HP-DDG did not have detrimental effect on pellet durability. Increasing levels of SWF produced less expanded and more compact textured extrudates. Based on the results obtained, further research may be conducted to study the effects of increased level of SWF (more than 30%) with different die dimension on the extrudate quality.

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