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Physical Properties of Extruded Tilapia feed with Distiller Dried grains with Solubles

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Abstract. *Distillers' dried grains with solubles (DDGS) from ethanol manufacturing plants contain a high percentage of protein, and are primarily used as livestock feed. The conversion efficiency of feed into body tissue is generally much higher in fish than farm animals. Fish can convert up to 36% of feed protein into body protein, whereas beef typically converts only 15%. Extrusion technology is very widely used for the production of floating and non floating aquaculture feeds. Therefore, the objective of this study was to quantify physical properties of extrudates containing 20,30 & 40% DDGS and net protein content adjusted to 28%. Three feed blends containing 28% protein with an energy content of 350 Kcal/100 grams were formulated with 20, 30 and 40% of DDGS along with appropriate levels of fish meal, soybean meal, corn flour, vitamin mix and mineral mix. These ingredient blends were extruded in a Brabender single screw extruder at 100, 130, and 160 rpm and 15, 20 and 25% moisture content and the physical properties were determined. The pellet durability of the extrudates was in the range of 0.37 to 0.96, and the percentage of DDGS present in the feed significantly affected the pellet durability. The specific gravity of the extrudates which determines the floatability was in the range of 0.82 to 1.05, and the lowest specific gravity of 0.82 was recorded at 20% DDGS, 20% moisture and 100 rpm screw speed.*

Keywords. Dried distillers grains with solubles, single screw extruder, physical properties, response surface methodology

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Introduction

United States is the largest producer of corn and mostly used for food, feed and ethanol production. During 2004, the ethanol production from corn was 3.5 million gallons and 23.3 million tones of dried distiller grains with solubles (DDGS) were produced as a co product in the ethanol industries. DDGS contains very high amount of protein, fiber and low amount of carbohydrates and is mostly used as animal feed. The protein conversion efficiency of fish is very high compared to the other animals. Hence DDGS has a greater potential to be used as a base material for aquaculture feed production. Research carried out by Wu et al. (1994,1996) indicated that tilapia fish can be grown with DDGS, and can improve the economic viability of aquaculture farms. Since starch is converted to ethanol during fermentation process, micro nutrients are available in concentrated quantities compared to whole corn. This makes it a better base material for aquaculture feed production compared to corn flour.

Extrusion cooking is very widely used in the food and feed industries due to the versatility in obtaining the required textural properties. In aquaculture feed production, the important physical properties that determine the quality are floatability and pellet durability. The floatability of the feed is achieved by the expansion attained during extrusion process and the pellet durability is determined by various biochemical changes occurring inside the barrel including gelatinization of starch. The carbohydrate content present in the ingredient mix plays an important role in determining the expansion ratio during extrusion cooking. But the fish feed requires high percentage of protein (26-50%) and this has a negative effect in expansion obtained during production of extruded feed with low specific gravity and pellet durability. The percentage of fiber present in the feed ingredient mix also suppresses the degree of expansion obtained during extrusion processing. The low amount of carbohydrate and high amount of fiber are the two basic problems in manufacturing aquaculture feed with DDGS as a base material. The amount of water present in the feed ingredient mix plays an important role in determining the expansion as well as strength of the extruded feed. The screw speed has a definite effect on the extent of pressure developed inside the barrel and affects the physical properties of extruded feed. Hence in our experiments, feed ingredient blends were formulated with varying levels of DDGS along with soy flour, corn flour, vitamin mix, mineral mix and extruded in a single screw extruder. The effect of varying the screw speed at different moisture content of the feed ingredient mix on the physical properties of extrudates were studied and reported in this paper.

Methods and Materials

Feed blends formulation

Three isocaloric ingredient blends were formulated with 28% protein with an energy content of 350 kcal/100 grams. During energy calculations the 4.5 kcal/gram for protein, 4.1 kcal/gram for carbohydrate and 9.1 kcal/gram for fat were assumed. The different ingredients in the in the feed blends include distillers dried grains, soy flour, corn flour, menhaden fish meal, vitamin mix and mineral mix. The yellow corn flour was provided by Cargill Dry Ingredients, Illinois and defatted soy flour was provided by Cargill Soy Protein Solutions, Iowa. The vitamin mix and mineral mix were purchased from the SDSU feed mill and mixed at 1% and 2% respectively on weight basis. The weight components of the different ingredients used in the experiments are given in the Table.1.

Table.1. Ingredient components in the different feed blends.

Feed Ingredients	Weight of ingredients (%)		
	Blend I	Blend II	Blend III
DDGS	20	30	40
Soy flour	32	28	24
Corn flour	35	29	23
Fish meal	6	6	6
Mineral mix	1	1	1
Vitamin mix	2	2	2

Experimental design and extrusion studies

The extrusion studies were carried out in a single screw extruder (Brabender Plasti-Corder extruder model PL 2000). The single screw extruder had a barrel of 12.5” length with a length to diameter ratio was 20:1. The die assembly had conical section inside and had a length of 4”. A uniform pitch screw with 0.75” pitch was used in the experiments. The screw had variable flute height and the flute height at the feed end was 0.75” and the near the die was 0.15”. The compression ratio achieved inside the barrel was 3:1. The speed of the screw, and the temperature inside the barrel were controlled by a computer. The extruder barrel had provisions to control the temperature of feed and transition zone in the barrel. The die section was fitted with a separate heater and thermostats and the temperature was controlled independent of the barrel. Compressed air cooling was provided in the barrel section and was controlled by solenoid switch fitted with the temperature console. The die section was not provided with compressed air for controlling the temperature. The single screw extruder was fitted with 7.5 HP motor, with the speed of the screw variable from 0 to 210 rpm. The extrusion studies were conducted as per the experimental design in the Table 2. During experiments the temperature of the feeding zone was maintained at 90° C and the temperature of the transition zone and the die section were maintained at 120°C for all the experiments.

Table 2. Experimental design followed during extrusion studies

Parameter	Levels of the parameter		
	I	II	III
% DDGS	20	30	40
Moisture content of feed ingredient(% wb)	15	20	25
Screw speed (rpm)	100	130	160

Measurement of physical properties

Throughput

The capacity of the machine (throughput) was measured as the weight of extrudate collected per hour. During the experiments the extrudates were collected for every 30 seconds and the throughput was calculated.

Pellet durability:

Pellet durability was determined as per ASAE standards method S269.4 DEC01. Two hundred grams of the extrudates were tumbled inside a pellet durabilty tester for 10 minutes and sieved through No.6 sieve. The pellet durability was calculated as

Pellet durability = (Mass of pellet after tumbling/Mass of pellet before tumbling) (1)

Specific gravity, Bulk Density and Porosity

Specific gravity of extrudates was determined as the ratio of true density of extrudates to the true density of water. During the experiments, the true density of water was assumed to be 1 gram/cc. The true density of extrudates was determined as a ratio of weight to the volume of the extrudates measured from the length and diameter of the cylindrical extrudates (Harris et al.1988; Das, H.K., 1993).

The porosity of the pellets were determined as

Porosity = 1-(Bulk density/ True density) (2)

Color

Color of the extrudates was determined using a Minolta color meter as per Hunter labs color code. The color of the pellets were determined with L*, a* and b* value. As per Hunters color code, L* value represents the whiteness of the sample, a* value represents the redness of the sample and b* value represents the yellowness of the sample.

Statistical analysis

Three measurements were done for bulk density, specific gravity, porosity and color and two measurements were done for throughput and pellet durability. The data were analyzed with Proc GLM procedure in SAS to determine the main and interaction effects of levels of DDGS, screw speed and moisture content on different physical properties and throughput.

Results and Discussion

The results of changing the levels of DDGS, screw speed and moisture content on the physical properties and throughput of the extrudates are given in the Table 3.

Throughput

The effect of changing the levels of DDGS, moisture content and screw speed on the throughput of the single screw extruder is shown in Figure 1. Statistical analysis showed that the percentage of DDGS had significant effect on the throughput of the single screw extruder, but did not show any trend indicating that the interaction of DDGS with other component played an important role in the mass flow rate of the single screw extruder. The screw speed had the most significant role in the throughput of the extruder. This was expected because, the speed of the screw was increased, the driving force for the movement of the dough has increased leading to increased mass flow rate resulting in higher throughput. Moisture content had significant effect on the throughput and as the moisture content was increased form 15% to 25%, the throughput had increased from 9.42 kg/hr to 11.29 kg/hr.

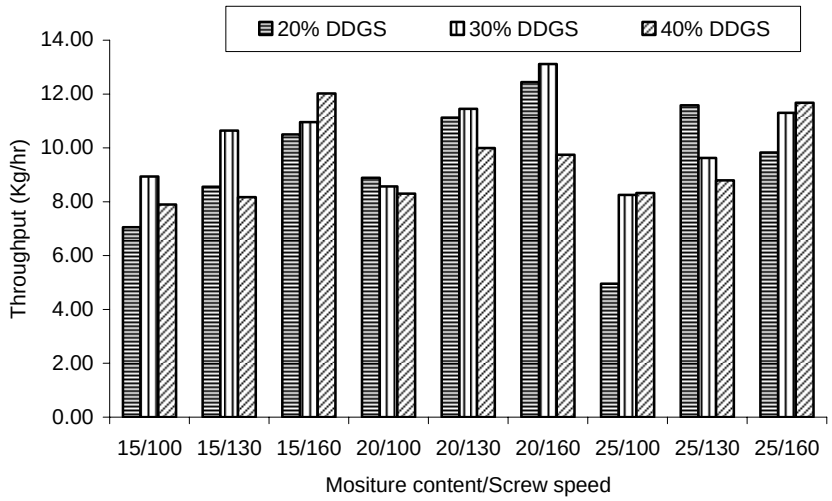

Fig.1. Effect of DDGS content, screw speed and moisture content on the throughput of single screw extruder.

Pellet durability

The effect of percentage of DDGS, moisture content and screw speed on the pellet durability of the extrudate is shown in Figure 2. As the moisture content was increased the pellet

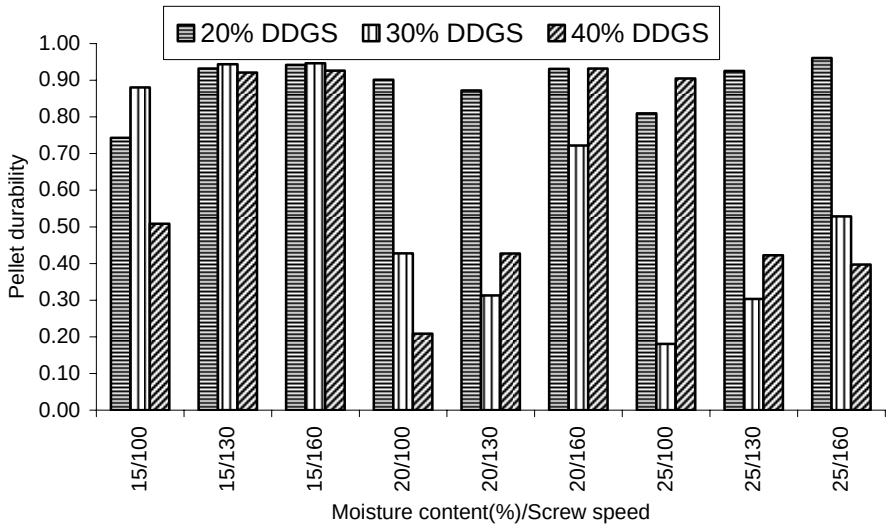

Fig.2. Effect of DDGS content, screw speed and moisture content on the pellet durability of extrudates.

Table 3. Effect of percentage of DDGS, screw speed and moisture content on the physical properties of extrudates

	Physical properties of extrudates and throughput of single screw extruder							
	Throughput (Kg/hr)	Pellet durability	Specific gravity	Bulk density (Kg/m^3)	Porosity (%)	Color L* value	Color a* Value	Color b* Value
DDGS – 20%	9.43[a]	0.89[a]	0.9563 [a]	401.9 [b]	57.89 [a]	52.33 [a]	6.79 [c]	31.90 [c]
DDGS – 30%	10.32[b]	0.65[b]	0.9307 [b]	416.7 [ab]	55.07 [ab]	50.87 [b]	7.89 [b]	36.29 [b]
DDGS – 40%	9.39[a]	0.56[c]	0.9270 [b]	434.4 [a]	53.00 [b]	47.78 [c]	8.59 [a]	38.63 [a]
Screw speed 100 rpm	7.91[a]	0.63[a]	0.9337 [a]	441.1 [a]	54.07 [b]	49.85 [b]	7.94 [a]	35.89 [a]
Screw speed 130 rpm	9.99[b]	0.69[b]	0.9370 [a]	427.8 [a]	52.59 [b]	51.29 [a]	7.89 [a]	36.45 [a]
Screw speed 160 rpm	11.29[c]	0.79[c]	0.9433 [a]	384.1 [b]	59.30 [a]	49.84 [b]	7.44 [b]	34.51 [a]
Moisture content 15%	9.42[a]	0.85[a]	0.9867 [a]	411.4 [a]	58.56 [a]	52.21 [a]	7.54 [b]	34.78 [a]
Moisture content 20%	10.40[b]	0.63[b]	0.9222 [b]	417.5 [a]	53.81 [b]	50.22 [b]	8.29 [a]	35.45 [a]
Moisture content 25%	11.29[c]	0.61[c]	0.9052 [c]	417.6 [a]	53.59 [b]	48.54 [c]	7.44 [c]	36.60 [a]

durability had increased. The same trend was observed by Rolfe et al. 2001 during extrusion processing of aquaculture feed. Amount of DDGS, and the screw speed also had significant effect on the pellet durability of the extrudates. The maximum pellet durability of 0.89 was achieved at 20% DDGS. As the DDGS content was increased, the pellet durability was found to decrease. This was because the amount of carbohydrate present in the ingredient mix played an important role in the strength of binding of the extrudates. As the DDGS content was increased, the amount of carbohydrate had decreased resulting in decreased pellet durability of the extrudates. The screw speed also had significant effect on the pellet durability and the as the screw speed was increased, the pellet durability increased. As the screw speed was increased, the pressure developed inside barrel increased, and the increased barrel pressure had effect on the nature of binding of the particles and affected the pellet durability.

Specific gravity

The effect of changing the levels of DDGS, moisture content and screw speed on the specific gravity is shown in the Figure 3. The specific gravity which determines the floatability of the extruded feed is very important in production of aquaculture feed. Changing the levels of the moisture content had significant effect on the specific gravity of the extrudates. As the moisture content was increased, the specific gravity was found to be decreasing. The amount of water present in the feed ingredient mix played an important role in the extent of gelatinization of starch occurring inside the barrel and significantly affected the nature bonding the extrudates. Hence the amount of water present in the feed ingredient mix played an important role in determining the specific gravity of the extrudates. As the amount of DDGS was increased, the specific gravity had decreased. This was expected, because as the DDGS content was high, the amount of carbohydrate was less and this adversely affected the nature of binding in the extrudate and different components were held very loosely. This has resulted in reduced specific gravity of the extrudates. The same type of results was observed by Chin et al. (1989) also. Changing the levels of screw speed had no significant effect on the specific gravity of the extruded feed.

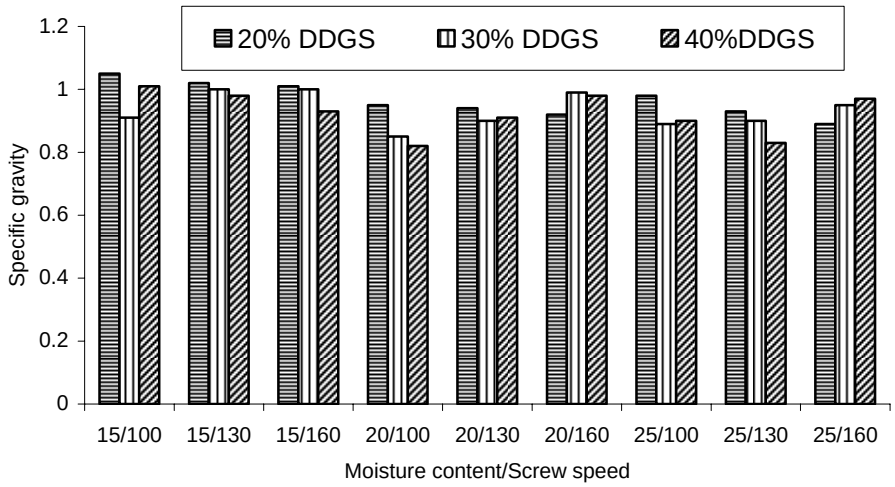

Fig.3. Effect of DDGS content, screw speed and moisture content on the specific gravity of extrudates.

Bulk density

The effect of changing the levels of the DDGS, screw speed and moisture content on the bulk density is given in the Figure 4. The bulk density of the extrudates in a single screw extruder with DDGS was in the range of 384.1 kg/m^3 to 434.4 kg.m^3. The variation in the

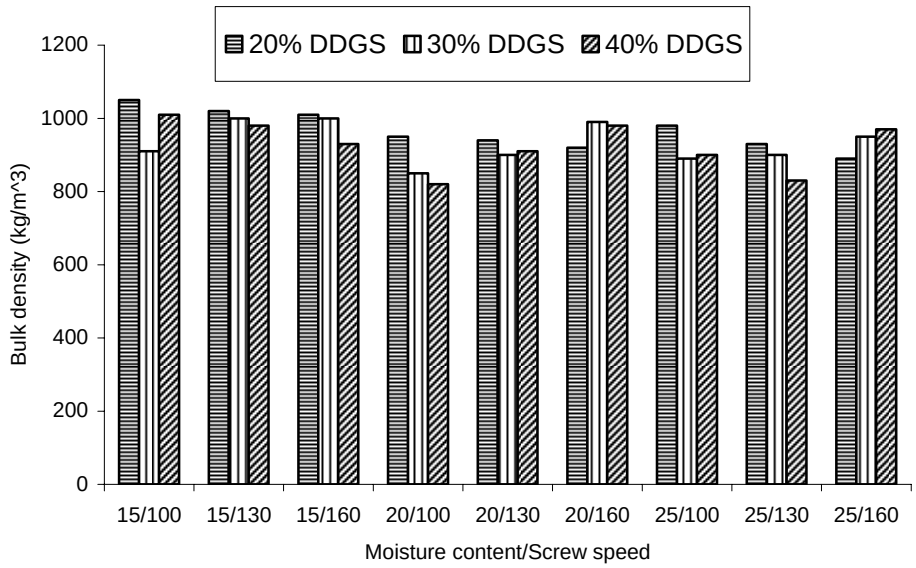

Fig.4. Effect of DDGS content, screw speed and moisture content on the bulk density of extrudates.

moisture content in the feed ingredient mix did not show any significant difference in the bulk density of the extrudates. But changing the levels of the DDGS and screw speed had significant effect on the bulk density of the extrudates. As the DDGS content was increased from 20% to 40%, the bulk density was found to increase and the lowest bulk density of 401.9 kg/m^3 was achieved at 20% DDGS. This was expected because, as the percentage of DDGS was decreased, the amount of starch present in the feed ingredient mix increased and improved the expansion obtained in the extrusion processing. This improved expansion resulted in reduced bulk density. As the screw speed was increased, the bulk density had also decreased. Higher screw speed increases the absolute pressure developed inside the barrel. During extrusion process, expansion occurs when the molten dough at a high pressure inside the barrel exits thorough nozzle and sudden drop in the pressure of the dough. Due to this, the expansion obtained at higher screw speeds was higher and resulted in reduced bulk density.

Porosity

The effect of changing the levels of DDGS content, screw speed and moisture content on the porosity is given in the Figure 5. The porosity of the extrudates is very important because it determines the storage space needed both at the manufacturing plant and at aquaculture farms. The porosity of extruded feed has two components. The air spaces in the extrudates due to expansion obtained during expansion process, and the air spaces formed during irregular shaped feed are arranged in any storage space. Both of these air spaces contribute to the porosity of the extruded feed. The size, shape and method of filling in the packages affect the porosity. As the DDGS content was increased, the porosity of the extrudates was found to decrease and this might be due to the expansion obtained during extrusion. As the moisture

content was decreased, the porosity of the extrudates was also found to decrease, but screw speed did not show any trend in porosity.

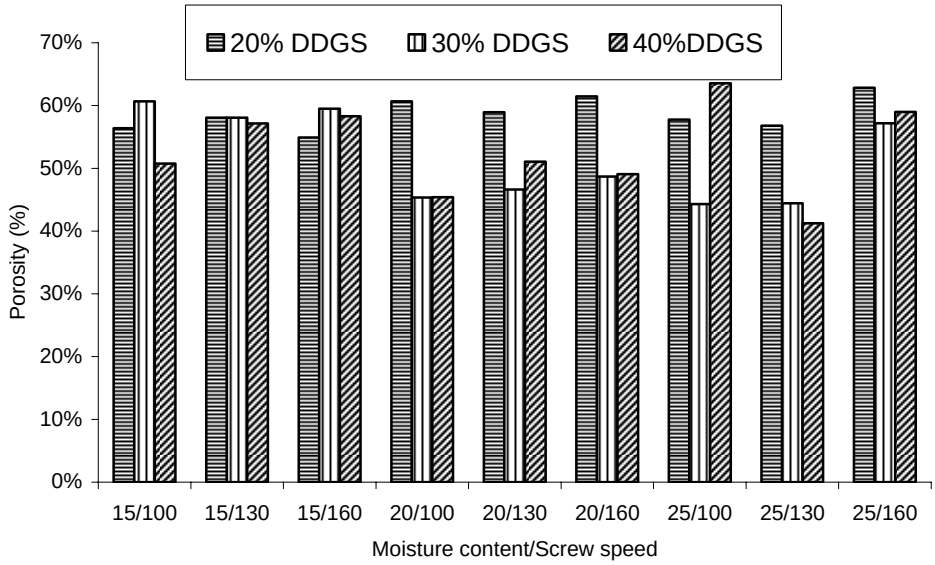

Fig.5. Effect of DDGS content, screw speed and moisture content on the porosity of extrudates.

Color

L* Value

The effect of changing the levels of moisture content, screw speed and DDGS on the L* value is given in Figure 6. The brightness of the extruded feed is measured with L* value in Hunters

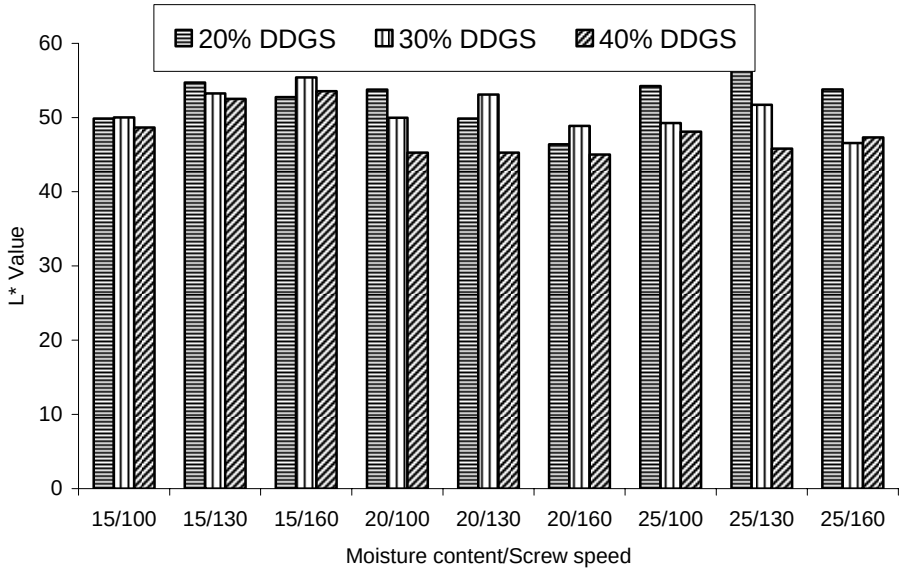

Fig.6. Effect of DDGS content, screw speed and moisture content on the brightness (L*) of extrudates.

color lab code. As the DDGS content was increased, the brightness was also decreased. DDGS is very dark in color compared to the soy flour and corn flour. Due to this as the DDGS content was increased, the brightness had reduced indicated by the significant reduction in L* value. As the moisture content was increased, the brightness was also decreased. But the screw speed did not show any trend in the brightness of the extrudate feed.

a* Value

The effect of changing the levels of DDGS, screw speed and moisture content on the redness of the extrudates is shown in Figure 7. As the DDGS content was increased, the redness of the extrudate had increased indicated by the increase in a* value. The redness in extrudate might be due to the biochemical reactions including Maillard reactions occurring inside the barrel at higher temperature and pressure. The amount of DDGS present in the feed significantly affected the biochemical reaction and effected significant changes in the a* value. As the screw speed was increased, the redness has increased and the level of moisture content had no significant effect on the redness of the extrudates.

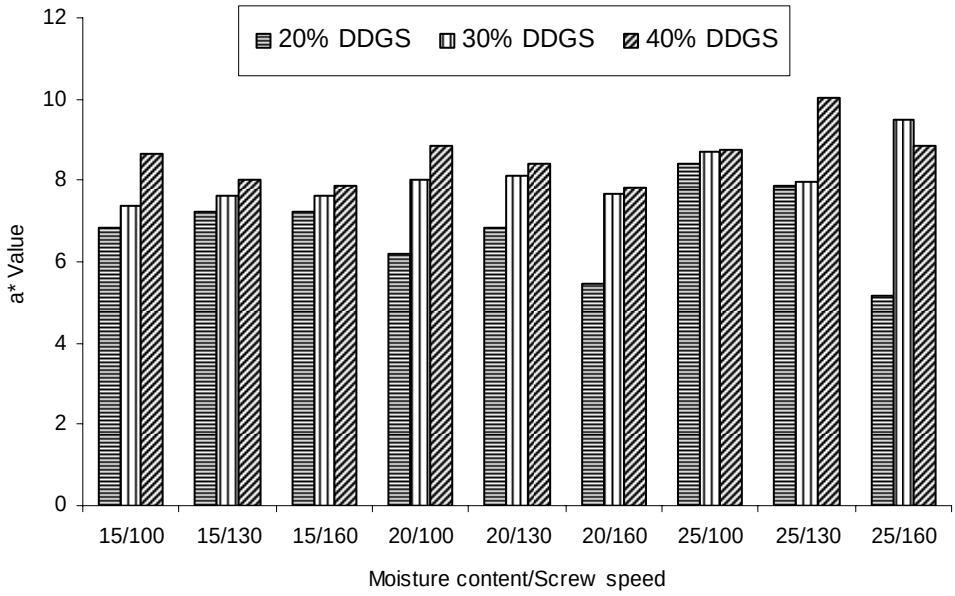

Fig.7. Effect of DDGS content, screw speed and moisture content on the redness (a*) of extrudates.

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b* Value

The effect of percentage of DDGS, moisture content of feed ingredient mix and the screw speed on the yellowness of the extrudates is shown in the Figure 8. As the DDGS content was increased, the yellowness of the extrudates increased. This is expected because, DDGS is golden yellow in color and as the DDGS content was increased, the yellowness of the sample increased. The moisture content and screw speed had no significant effect on the yellowness of the extrudates during extrusion cooking in a single screw extruder..

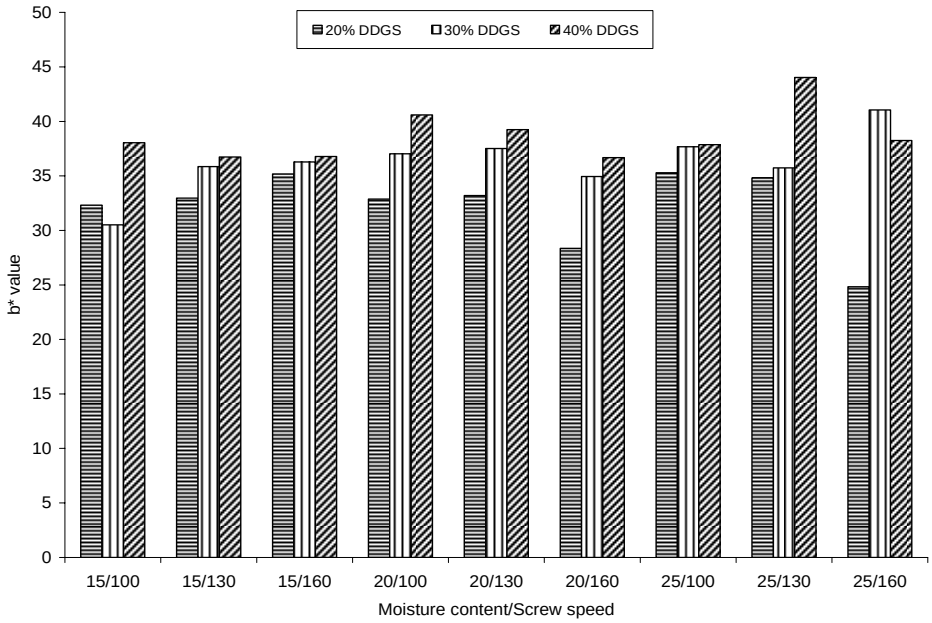

Fig.8. Effect of DDGS content, screw speed and moisture content on the yellowness (b*) of extrudates.

Optimization of DDGS content, screw speed and moisture content for pellet durability

Pellet durability, which determines the stability of the extruded feed during transportation and also in the feeding tank, is a very important quality of aquaculture feed. Hence the optimization of the operating parameters and feed parameters to get high pellet durability is very important. The levels of DDGS, moisture content and screw speed were optimized with response surface methodology. Among the three factors, amount of DDGS was the most significant factor affecting the pellet durability, followed by moisture content and screw speed. During response surface analysis, minimum critical point was found at 35% DDGS, 23% moisture content and 103 rpm. The response surface obtained for the pellet durability with different levels of DDGS and moisture content is shown in the figure 9. The response surface followed the equation:

$$\text{Pellet durability} = 3.42 - 0.10 * DDGS - 0.03\ MC + 0.03 * MC^2 - 0.001 * RPM * (DDGS + MC + RPM) \quad (3)$$

and all the coefficients of the terms were found to be significant. From the equation, we can see that the coefficient of DDGS was the largest and significantly affected the pellet durability of the extrudates. Reduction in DDGS content from the critical point increased pellet durability. This was expected due to the higher starch content as the DDGS content was decreased and affects the extent of gelatinization and expansion obtained during extrusion. An increase or decrease in moisture content from 23% will significantly increase the pellet durability.

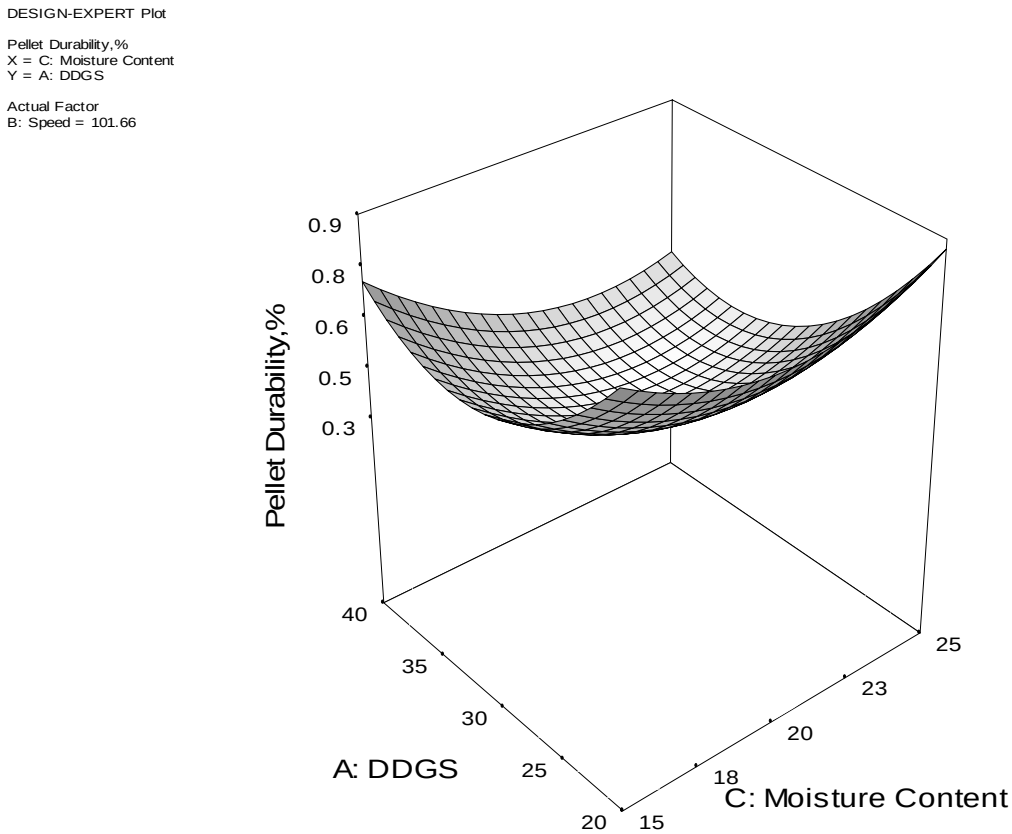

Fig.9. Response surface on the effect of moisture content, DDGS on the pellet durability

Optimization of DDGS content, screw speed and moisture content for specific gravity

Specific gravity, which determines the floatability of extrudates, was in the range of 0.83 to 1.10 in our experiments. To get good floatability, the specific gravity should be as low as possible. Hence optimization of the different machine and ingredient parameters are very much essential get lowest specific gravity. For optimization of levels of DDGS, moisture content and screw speed with response surface analysis, we found that amount of moisture content was the most significant factor affecting the specific gravity of the extrudates. The response surface for optimization of the parameters is shown in the Figure 10. The response surface followed the equation:

$$\text{Specific gravity} = 0.9907 - 0.015 * DDGS - 0.041 * MC + 0.019 * RPM + 0.009 * (DDGS)^2 + 0.011 *(MC * DDGS) + 0.030 * (MC)^2 + 0.019 *(RPM * DDGS) + 0.012 * (RPM * MC) + 0.006 *(RPM)^2 \quad (4)$$

Among the coefficients of the equation, the intercept, DDGS, moisture content, RPM * DDGS were found to be significant at $P<0.05$. The critical point was found to be outside the experimental region.

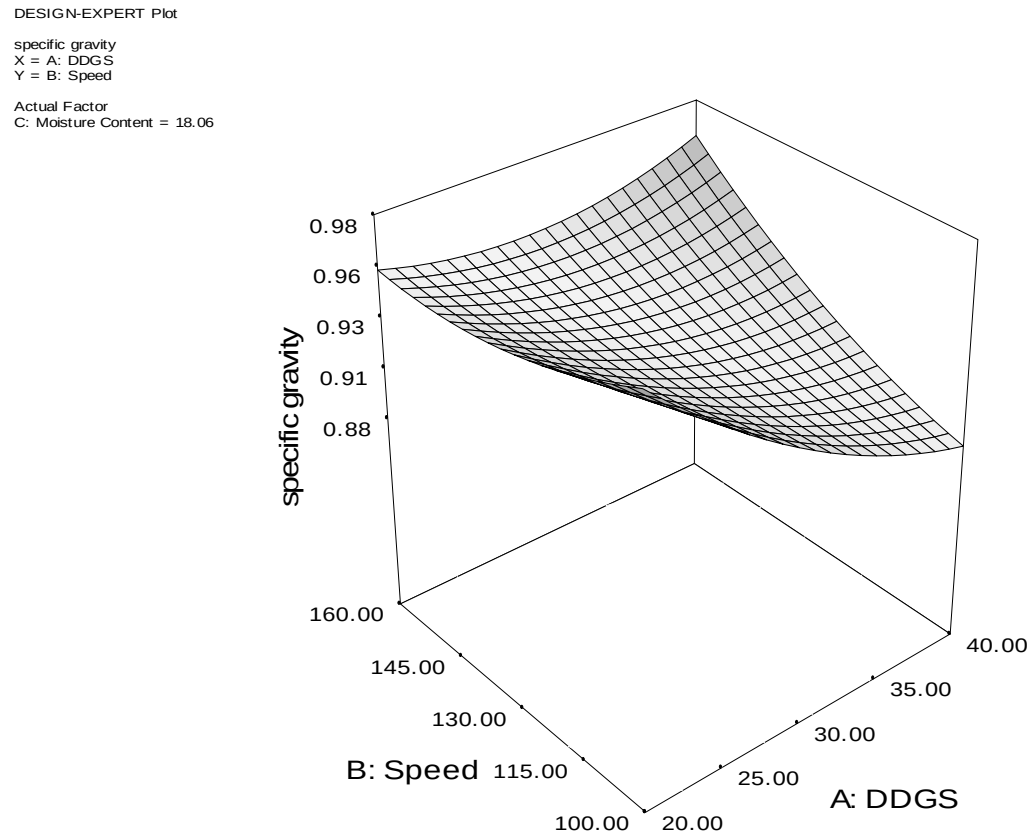

Fig.10. Response surface on the effect of moisture content, DDGS on the pellet Specific gravity

Conclusions

Extrudates with good pellet durability can be produced in a single screw extruder containing up to 40% DDGS and net protein content adjusted to 28% along with soy flour, corn flour, vitamin mix, mineral mix and fish meal. The amount of DDGS, moisture content in the feed ingredient mix and the screw speed had significant effect on the pellet durability of the extrudates. The pellet durability of the extrudates was found to decrease as the DDGS content was increased. The amount of DDGS, moisture content of the feed ingredient mix and the screw speed had significant effect on the specific gravity of the extrudates. The specific gravity of the extrudates was found to decrease as the DDGS content was increased. Hence optimization of DDGS and the operating parameters are necessary to obtain extrudates with good pellet durability and low specific gravity.

Acknowledgments

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