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Physical and Mechanical Properties of Fish Feed Pellets

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Abstract

This work presents a useful information about different fish feed pellets, which will be database for the people work in the intensive fish farming which help then in solving many problems concerning the feeding effectiveness and feed handling and storage. The main objective of this work was to study the physical and mechanical properties of fish feed pellets contained different protein ratios and pellets sizes. These properties include: actual diameter, expansion rate, surface area, volume, weight, bulk density, durability, floatability, moisture content, water stability, repose angle and crushing load. The actual diameter of pellets fish feed value ranged from 1.51 to 4.55 mm. The expansion rate of pellets fish feed value ranged from 33.31 to 40.94%. The surface area of pellets fish feed value ranged from 10.57 to 71.13 mm^2. The volume of pellets fish feed 4.04 to 79.09 mm^3. The weight of 100 pellets value ranged from 0.11 to 5.51 g. The bulk density of pellets of fish feed value ranged from 267.11 to 711.35 kg m^{-3}. The durability of pellets of fish feed value ranged from 70.66 to 92.62%. The floatability of pellets of fish feed value ranged from 79.51 to 96.45%. The moisture content of pellets of fish feed value ranged from 16.68 to 17.82%. The water stability of pellets of fish feed value ranged from 54.15 to 91.78%. The repose angle of pellets fish feed value ranged from 27.00 to 38.00°. The crushing load of pellets fish feed value ranged from 6.13 to 33.28 N.

Keywords: Physical properties; Mechanical properties; Extruded fish feed; Durability; Floatability; Water stability; Crushing load

Introduction

Aquaculture is one of the fastest growing food production activities in the world. It plays a significant role in many countries by providing a higher income, better nutrition, and better employment opportunities [1]. Thus, the aqua-feed technology is moving in tandem with the aquaculture growth with the usage of extrusion procedures for the improvement of digestibility [1,2] stated the advantages of extrusion cooking process for aquaculture feed production including improved feed conversion ratio, control of pellet density, greater feed stability in water, better production efficiency and versatility. During extrusion cooking, various reactions take place including thermal treatment, gelatinization, protein denaturation, hydration, texture alteration, partial dehydration, and destruction of microorganisms and other toxic compounds.

Extrusion is the predominant process in the manufacturing of compound fish feed. Extrusion microbial load, reduces the level of thermolabile antinutrients present in plant material and improves the digestibility of dietary components [3,4].

Production of extruded fish feed pellets demands a strict process control to obtain acceptable physical product quality and density specifications. The physical quality of extruded fish feed has become important due to increased use of big bags, bulk transport and pneumatic feed delivery systems. Harsh treatments expose pellets to stress that might increase attrition and product loss [5]. Attrition of feed pellets comprises two phenomena, fragmentation and abrasion, and is normally measured by the combined use of a hardness test (fragmentation) and a pneumatic durability test (fragmentation and abrasion) [6].

Hilton et al. [7] reported that the impact of physical pellet quality on the biological response of the fish has not been studied in detail. Trouts fed extruded feed had prolonged gastric emptying and lower weight gain but higher feed efficiency than trouts fed steam pelleted feeds. The effect was attributed to higher physical and water stability as well as higher water adsorption capacity of the extruded feed. Most published studies on fish nutrition do not report data on physical quality of the feeds. Variation in sinking and floating properties, hardness and physical and water stability might be underlying and uncontrolled variables adding experimental bias that can weaken the interpretation of the biological response.

Studies regarding the physical characteristics of feed pellets involved in seawater [8,9] and freshwater [10] fish farming sand systems have been previously published but there is a complete lack of information regarding the characteristics of the feed employed in the rearing of Mediterranean species.

The physical properties of pellets should be high in order to withstand handling, transportation and pneumatic conveying, without generation of excessive amount of dust and fine particles. Except for this general definition, no standards are established in terms of hardness or durability. Besides, there is a lack of standardization of equipment and measurements for describing physical properties of extruded fish feed. Establishing standards with regard to physical properties is therefore a challenge [11]. In particular, there is a need to establish methods and procedures that can be used to simulate degradation of pellets during conveying in pneumatic feeding devices. Different methods are used to assess durability of the pellets such as the Holmen durability tester, Tumbling box procedure and Lignotest [6,12,13].

Due to the lack of information about the physical and mechanical properties of fish feed pellets which are very important to understand its behavior during processing, transporting, packaging and floatability during fish feeding, therefore, the main aim of this work was to study the physical and mechanical properties of fish feed pellets contained different protein ratios and pellets sizes.

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Materials and Methods

Extruded fish feed with different protein ratios (25, 27, 30 and 32%) and different sizes (1, 1.5, 2.2 and 3 mm) were produced at Zocontrol processing, Cairo, Egypt. The chemical composition of the fish feed are listed in Table 1.

Measurements

Physical properties: The dimensions of pellets (diameter and length of each 10 pellets sample) were measured by digital vernier caliper (Model TESA 1p65- Range 0-150 mm ± 0.01 mm, Swiss). The surface area and volume were calculated by measuring the height and radius of 10 feed pellets. The mass was measured by electric digital balance (Model HG – 5000– Range 0-5000 g ± 0.01 g, Japan).

The moisture content of randomly selected feed pellets of each category was determined according to [14]. Three samples of each feed pellets were randomly selected and weighed on an electric digital balance. Drying oven (Fisher Scientific Isotemp Oven, Model 655F Cat. No. 13-245-655, Fisher Scientific, Toronto, Ontario, Canada) at 105°C until a constant weight was used to measure the moisture content.

The bulk density was a measurement of a feed mass per unit volume of space the feed occupies [15]. For each case, the determination was replicated three times and the mean was considered.

Durability was measured using a Holmen tester (BorregaardLignoTech, Hull, UK). Three samples of approximately 100 g of pellets were weighed into the analytical instrument and run for 120 s. The amount of material left in the sieve was weighed and durability expressed as percentage the material left on the sieve.

Floatability of each replicate feeds was tested using 100 ml beakers. The characteristics of 10 pellets (floated or sunk) were noted after 20 min. Water stability (WS) was measured as the ratio of the pellets retained on a wire mesh screen after immersion of 3-4 g of each replicate feeds in 100 ml water for 20 min and oven-drying at 105°C for 24 h to whole pellets at the start [16].

Expansion rate (ER) was calculated using Eq. 1 after measuring the final diameters of 10 pellets (Df) of each replicate:

Where:-

Di is the initial die diameter, mm

Mechanical properties: The angle of repose is the minimum angle at which any piled-up bulky or loose material will stand without falling downhill. There is a minimum angle or maximum slope the pellets will maintain due to the forces of gravity and the effect of friction between the particles of pellets. The angle is calculated between the peak of the pile and the horizontal ground [17].

Crushing load implies the partial or complete destruction of pellets, feed pellet was sat upon a flat plate until the cross-head of a handmade apparatus was brought in contact with the pellet and compression force was applied by adding weights or loads until permanent (destruction) was caused and then the loads were recorded [18].

Results and Discussions

Physical properties

The mean diameter and expansion rate of fish feed pellets: Table 2 shows the mean values, standard deviation (SD) and coefficients of variation (CV) of the actual diameter and expansion rate of the fish feed pellets. It shows that the average of actual diameter and expansion rate of the fish feed pellets were 1.54 ± 0.14, 2.45 ± 0.13, 3.39 ± 0.17 and 4.40 ± 0.26 mm and 34.70 ± 5.82, 38.67 ± 3.19, 34.90 ± 3.10 and 32.23 ± 3.85% for 1.0, 1.5, 2.2 and 3.0 mm pellets sizes, respectively, at 25% protein ratio. The coefficients of variation of the actual diameter data recorded the highest value (0.09) on the 1.0 mm pellets sizes, while the minimum value (0.05) on the 1.5 and 2.2 mm pellets sizes at 25% protein ratio. Also, the highest value the CV values of the expansion rate was 0.17 for 1.0 mm pellets sizes, while the minimum value was 0.08 for the 1.5 mm pellets sizes at the same protein ratio.

The results indicate that the average of actual diameter and expansion rate of the fish feed pellets were 1.52 ± 0.13, 2.44 ± 0.11, 3.34 ± 0.15 and 4.55 ± 0.30 mm and 33.60 ± 5.60, 38.46 ± 2.73, 34.03 ± 2.98 and 33.79 ± 4.50% for 1.0, 1.5, 2.2 and 3.0 mm pellets sizes, respectively, at 27% protein ratio. The highest value of CV of the actual diameter (0.09) was found for 1 mm pellets sizes and the lowest value (0.04) was found for 1.5 mm pellets sizes at 27% protein ratio. The same trend for CV was happened with the expansion rate.

The results also indicate that the average of actual diameter and expansion rate of the fish feed pellets were 1.51 ± 0.14, 2.54 ± 0.11, 3.40 ± 0.13 and 4.34 ± 0.31 mm and 33.31 ± 6.45, 40.94 ± 2.52, 35.24 ± 2.50 and 31.32 ± 4.91% for 1.0, 1.5, 2.2 and 3.0 mm pellets sizes, respectively, at 30% protein ratio. The highest value of CV for actual diameter and expansion rate were 0.10 and 0.19, respectively, were found for 1 mm pellets sizes. The lowest value of CV of actual diameter (0.04) was found for 1.5 and 2.2 mm pellets sizes, while the lowest value of CV of expansion rate (0.06) was found for 1.5 mm pellets sizes at the same protein ratio.

On the other hand, the average of actual diameter and expansion rate of the fish feed pellets were 1.51 ± 0.09, 2.37 ± 0.10, 3.39 ± 0.17 and 4.55 ± 0.22 mm and 33.44 ± 3.89, 36.53 ± 2.67, 34.94 ± 3.21 and 33.93 ± 3.21% for 1.0, 1.5, 2.2 and 3.0 mm pellets sizes, respectively, at 32% protein ratio. The highest value of CV of the actual diameter (0.06) was found for 1 mm pellets sizes and the lowest value (0.04) was found for 1.5 mm pellets sizes at 32% protein ratio. The same trend for CV was happened with the expansion rate.

Multiple regression analysis has resulted in a good relationship between the mean of Actual Diameter (AD), pellet sizes (PS) and protein ratios (PR), where, the mean of actual diameter has a high correlation with both PS and PR with r^2 of 0.991 at P<0.001. The mean of Expansion Rate (ER), Pellet Sizes (PS) and Protein Ratios (PR) relationship with r^2 of 0.881 at P<0.001. The best forms were as follows:

$$AD = 0.158 + 1.445PS + 0.0004PR \qquad R^2 = 0.991 \quad (2)$$

$$ER = 38.498 - 1.243PS - 0.039PR \qquad R^2 = 0.881 \quad (3)$$

Where:

AD is the actual diameter of pellets fish feed, mm

ER is the expansion rate of pellets fish feed, %

PS is the pellet sizes, mm

PR is the protein ratios, %

Ingredients	Protein Ratio of Fish Feed, %			
	25	27	30	32
Fish Meal, %	8	10	11	12
Soybean, %	29	33	38	42
Yellow Corn, %	24	20	18	17
Wheat Bran, %	30	28	24	20
Fish additives, %	9	9	9	9

Table 1: Chemical composition of the feed fish

Protein ratio (%)		Pellet Sizes (mm)				Pellet Sizes (mm)			
		1	1.5	2.2	3	1	1.5	2.2	3
		Actual Diameter (mm)				Expansion Rate (%)			
25	Mean	1.54	2.45	3.39	4.40	34.72	38.67	34.90	32.23
	SD	0.14	0.13	0.17	0.26	5.82	3.19	3.10	3.85
	CV	0.09	0.05	0.05	0.06	0.17	0.08	0.09	0.12
27	Mean	1.52	2.44	3.34	4.55	33.60	38.46	34.03	33.79
	SD	0.13	0.11	0.15	0.30	5.60	2.73	2.98	4.50
	CV	0.09	0.04	0.05	0.07	0.17	0.07	0.09	0.13
30	Mean	1.51	2.54	3.40	4.34	33.31	40.94	35.24	31.32
	SD	0.14	0.11	0.13	0.31	6.45	2.52	2.50	4.91
	CV	0.10	0.04	0.04	0.07	0.19	0.06	0.07	0.16
32	Mean	1.51	2.37	3.39	4.55	33.44	36.53	34.94	33.93
	SD	0.09	0.10	0.17	0.22	3.89	2.67	3.21	3.21
	CV	0.06	0.04	0.05	0.05	0.12	0.07	0.09	0.09

SD: Standard Division
CV: Coefficient of Variation

Table 2: The mean of actual diameter and expansion rate of feed fish pellets.

Surface area and volume of fish feed pellets: Table 3 shows the mean values, Standard Deviation (SD) and Coefficients of Variation (CV) of the surface area and volume of the fish feed pellets. It shows that the average of surface area and volume of the fish feed pellets were 11.83 ± 2.54, 23.02 ± 3.65, 41.24 ± 9.19 and 71.13 ± 9.96 mm^2 and 4.64 ± 1.38, 14.19 ± 2.88, 32.80 ± 3.98 and 79.09 ± 13.04 mm^3 for 1.0, 1.5, 2.2 and 3.0 mm pellets sizes, respectively, at 25% protein ratio. The highest value of CV of the surface area (0.22) for the 2.0 mm pellets sizes, while the minimum value (0.14) for the 3.0 mm pellets sizes at 25% protein ratio. Also, the highest value the CV values of the volume was 0.30for 1.0 mm pellets sizes, while the minimum value was 0.12 for the 2.0 mm pellets sizes at the same protein ratio.

The results indicate that the highest value of surface area and volume of the fish feed pellets were 71.13 ± 9.96 mm^2 and 79.09 ± 13.04 mm^3, respectively, at the pellet sizes 3.0 mm with 25% protein ratio. The lowest value of surface area and volume of the fish feed pellets were 10.57 ± 1.69 mm^2 and 4.04 ± 0.98 mm^3, respectively, for the pellet sizes of 1.0 mm with 30% protein ratio. The highest value of CV of the surface area (0.92) was found for 3.0 mm pellets sizes with 32% protein ratio and the lowest value (0.05) was found for 2.2 mm pellets sizes at 27% protein ratio. The highest value of CV of the volume (0.30) was found for 1.0 mm pellets sizes at 25% protein ratio and the lowest value (0.08) was found for 2.2 mm pellets sizes at 27% protein ratio.

Multiple regression analysis has resulted in a good relationship between the mean of Surface Area (SA), Pellet Sizes (PS) and Protein Ratios (PR), where, the mean surface area has a high correlation with both PS and PR with r^2 of 0.969 at P<0.001. The mean of volume (V), pellet sizes (PS) and protein ratios (PR) relationship with r^2 of 0.936 at P<0.001. The best forms were as follows:

$$SA = -2.714 + 27.669PS - 0.5702PR \qquad R^2 = 0.969 \quad (4)$$

$$V = -28.5391 + 35.2699PS - 0.2864PR \qquad R^2 = 0.936 \quad (5)$$

Where:

SA is the surface area of pellets fish feed, mm^2

V is the volume of pellets fish feed, mm^3

Weight and bulk density of fish feed pellets: Table 4 shows the mean values, standard deviation (SD) and coefficients of variation (CV) of the weight and bulk density of the fish feed pellets. The results indicated that the mean weight and bulk density of the fish feed pellets increases with increasing the pellet sizes and protein ratio. It indicated that when the pellet sizes increased from 1.0 to 3.0 mm, the mean weight of 100 pellets and bulk density increased from 0.28 ± 0.038 to 5.51 ± 0.237 g and 630.02 ± 156.99 to 711.35 ± 105.60 kg m^{-3}, respectively, at 25% protein ratio. The highest value of CV for weight (0.137) was found for 1.0 mm pellets sizes, while the highest value of CV for bulk density (0.25) was found for 1.0 mm pellets sizes. The lowest value of CV of weight (0.030) was found for 2.2 mm pellets sizes, while the lowest value of CV of bulk density (0.11) was found for 2.2 mm pellets sizes at the same protein ratio.

Also, the mean weight of 100 pellets and bulk density increased from 0.11 ± 0.006 to 3.70 ± 0.173 g and 267.11 ± 117.65 to 505.78 ± 63.61 kg m^{-3}, respectively, at 32% protein ratio. The highest value of CV for weight (0.052) was found of 1.0 and 1.5 mm pellets sizes, while the highest value of CV for bulk density (0.29) was found for 1.0 mm pellets sizes. The lowest value of CV of weight (0.028) was found for 2.2 mm pellets sizes, while the lowest value of CV of bulk density (0.13) was found for 2.2 and 3.0 mm pellets sizes at 32% protein ratio.

The lowest value of weight of 100 pellets and bulk density were 0.11 ± 0.006 g and 267.11 ± 117.65 kg m^{-1}, respectively, at the pellet sizes 1.0 mm with 32% protein ratio and the highest value of weight of 100 pellets and bulk density were 5.51 ± 0.043 g and 711.35 ± 105.60 kg m^{-3}, respectively, at the pellet sizes 3.0 mm with 25% protein ratio.

Protein ratio (%)		Pellet Sizes (mm)				Pellet Sizes (mm)			
		1	1.5	2.2	3	1	1.5	2.2	3
		area (mm^2)				Volume (mm^3)			
25	Mean	11.83	23.02	41.24	71.13	4.64	14.19	32.80	79.09
	SD	2.54	3.65	9.19	9.96	1.38	2.88	3.98	13.04
	CV	0.21	0.16	0.22	0.14	0.30	0.20	0.12	0.16
27	Mean	11.79	20.79	37.44	67.08	4.51	12.73	31.29	75.74
	SD	1.82	1.77	2.00	6.50	1.01	1.63	2.47	11.37
	CV	0.15	0.09	0.05	0.32	0.22	0.13	0.08	0.15
30	Mean	10.57	21.99	37.52	65.32	4.04	13.97	31.97	71.86
	SD	1.69	1.80	2.74	8.69	0.98	1.52	3.28	12.14
	CV	0.16	0.08	0.07	0.13	0.22	0.11	0.11	0.17
32	Mean	11.18	20.40	32.46	65.01	4.24	12.09	31.82	74.12
	SD	1.75	2.05	3.63	5.99	0.86	1.47	4.21	9.25
	CV	0.16	0.10	0.10	0.92	0.20	0.12	0.13	0.12

SD: Standard Division
CV: Coefficient of Variation

Table 3: The mean of surface area and volume of feed fish pellets

Protein ratio (%)		Pellet Sizes (mm)				Pellet Sizes (mm)			
		1	1.5	2.2	3	1	1.5	2.2	3
		100 pellets weight (g)				Bulk density (kg m^{-3})			
25	Mean	0.28	1.15	3.12	5.51	630.02	696.23	702.40	711.35
	SD	0.038	0.087	0.094	0.237	156.99	142.03	98.11	105.60
	CV	0.137	0.075	0.030	0.043	0.25	0.18	0.11	0.15
27	Mean	0.19	0.85	2.45	4.93	442.67	681.07	816.14	663.37
	SD	0.030	0.035	0.058	0.234	139.29	129.95	76.30	102.96
	CV	0.159	0.065	0.023	0.048	0.31	0.19	0.09	0.16
30	Mean	0.13	0.69	2.10	4.45	330.01	500.77	663.79	635.33
	SD	0.017	0.304	0.00	0.029	114.25	101.01	77.18	108.58
	CV	0.133	0.044	0.00	0.006	0.35	0.20	0.12	0.17
32	Mean	0.11	0.55	1.99	3.70	267.11	462.98	634.50	505.78
	SD	0.006	0.029	0.056	0.173	77.4	117.65	79.79	63.61
	CV	0.052	0.052	0.028	0.047	0.29	0.25	0.13	0.13

SD: Standard Division
CV: Coefficient of Variation

Table 4: The mean of weight and bulk density of pellets feed fish

These results indicated that the bulk density of the fish feed pellets increases with increasing the expansion rate. These results were in agreement with those obtained by [19-21].

Multiple regression analysis has resulted in a good relationship between the mean of weight (W), pellet sizes (PS) and protein ratios (PR), where, the mean weight has a high correlation with both PS and PR with r^2 of 0.961 at P<0.001. The Bulk Density (BD), Pellet Sizes (PS) and Protein Ratios (PR) relationship with r^2 of 0.891 at P<0.001. The best forms were as follows:

$$W = 1.194 + 2.2726PS - 0.1246PR \qquad R^2 = 0.961 \qquad (6)$$

$$BD = 1306.798 + 103.597PS - 32.359PR \qquad R^2 = 0.891 \qquad (7)$$

Where:

W is the weight of pellets fish feed, g

BD is the bulk density of pellets fish feed, kg m^{-3}

Durability and floatability of fish feed pellets: Table 5 shows the mean values, standard deviation (SD) and Coefficients of Variation (CV) of the durability and floatability of the fish feed pellets. The results indicated that the mean durability of the fish feed pellets decreases with increasing the pellet sizes and protein ratio. It indicated that when the pellet sizes increased from 1.0 to 3.0 mm, the mean durability decreased from 92.62 ± 3.86 to 75.64 ± 5.73 % at 25% protein ratio. The highest value of CV for durability (0.08) was found for 3.0 mm pellet sizes. The lowest value of CV of durability (0.03) was found for 1.5 mm pellet sizes at 25% protein ratio. The mean durability decreased from 87.52 ± 4.44 to 70.66 ± 4.22% at 32% protein ratio. The highest value of CV for durability (0.06) was found for 3.0 mm pellet sizes. The lowest value of CV of durability (0.04) was found for 2.2 mm pellet sizes. The lowest value of durability was 70.66 ± 4.22% at the pellet sizes 3.0 mm with 32 % protein ratio and the highest value of durability was 92.62 ± 3.86% at the pellet sizes 1.0 mm with 25% protein ratio.

The results indicated that the mean floatability of the fish feed pellets decreases with increasing the pellet sizes and decreasing protein ratio. It indicated that when the pellet sizes increased from 1.0 to 3.0 mm, the mean floatability decreased from 96.45 ± 1.02 to 79.51 ± 2.01% at 25% protein ratio. The highest value of CV for floatability (0.03) was found for 3.0 mm pellet sizes. The lowest value of CV of floatability (0.01) was found for 1.0 mm pellet sizes at 25% protein ratio. The mean floatability decreased from 98.00 ± 0.00 to 87.82 ± 2.01% at 32% protein ratio. The highest value of CV for floatability (0.02) was found for 1.5, 2.2 and 3.0 mm pellet sizes. The lowest value of CV of floatability (0.00) was found for 1.0 mm pellet sizes at 32% protein ratio. The lowest value of floatability was 79.51 ± 2.01% at the pellet sizes 3.0 mm with 25% protein ratio and the highest value of durability was 98.00 ± 0.00% at the pellet sizes 1.0 mm with 32% protein ratio.

These results indicated that the durability of the fish feed pellets increases with increasing the expansion rate. These results were in agreement with those obtained by [22,23].

Multiple regression analysis was carried out to get a relationship between the mean of durability (PD), pellet sizes (PS) and protein ratios (PR), where, the mean durability has a high correlation with both PS and PR with r^2 of 0.982 at P<0.001. The mean of floatability (PF), pellet sizes (PS) and protein ratios (PR) relationship with r^2 of 0.876 at P<0.001. The best forms were as follows:

$$PD = 122.8685 - 8.058PS - 0.9013PR \qquad R^2 = 0.982 \qquad (8)$$

$$PF = 96.854 - 6.205PS + 0.4637PR \qquad R^2 = 0.876 \qquad (9)$$

Where:

PD is the durability of pellets fish feed, %

PF is the floatability of pellets fish feed, %

Moisture content and water stability of fish feed pellets: Table 6 shows the mean values, standard deviation (SD) and coefficients of variation (CV) of the moisture content and water stability of the fish feed pellets. It shows that the average of moisture content of the fish feed pellets was 16.72 ± 2.11, 17.01 ± 2.03, 16.92 ± 1.75 and 17.35 ± 1.32% for 1.0, 1.5, 2.2 and 3.0 mm pellets sizes, respectively, at 25% protein ratio. The highest value of CV of the moisture content (0.13) on the 1.0 mm pellet sizes, while the minimum value (0.08) on the 3.0 mm pellet sizes at 25% protein ratio.

The results show that the average of moisture content of the fish feed pellets was 17.03 ± 0.99, 16.68 ± 1.72, 17.56 ± 1.04 and 16.95 ± 1.91% for 1.0, 1.5, 2.2 and 3.0 mm pellets sizes, respectively, at 27% protein ratio. The highest value of CV of the moisture content (0.11) on the 3.0 mm pellet sizes, while the minimum value (0.06) on the 1.0 and 2.2 mm pellet sizes at 27% protein ratio.

The results show that the average of moisture content of the fish feed pellets was 17.50 ± 1.11, 17.54 ± 1.54, 16.99 ± 1.36 and 17.82 ± 0.98% for 1.0, 1.5, 2.2 and 3.0 mm pellets sizes, respectively, at 30% protein ratio. The highest value of CV of the moisture content (0.09) on the 1.5 mm pellet sizes, while the minimum value (0.05) on the 3.0 mm pellet sizes at 30% protein ratio.

The results show that the average of moisture content of the fish feed pellets was 17.20 ± 1.03, 16.93 ± 1.00, 17.77 ± 0.96 and 17.36 ±

Protein ratio (%)		Pellet Sizes (mm)				Pellet Sizes (mm)			
		1	1.5	2.2	3	1	1.5	2.2	3
		Durability (%)				Floatability (%)			
25	Mean	92.62	87.98	83.33	75.64	96.45	93.72	91.55	79.51
	SD	3.86	2.82	5.03	5.73	1.02	2.32	2.17	2.01
	CV	0.04	0.03	0.06	0.08	0.01	0.02	0.02	0.03
27	Mean	91.08	85.44	80.97	74.01	97.26	94.05	91.31	84.63
	SD	3.68	5.00	3.35	6.90	0.50	2.51	2.99	2.65
	CV	0.04	0.06	0.04	0.09	0.01	0.03	0.03	0.03
30	Mean	87.91	83.03	78.01	72.84	97.03	94.88	93.24	85.01
	SD	5.96	5.11	6.39	5.55	0.70	2.05	2.93	3.72
	CV	0.07	0.06	0.08	0.08	0.01	0.02	0.03	0.04
32	Mean	87.52	80.69	74.99	70.66	98.00	95.51	94.02	87.82
	SD	4.44	4.75	3.18	4.22	0.00	2.11	2.07	2.01
	CV	0.05	0.06	0.04	0.06	0.00	0.02	0.02	0.02

SD: Standard Division
CV: Coefficient of Variation

Table 5: The mean of durability and floatability of pellets feed fish

Protein ratio (%)		Pellet Sizes (mm)				Pellet Sizes (mm)			
		1	1.5	2.2	3	1	1.5	2.2	3
		Moisture content (%)				Water Stability (%)			
25	Mean	16.72	17.01	16.92	17.35	54.15	69.60	71.73	76.51
	SD	2.11	2.03	1.75	1.32	4.05	3.93	3.81	4.97
	CV	0.13	0.12	0.10	0.08	0.07	0.06	0.05	0.06
27	Mean	17.03	16.68	17.56	16.95	57.89	71.36	75.03	79.62
	SD	0.99	1.72	1.04	1.91	3.83	4.07	4.22	3.61
	CV	0.06	0.10	0.06	0.11	0.07	0.06	0.06	0.05
30	Mean	17.50	17.54	16.99	17.82	58.91	73.49	78.94	84.25
	SD	1.11	1.54	1.36	0.98	3.72	4.12	3.96	3.73
	CV	0.06	0.09	0.08	0.05	0.06	0.06	0.05	0.04
32	Mean	17.20	16.93	17.77	17.36	60.65	76.55	82.14	91.78
	SD	1.03	1.00	0.96	1.05	3.38	2.86	3.00	2.50
	CV	0.06	0.06	0.05	0.06	0.06	0.04	0.04	0.03

SD: Standard Division
CV: Coefficient of Variation

Table 6: The mean of moisture content and water stability of pellets feed fish

1.05% for 1.0, 1.5, 2.2 and 3.0 mm pellets sizes, respectively, at 32% protein ratio. The highest value of CV of the moisture content (0.06) on the 1.0, 1.5 and 3.0 mm pellet sizes, while the minimum value (0.05) on the 2.2 mm pellet sizes at 32% protein ratio.

The results indicated that the mean water stability of the fish feed pellets increases with increasing the pellet sizes and protein ratio. It indicated that when the pellet sizes increased from 1.0 to 3.0 mm, the mean water stability increased from 54.15 ± 4.05 to 76.51 ± 4.97% at 25% protein ratio. The highest value of CV of the water stability (0.07) on the 1.0 mm pellet sizes, while the minimum value (0.05) on the 2.2 mm pellet sizes at 25% protein ratio.

Also, the results indicated that when the pellet sizes increased from 1.0 to 3.0 mm, the mean water stability increased from 60.65 ± 3.38 to 91.78 ± 2.50% at 32% protein ratio. These results were in agreement with those obtained by [24]. The highest value of CV of the water stability (0.06) on the 1.0 mm pellet sizes, while the minimum value (0.03) on the 3.0 mm pellet sizes at 32% protein ratio.

Multiple regression analysis has resulted in a good relationship between the mean of moisture content (MC), pellet sizes (PS) and protein ratios (PR), where, the mean of moisture content has a high correlation with both PS and PR with r^2 of 0.729 at P<0.001. The mean of water stability (WS), pellet sizes (PS) and protein ratios (PR) relationship with r^2 of 0.839 at P<0.001. The best forms were as follows:

$$MC = 15.2167 + 0.1596PS + 0.0591PR \qquad R^2 = 0.729 \qquad (10)$$

$$WS = 12.6707 + 11.4459PS + 1.3318PR \qquad R^2 = 0.839 \qquad (11)$$

Where:

MC is the moisture content of pellets fish feed, %

WS is the water stability of pellets fish feed, %

Mechanical properties

Repose angle and crushing load of fish feed pellets: Table 7 shows the mean values, Standard Deviation (SD) and coefficients of variation (CV) of the repose angle and crushing load of the fish feed pellets. The results indicated that the mean repose angle and crushing load of the fish feed pellets increases with increasing the pellet sizes and decreasing protein ratio. It indicated that when the pellet sizes increased from 1.0 to 3.0 mm, the mean repose angle and crushing load increased from 28.67 ± 0.27 to 38.00 ± 0.94 degrees and 8.65 ± 0.70 to 33.28 ± 1.99 N, respectively, at 25% protein ratio. The highest value of CV for repose angle (0.02) was found of 1.5, 2.2 and 3.0 mm pellet sizes, while the highest value of CV for crushing load (0.08) was found for 1.0 mm pellet sizes. The lowest value of CV of repose angle (0.01) was found for 1.0 and 2.2 mm pellet sizes, while the lowest value of CV of crushing load (0.03) was found for 2.2 mm pellet sizes at 25% protein ratio.

The results indicated that when the pellet sizes increased from 1.0 to 3.0 mm, the mean repose angle and crushing load increased from 27.00 ± 0.47 to 35.67 ± 0.54 degrees and 6.13 ± 0.33 to 24.98 ± 1.15 N, respectively, at 32% protein ratio. The highest value of CV for repose angle (0.02) was found for 3.0 mm pellet sizes, while the highest value of CV for crushing load (0.11) was found for 2.2 mm pellet sizes. The lowest value of CV of repose angle (0.01) was found for 1.0, 1.5 and 2.2 mm pellet sizes, while the lowest value of CV of crushing load (0.05) was found for 3.0 mm pellet sizes at 32% protein ratio.

The lowest value of repose angle and crushing load were 27.00 ± 0.47 degrees and 6.13 ± 0.33 N, respectively, at the pellet sizes 1.0 mm with 32% protein ratio and the highest value of repose angle and crushing load were 38.00 ± 0.94degrees and 33.28 ± 1.99 N, respectively, at the pellet sizes 3.0 mm with 25% protein ratio.

Multiple regression analysis has resulted in a good relationship between the mean of Repose Angle (RA), Pellet Sizes (PS) and Protein Ratios (PR), where, the mean repose angle has a high correlation with both PS and PR with r^2 of 0.988 at P<0.001. The mean of Crushing Load (CL), Pellet Sizes (PS) and Protein Ratios (PR) relationship with r^2 of 0.896 at P<0.001. The best forms were as follows:

$$RP = 29.999 + 4.4151PS - 0.217PR \qquad R^2 = 0.988 \qquad (12)$$

$$CL = 25.2367 + 11.6199PS - 1.077PR \qquad R^2 = 0.896 \qquad (11)$$

Where:

RP is the repose angle of pellets fish feed, degree

WS is the crushing load of pellets fish feed, N

Conclusion

An experimental study was carried out successively to determine the physical and mechanical properties of extruded fish feed with different protein ratios (25, 27, 30 and 32%) and different sizes (1.0, 1.5, 2.2 and 3.0). The obtained results can be summarized as follows:

- The actual diameter of pellets fish feed value ranged from 1.51 ± 0.17 to 4.55 ± 0.22 mm with CV of 0.04 to 0.06.
- The expansion rate of pellets fish feed value ranged from 33.31 ± 6.45 to 40.94 ± 2.52% with CV of 0.09 to 0.19.
- The surface area of pellets fish feed value ranged from 10.57 ± 1.69 to 71.13 ± 9.96 mm^2 with CV of 0.05 to 0.92.
- The volume of pellets fish feed 4.04 ± 0.98 to 79.09 ± 13.04 mm^3 with CV of 0.08 to 0.30.
- The mean weight of the fish feed pellets increases with increasing the pellet sizes and protein ratio. It indicated that when the pellet sizes increased from 1.0 to 3.0 mm, the mean weight of 100 pellets increased from 0.28 ± 0.038 to 5.51 ± 0.237 and 0.11 ± 0.006 to 3.70 ± 0.173 g at 25 and 32% protein ratio, respectively.
- The mean bulk density of the fish feed pellets increases with increasing the pellet sizes and protein ratio. It indicated that when the pellet sizes increased from 1.0 to 3.0 mm, the mean bulk density increased from 630.02 ± 156.99 to 711.35 ± 105.60 and 267.11 ± 117.65 to 505.78 ± 63.61 kg m^{-3} at 25 and 32% protein ratio, respectively.
- The mean durability of fish feed pellets decreases with increasing the pellet sizes and protein ratio. It indicated that when the

Protein ratio (%)		Pellet Sizes (mm)				Pellet Sizes (mm)			
		1	1.5	2.2	3	1	1.5	2.2	3
		Repose Angle				Crashing Load (N)			
25	Mean	28.67	31.00	34.67	38.00	8.65	11.57	30.00	33.28
	SD	0.27	0.47	0.72	0.94	0.70	0.56	0.82	1.99
	CV	0.01	0.02	0.02	0.02	0.08	0.05	0.03	0.06
27	Mean	28.33	30.67	34.00	37.33	7.27	8.83	26.53	30.70
	SD	0.54	0.72	0.47	1.19	0.35	1.24	1.75	3.79
	CV	0.02	0.02	0.01	0.03	0.05	0.14	0.07	0.12
30	Mean	28.00	30.67	33.00	36.67	6.48	8.90	19.43	25.27
	SD	0.47	0.27	0.47	1.36	0.47	1.22	0.70	1.53
	CV	0.02	0.01	0.01	0.04	0.07	0.14	0.04	0.06
32	Mean	27.00	30.33	33.00	35.67	6.13	8.00	14.36	24.98
	SD	0.47	0.27	0.47	0.54	0.33	0.71	1.52	1.15
	CV	0.01	0.01	0.01	0.02	0.08	0.09	0.11	0.05

SD: Standard Division
CV: Coefficient of Variation

Table 7: The mean of Repose angle and crushing load of pellets feed fish

pellet sizes increased from 1.0 to 3.0 mm, the mean durability decreased from 92.62 ± 3.86 to 75.64 ± 5.73 and 87.52 ± 4.44 to 70.66 ± 4.22% at 25 and 32% protein ratio, respectively.

- The mean floatability of the fish feed pellets decreases with increasing the pellet sizes and decreasing protein ratio. It indicated that when the pellet sizes increased from 1.0 to 3.0 mm, the mean floatability decreased from 96.45 ± 1.02 to 79.51 ± 2.01 and 98.00 ± 0.00 to 87.82 ± 2.01% at 25 and 32% protein ratio, respectively.

- The moisture content of pellets of fish feed value ranged from 16.68 ± 1.72 to 17.82 ± 0.98% with CV of 0.05 to 0.13.

- The mean water stability of the fish feed pellets increases with increasing the pellet sizes and protein ratio. It indicated that when the pellet sizes increased from 1.0 to 3.0 mm, the mean water stability increased from 54.15 ± 4.05 to 76.51 ± 4.97 and 60.65 ± 3.38 to 91.78 ± 2.50% at 25 and 32% protein ratio, respectively.

- The mean repose angle of the fish feed pellets increases with increasing the pellet sizes and decreasing protein ratio. It indicated that when the pellet sizes increased from 1.0 to 3.0 mm, the mean repose angle increased from 28.67 ± 0.27 to 38.00 ± 0.94 and 27.00 ± 0.47 to 35.67 ± 0.54 degrees at 25 and 32 % protein ratio, respectively.

- The mean crushing load of the fish feed pellets increases with increasing the pellet sizes and decreasing protein ratio. It indicated that when the pellet sizes increased from 1.0 to 3.0 mm, the mean crushing load increased from 8.65 ± 0.70 to 33.28 ± 1.99 and 6.13 ± 0.33 to 24.98 ± 1.15 N, respectively, at 25 and 32% protein ratio, respectively.

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