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OPTIMIZATION OF EXTRUSION COOKING PROCESS FOR RICE-FISH EXTRUDATES WITH AN UNDERUTILIZED FISH MINCE BASED ON PHYSICAL, FUNCTIONAL AND TEXTURAL PROPERTIES

Gourikutty Kunjurayan Rajesh*, Venkatachalam Thirupathi, Vijayaram Eyarkai Nambi, Ravi Pandiselvam

Tamil Nadu Agricultural University, Department of Food and Agricultural Process Engineering, Coimbatore, India

Abstract: Extrudates were prepared with Sea bass, an underutilized fish and rice flour using a twin screw extruder. Different process parameters viz. moisture content of feed (10%, 15%, 20% and 30%), fish content in feed (10%, 15%, 20% and 30%) and barrel temperatures (100°C and 110°C) were used for extrusion. The physical properties viz., bulk density, expansion ratio and moisture content of extrudates, functional properties such as water absorption index, water solubility index and textural properties of the extrudates were studied. The results shown that the expansion ratio and bulk density of the extrudates were in the range from 2.85 to 4.10 and 130 to 225 kg/m^3 respectively. The WAI and WSI of the extrudates varied from 5.2 to 6.7g·g^{-1} and 17% to 30% respectively. Maximum hardness was observed at 30% feed moisture, 30% fish mince content and 110°C barrel temperature. Analysis of Variance (ANOVA) revealed that all the process parameters significantly affected the physical, functional and textural properties of extrudates. The optimum process parameter to extrude rice fish extrudates were obtained at 10% feed moisture, 10% fish content and barrel temperatures of 110°C.

Key words: *Extrusion, rice-fish extrudates, extrusion cooking, underutilized fish extrudate*

* Corresponding author. E-mail: rajesh.raj.gk@gmail.com

INTRODUCTION

Extrusion refers to the forming of products to the desired shape and size by forcing the material through a die opening under pressure. It also involves thermal and mechanical energy input, which triggers chemical reactions in the food being extruded [9]. During extrusion cooking, the raw materials undergo many chemical and structural transformations, such as starch gelatinization, protein denaturation, complex formation between amylose and lipids, and degradation reactions of vitamins, pigments, etc. The usage of extrusion cooking increased in the production of food ingredients and food such as breakfast cereals, baby foods, flat breads, snacks, meat and cheese analogues, and modified starches etc [1]. At present, most of the extruded snacks commercially available are prepared from grains due to their good expansion properties. But, they contain low quantities of protein and other essential nutrients. Hence, there is an increasing demand for nutritious snacks. Fish is not only excellent sources of high nutritional value protein but also excellent sources of lipid that contains ω-3 fatty acids, especially, eicosapentaenoic acid (EPA) and docosahexaenoic acids (DHA) [17]. Moreover, it contains vitamins and minerals for human nutrition. Fish oil is the richest source of vitamin A and D. It is estimated that there are 25,000 species of fish living today. Out of which 250 species are used for edible purpose. Presence of peroxidants, oxidative susceptible lipids, scales, skin, bones, connective tissue and viscera etc are the other reasons for limited utilization. Mostly these underutilized products are transferred into fish meal for animal feed or fertilizer. 30-60% of total fish catch is not utilized for human consumption and hence transformed into fish meal for animal feed. There is an obvious need to better utilize of underutilized species in light of world fishing situation and growing need for quality protein and lipids for human and animals. Some exciting developments in the science and technology of fish utilization have developed recently moves up closer to this goal. [14] Conducted study on the effects of extrusion conditions on the physical properties of soybean-fish based ready to eat snacks. The quality of extrudate depends on the selection of ingredients. The objective of the present study was to develop under-utilized fish based extruded products with rice flour and to study the effect of barrel temperature, feed moisture content and fish content on physical, functional and textural properties of extrudate.

MATERIALS AND METHODS

Preparation of Fish Mince: Sea bass (underutilized fish) procured from local market was de-scaled and beheaded using a fillet knife. Intestines were removed by open the belly and washed with ordinary water. The flesh was then deboned using a knife and ground in a laboratory mixer.

Preparation of Rice Flour -Fish Blend: Rice flour, fish mince, water and salt were used for the preparation. The ingredients were weighed and mixed properly to a desired level of fish mince content (FMC) and moisture content of feed (MCF) viz. 10%, 15%, 20%, 30% and 10%, 15%, 20%, 30% (wb) respectively. Then the blend was placed in a close vessel at room temperature for 2 hours to equilibrate before extrusion. The mixtures were then sieved using 0.5 mm mesh screen.

Extrusion Process: Extrusion was performed with a co-rotating twin-screw extruder (Model BTPL-1, Basic Technology Pvt. Ltd. India). The extruder screw and ply cutter were driven by 5 hp motor and a variable speed DC motor respectively. The barrel sections *viz.,* feed zone, compression zone and metering zone was fitted with a gasket to prevent the heat transfer from one section to another. Temperature inside the barrel was controlled with temperature controllers. The barrel temperatures considered in this study were 100°C and 110°C. The extrudate were packed in polypropylene pouches and stored for further analysis.

Physical Properties of the Extrudates

Expansion Ratio (ER): The expansion ratio was calculated as the cross sectional diameter of the extrudate divided by the diameter of the die opening [7]. The diameter of the extrudates was measured using a vernier caliper Expansion ratio was calculated from ten places randomly for each run and the average value was taken. The expansion ratio was calculated as given below.

$$ER = D^2 \cdot d^{-2} \tag{1}$$

Where:
D [m] - diameter of the extrudate,
d [m] - diameter of the extruder die.

Bulk Density (BD): Bulk density was calculated based on the method proposed by [19]. Bulk density of 10 samples was calculated for each run and the average value was taken. The weight per unit length of extrudate was measured then the bulk density was calculated based on:

$$BD = \frac{D^2 \cdot L \cdot \pi}{4} \tag{2}$$

Where:
L [mm] - total length of the extrudate,
D [mm] - average diameter of the extrudate.

Functional Properties of Extrudates: The water absorption index (WAI) and water solubility indices (WSI) of the fish-rice flour extrudates were determined according to the method prescribed by [1]. Powdered sample (2.5 g) was suspended in 30 ml of distilled water in a 50 ml pre-weighed centrifuge tube by vortexing. The tubes were placed in a 30°C water bath and intermittently stirred for 30min. The suspension was centrifuged for 10 min at 3000 × *g* and the supernatant was decanted into a pre-weighed 50 ml beaker. The weight of the wet sediment was used to calculate the water absorption index using the following equation.

WAI (g gel/g dry sample) = weight of the wet sediment (g)/initial weight of the dry starch (g)

The supernatant was dried at 95ºC to constant weight and the weight of the dried solids was used to determine the WSI.

WSI (%) = weight of the solids recovered by evaporating the supernatant (g) ×100/initial weight of the dry starch (g)

Textural Properties: Textural properties were evaluated using a food texture analyzer (TAHDi, Stable Microsystems, England). Cylindrical probe of 4 mm diameter was used. The detailed experiment conditions of textural analyzer are as follows:

Load cell	:	5 kg
Test Mode	:	Measure force in compression
Test option	:	Return to start
Pre test Speed	:	2 mm·s^{-1}
Test Speed	:	0.1 mm·s^{-1}
Post test Speed	:	2 mm·s^{-1}
Distance	:	5 mm
Test probe	:	P 4

The area and peak force under the force-deformation curve was represented as toughness and hardness respectively.

Experimental design and data analysis: The independent process variables selected for the study were process barrel temperature (100°C, 110°C), moisture content of feed (10%, 15%, 20%, 30% (w.b) and fish content of feed (10%, 15%, 20%, 30% (wb). A full factorial design has been developed with three replications using Minitab. The observed data were analyzed using ANOVA and correlation studies were carried out.

RESULTS AND DISCUSSION

Extrudates were prepared based on the full factorial design with all possible combination of process parameters discussed in the previous chapter. All the extrudates were tested for its quality in terms of physical properties (BD, MC, ER), functional properties (WAI, WSI) and textural property (Harness). The process parameters were tested for its significance on the quality of extrudates and optimized using full factorial ANOVA. P value and r-square value obtained from ANOVA for each quality factors were consolidated and given in the Tab. 1 to estimate the level of significance of process parameters on various quality factors.

Changes in Physical Properties of Fish-Rice Flour Extrudates

The effect of process parameters on physical properties viz., bulk density, expansion ratio and moisture content of extrudates are discussed below.

Table 1. Pearson correlation coefficient between the process parameters and quality factor of extrudates (-ve shows the negative correlation)

Parameter	*Fish Content*	*Barrel temperature*	*Moisture content of feed*
Bulk Density	*0.458*	*-0.166*	*0.841*
Expansion ratio	*-0.305*	*0.236*	*-0.853*
Moisture content of extrudate	*0.748*	*-0.413*	*0.430*
WAI	*0.414*	*-0.502*	*0.650*
WSI	*-0.561*	*0.334*	*-0.677*
Hardness	*0.541*	*0.284*	*0.755*

1. Effect of Process Parameters on Bulk Density of Rice-Fish Extrudates

From the Tab. 2 it is obvious that all process parameters are affecting the bulk density of extrudate significantly (@ 1%) at individual as well as 2nd and 3rd level interaction. The r-square value was 0.998. The interaction plot for all 3 process parameters on bulk density were fitted and shown in Fig. 1.

Table 2. Consolidated ANOVA results for the quality factors of extrudates with full factorial interaction

Source	Bulk Density	Expansion Ratio	Moisture Content of the Product	WAI	WSI	Hardness
Blocks	0.965	0.828	0.135	0.490	0.438	0.066
Fish Content	0.000**	0.000**	0.000**	0.000**	0.000**	0.000**
Barrel Temperature	0.000**	0.000**	0.000**	0.000**	0.000**	0.000**
Moisture Content of the Feed	0.000**	0.000**	0.000**	0.000**	0.000**	0.000**
Fish Content x Barrel Temperature	0.000**	0.554	0.000**	0.081	0.000**	0.000**
Fish Content x Moisture Content of the Feed	0.000**	0.410	0.000**	0.355	0.000**	0.000**
Barrel Temperature x Moisture Content of the Feed	0.000**	0.000**	0.000**	0.012*	0.000**	0.000**
Fish Content x Barrel Temperature x Moisture Content of the Feed	0.000**	0.048*	0.000**	0.480	0.000**	0.000**
R^2 value	0.998	0.986	0.990	0.934	0.989	0.997

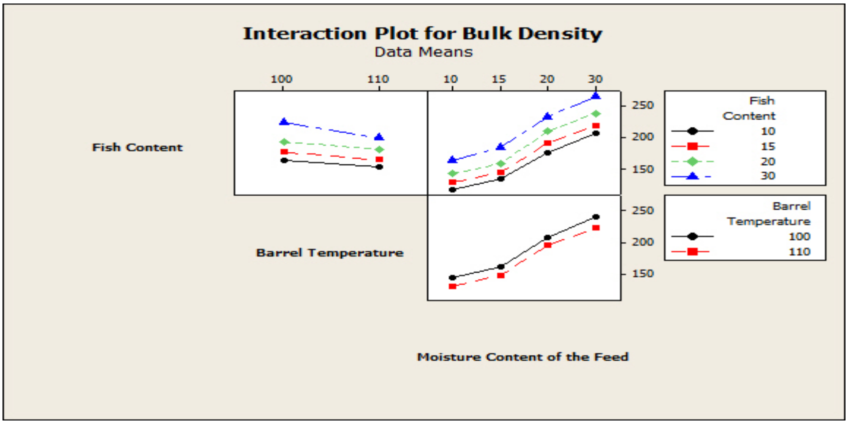

Figure.1. Interaction Plot for bulk density with the process parameters

Fig.1. shows that the bulk density increased significantly with an increase in feed moisture and fish content. However, a reverse effect was observed with barrel temperature. The bulk density increased from 135 to 225 kg·m^{-3} with increase in feed

moisture from 10 to 30% (wb). Same way, the bulk density increased from 165 to 215 kg·m^{-3} for the fish content increase from 10 to 30% respectively. The results are in agreement with [4] who have reported an increase in bulk density with an increase in feed moisture for corn, rice, and cassava flour extrudates. For higher fish content the bulk density were higher. This may be due to the high protein content may influence the expansion of extrudate thus resulting the higher bulk density. [6] Reported that low moisture content of starches may restrict flow inside the barrel, increase shear rate and residence time which could perhaps increase degree of starch gelatinization and expansion which could be linked to lower bulk density. But in case of barrel temperature, the bulk density decreased from 185 to 175 kg·m^{-3} with increase in temperature from 100 to 110°C. [11] Observed a reverse effect on bulk density with an increase in temperature on extruded foxtail millet. From Tab. 2, it can be observed that the bulk density is highly correlated with moisture content of the feed followed by fish content then barrel temperature. Both moisture content of the feed and fish content have positive correlation, but in case of barrel temperature, the bulk density is negatively correlated.

2. Effect of Process Parameters on Expansion Ratio of Extrudates

Analysis of variance (Tab.1) showed that each process parameters had a significant effect ($p \leq 0.01$) on expansion ratio of extrudates at individual level with r-square value 0.986. But some of the 2nd order interactions level between process parameters were not significant. At the same time there is a significant effect ($p \leq 0.05$) at 3rd order interaction. So the interaction effects may be considers. The interaction plot of process parameters on expansion ratio of extrudates is shown in Fig. 2.

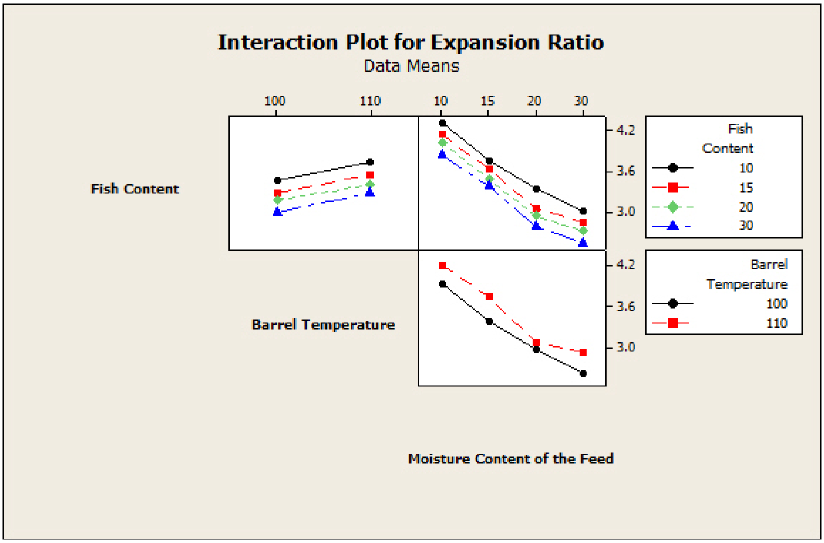

Figure.2. Interaction plot of process parameters on expansion ratio of extrudates

Expansion ratio of the extrudates ranged from 2.85 to 4.25 g gel·g^{-1} (Fig. 3). The expansion ratio of the extrudates decreased with an increase in feed moisture and fish content. Highly expanded products with very appealing color and appearance were obtained at 10% fish content with 10% feed moisture. At 10% feed moisture, the maximum expansion ratio of 4.10 was shown by the sample. It decreased to 2.8 g gel·g^{-1} with an increase in feed moisture from 10 to 30%. [5] Observed a similar trend. [5] Reported that in the arrowroot extrudates the lower moisture level showed higher expansion ratio indicating higher gelatinization. [10] Observed that decrease in moisture content from 32, 9 to 14.21%, increased the expansion ratio of corn starch from 1.36 to 2.78. Similarly, expansion ratio decreased from 3.6 to 3.2 g gel·g^{-1} with an increase in fish content from 10 to 30 %. But expansion ratio increased with barrel temperature (Figure 3). The same result given by [15] also suggested that higher protein content of the feed resulted in a lower melt viscosity and reduced extrudate expansion. In reverse to bulk density, the expansion ratio increased from 3.25 to 3.5 g gel·g^{-1}. while the barrel temperature varied from 100 to 110°C. Expansion ratio was influenced greatly by moisture content of feed followed by fish content then by barrel temperature (Tab. 3). Moisture content of feed and fish content have negative correlation with expansion ratio. High expansion ratio and low bulk density are the desired properties of the extrudates.

3. Effect of Process Parameters on Final Moisture Content of Extrudates

Analysis of variance (Tab. 2) indicates that all process parameters had a significant effect ($p \leq 0.01$) on the moisture content of rice flour-fish extrudates with r-square value 0.990. The interaction plot of process parameters on moisture content of extrudates is shown in Fig. 3. From the fig. it is obvious that the extrudate moisture content increase with increase in fish content as well as feed moisture content but decreases with increase in barrel temperature. Higher extrusion temperature resulted in lower extrudate moisture. The extrudate moisture content was in the range of 6.60 to 8.75% (Fig. 3).

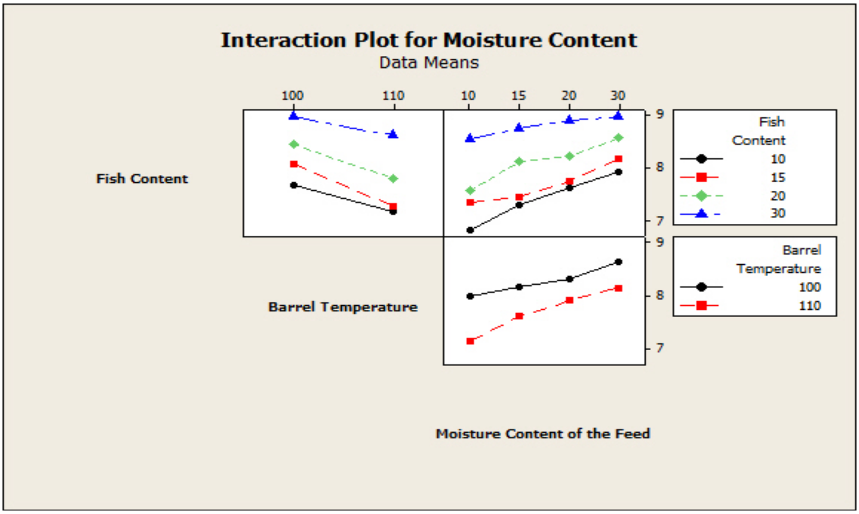

Figure.3. Interaction plot between process parameters and moisture content of extrudates

Highest extrudate moisture was obtained at the highest feed moisture of 30% and fish content of 30%. Similar results were reported by [2]. [2] Worked on cassava flour, reported that feed moisture was most significant on residual moisture content of extrudates. They also observed that the effect of increasing temperature produced lower overall extrudate moistures. According to [13], a rise in moisture feed from 17 to 20 per cent resulted an increase in extrudate moisture from 7.4 to 7.8 per cent. Also he observed a decline in product moisture from 7, 6 to 7.5 per cent with an increase in barrel temperature from 144 to 173°C. Moisture content of extrudates were highly influenced by fish content followed by moisture content of feed then by barrel temperature (Table 3).

Changes in Functional properties of Rice flour-Fish Extrudates

1. Effect of Process Parameters on Water Absorption Index of Extrudates

Water absorption index (WAI) is used to quantify the extent of starch damage during extrusion cooking. WAI has been generally attributed to the dispersion of starch in excess water, and the dispersion is increased by the degree of starch damage due to gelatinization and extrusion–induced fragmentation, that is, molecular weight reduction of amylose and amylopectin molecules [30]. ANOVA results (Tab. 2) indicated that all variables some of the interactions among process parameters had significant effect ($P \leq 0.01$) on the WAI of rice flour-fish extrudates with r-square value of 0.934. The effect of process parameters on water absorption index of rice flour-fish extrudates is presented in Fig. 4.

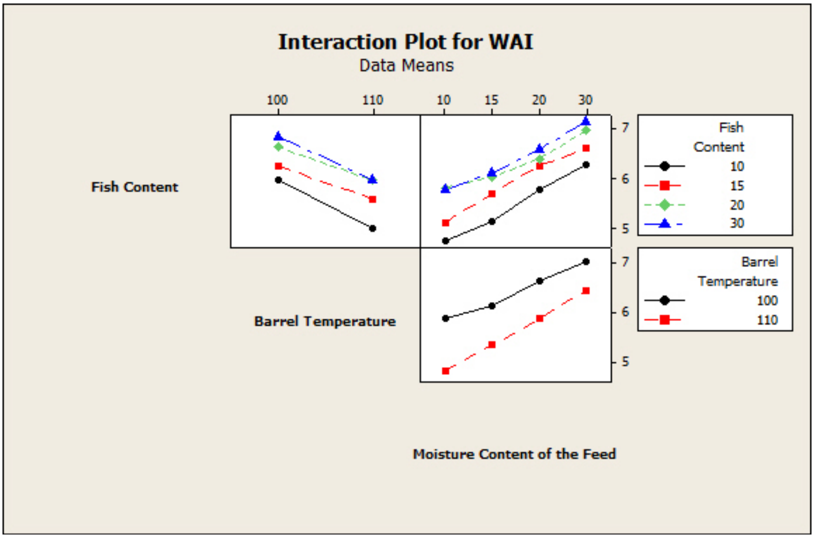

Figure.4. Interaction plot between process parameters and water absorption index of extrudates

WAI increased with increase in moisture content of feed as well as fish content. Colonna *et al.* (1989) reported same results in rice flours extruded with water absorption index increased with an increase in added moisture. According to [8], the lower WAI at low feed moisture may be related in shear resulting in structural modifications of the starch. From Fig. 5, it can be observed that the high barrel temperature resulted extrudates with low WAI. The WAI of 6.45 g·g^{-1} at 100°C reduced to 5.6g·g^{-1} at 110°C. [18] Observed a decrease in WAI with addition of pea grits in extrusion of rice. They explained that a decrease in WAI was due to the dilution of starch in rice pea blends [2] Obtained similar results. [13] Stated that this may be due to degradation of starch molecules. WAI was highly influenced by moisture content of feed followed by barrel temperature and then by fish content (Tab. 3).

2. Effect of Process Parameters on Water Solubility index of Rice Flour-Fish Extrudates

Water solubility index (WSI) is an indicator of degree of gelatinization. High WSI indicates high degree of gelatinization. WSI is often used as an indicator of degradation of molecular components, which measures the degree of starch conversion during extrusion which is the amount of soluble polysaccharide released from the starch component after extrusion process [21]. ANOVA result table indicates that all variables had significant effect ($P \leq 0.01$) level on WSI of rice flour-fish extrudates with r-square value 0.989. Also the interactions among the process variables were found to be significant at 1 per cent level.

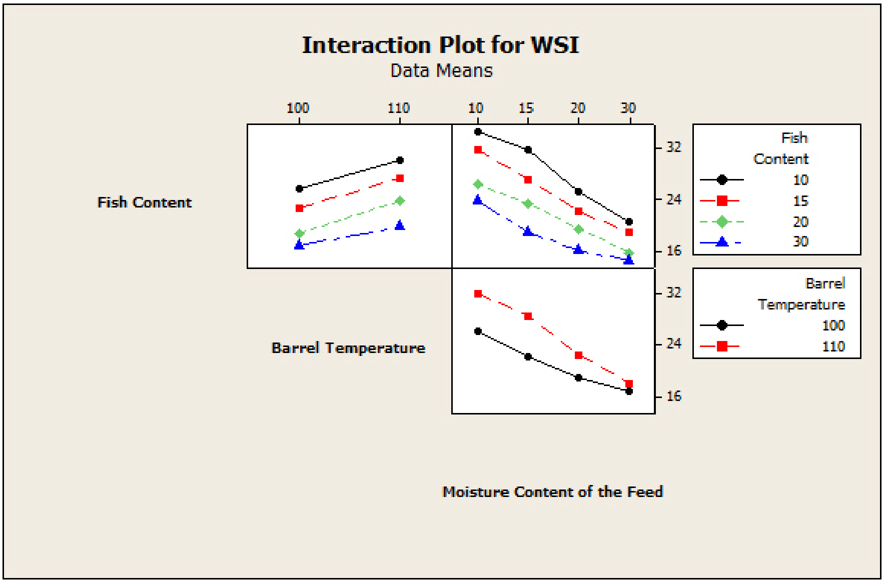

Figure.5. Interaction plot between process parameters and water solubility index of extrudates

The effect of process parameters on WSI is shown in Fig. 6. It is seen from the figure that WSI decreased with an increase in feed moisture and fish content. But increased with increase in barrel temperature. Max value of WSI (37%) was obtained at a feed moisture of 10%, having a fish content of 10% and barrel temperature of 110°C. [19] Reported that water solubility index increased from 33.1 to 45.2 per cent with an increase in barrel temperature from 144 to 172°C for corn meal. The increased solubility of extruded starches was related to stickiness of the end product. This may be due to the increase in shear degradation of starch during extrusion at high temperatures. [13] reported a reduction in WSI from 44.78% to 28.6% when moisture content of feed varies from 17% to 19.6% moisture. WSI relates to the extent of starch damage at low feed moisture levels. This may be due to low water content and exposure to high temperature. WSI was more correlated with moisture content of feed followed by fish content and then by barrel temperature (Tab. 3).

Changes in Textural Properties

Effect of Process Parameters on Hardness of Fish-Rice Flour Extrudates

Textural properties of rice flour-fish extrudates were determined by compression test and the results are given in Fig.7. ANOVA results (Tab. 2) Indicates that all variables had significant effect (P≤0.01) level on hardness of rice flour-fish extrudates with r-square value 0.997. The effect of process parameters on hardness is shown in Fig. 6.

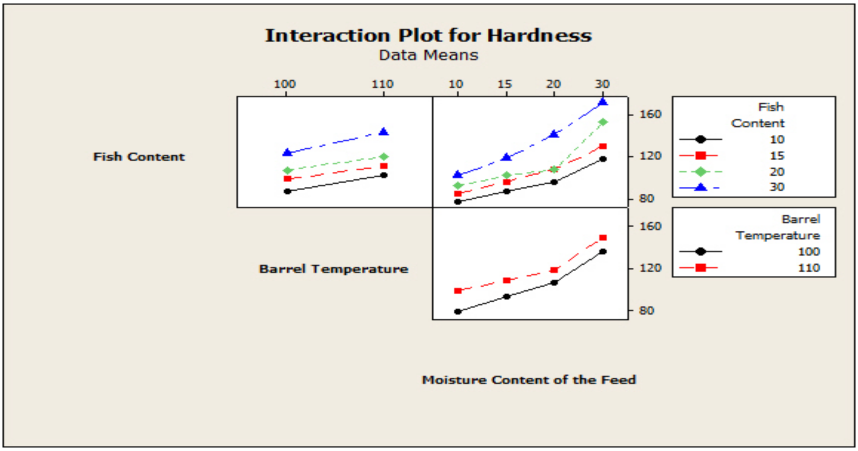

Figure.6. Interaction plot between process parameters and hardness of extrudates

Hardness of the products increased significantly with an increase in moisture content of feed (*P*<0.01), which implies that more energy is required to break the extrudates prepared at 30 % feed moisture. Also, the expansion ratio of the extrudate was lower at high moisture content of feed. An increased expansion results in a more friable product and it requires less force/energy to break. Extrusion temperature, fish content and their interactions also significantly (P<0.01) affected the hardness of the extrudates. Maximum hardness of 182 N was obtained for a feed moisture of 30%, fish content 30% and a barrel temperature of 110°C. Hardness was greatly influenced by fish content of the feed followed by and moisture content of feed and by barrel temperature. Similar report were reported by [16]. They stated the increasing protein content with increasing fish content of greater than 5% interfered the gelatinization of starch. Increasing the fish and protein content of the feed may have resulted in protein cross-linking and development of protein networks. [3] Also reported that the product hardness decreased with an increase in radial expansion. [12] Reported that the hardness of cereal-pulse based extrudates varied between 45 to 110 N, when the temperature varied between 150 and 190°C and moisture between 12 and 20 per cent. [2] Have studied the textural properties of cassava flour extrudates and they have noticed that the extrusion variables of feed moisture, feed composition and temperature significantly influenced the textural changes in extrudates. Increasing temperature would decrease melt viscosity, which favours bubble growth and produce low density less firm products. [7]. Hardness of the extrudates were influenced greatly by moisture content of feed followed by fish content then by barrel temperature (Tab. 3).

Optimization of Process Parameters

The aim of the optimization process was to get the final extrudate with lower bulk density, higher expansion ratio, lower moisture content of extrudate, higher WAI, lower WSI and lower hardness. Based on the empherical knowledge and sensory evaluation, the weightage was given to the quality factor with the following descending order viz. expansion ratio, moisture content of the extrudate, hardness, WAI, bulk density and WSI. The optimization was done in design expert package and the optimum values were 10 % feed moisture, 10% fish content and barrel temperatures of 110ºC.

CONCLUSIONS

The study revealed that the physical, functional and textural properties of fish – rice flour extrudates are affected significantly by moisture content of feed, fish content and barrel temperatures. Significant increases in expansion ratios and decreases in bulk densities were observed when feed-moisture content was decreased from 30 to 10 %. Extrudate hardness and WSI were significantly affected by feed-moisture content and fish content. At feed moisture content less than 15% and fish content of less than 15 % extrudate hardness decreased. Higher barrel temperatures results in dramatically increased expansion ratios and decreased bulk densities. Extrudates with most desirable physical properties and functional properties were obtained at 10% feed moisture, 10 % fish content and barrel temperatures of 110ºC. In case of process parameters, the moisture content of feed had high influence on the final quality of rice-fish extrudates then followed by fish content then by barrel temperature.

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OPTIMIZACIJA PROCESA EKSTRUDIRANJA PIRINAČ-RIBA EKSTRUDATA SA NEISKORIŠĆENIM DELOVIMA RIBE NA OSNOVU FIZIČKIH, FUNKCIONALNIH I TEKSTURNIH SVOJSTAVA

Rajesh. G.K, Thirupathi. V, Eyarkai Nambi. V, Pandiselvam. R.

Tamil Nadu Poljoprivredni Univerzitet, Institut za hranu i inženjering poljoprivrednih procesa, Coimbatore, Indija

Sažetak: Ekstrudati su pripremljeni od neiskorišćenih delova brancina i pirinčanog brašna pomoću dvopužnog ekstrudera. Različiti parametri procesa: sadržaj vlage u hrani (10%, 15%, 20% i 30%), procenat količine ribe u hrani (10%, 15%, 20% i 30%) i temperatura (100 °C i 110 °C) su menjani pri ekstrudiranju. Proučavane su fizičke osobine: gustina, nivo ekspanzije i sadržaj vlage ekstrudata, kao i funkcionalna svojstva kao što su: indeks apsorpcije vode, indeks rastvorljivosti u vodi i teksturna svojstva ekstrudata. Rezultati su pokazali da su odnos ekspanzije i gustina ekstrudata u opsegu od 2.85 do 4.10 i 130 do 225 $kg \cdot m^{-3}$, redom. WAI i WSI ekstrudata variraju od 5.2 do 6.7 $g \cdot g^{-1}$ i 17% do 30%, respektivno. Najveća tvrdoća je primećena na 30% vlage u hrani, 30% riba mlevenog sadržaja i temperaturi od 110°C u cevi. Analiza varijanse (ANOVA) je pokazala da su svi parametri procesa značajno uticali na fizička, funkcionalna i teksturna svojstva ekstrudata. Optimalni parametri procesa ekstruzije pirinča i ribe su iznosili: vlaga u hrani 10%, sadržaj ribe 10% i temperaturi u cevi od 110°C.

Ključne reči: *ekstruzija, ekstrudati pirinač-riba, kuvanje, neiskorišćeni ekstrudati ribe*

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