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EFFECT OF EXTRUSION CONDITIONS ON PHYSICOCHEMICAL PROPERTIES OF SNACKS FROM COMMONLY GROWN RICE VARIETIES OF KASHMIR

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ABSTRACT

Five varieties of rice *viz.*, 'Shalimar Rice-I', 'Jhelum', 'K-332', 'China-1039' and 'Pusa Sugandh', commonly grown in Kashmir valley were assessed for their extrusion behaviour. The rice obtained from above varieties was ground to flour and subjected to extrusion processing. The experiment was laid down in factorial completely randomized design with 3 feed moisture levels (14, 16 and 18%) and 3 barrel temperature levels (120, 140 and 160°C). The screw speed of 500 rpm was kept constant throughout the experiment. The effects of feed moisture and barrel temperature on system parameters (specific mechanical energy) product characteristics (density, expansion, water absorption index (WAI), water solubility index (WSI), texture (hardness) and colour of expanded rice snacks were studied. The study revealed that bulk density, WAI, L* value (whiteness) and hardness of snacks showed increase with increase in moisture content and decrease with increase in barrel temperature. Volume expansion ratio, WSI and a* (redness) and b* (yellowness) values showed decrease with increase in moisture and increase with rise in barrel temperature. The ogranoleptic evaluation revealed 14% moisture content and 160°C barrel temperature as most appropriate conditions for development of extruded snacks, irrespective of the variety used. Further, based on the physico-chemical and sensory attributes rice varieties 'Shalimar Rice 1' and 'Jhelum' were most suitable for development of snacks using extrusion technology.

Key words: Extrusion, feed moisture content, barrel temperature, rice, snacks

INTRODUCTION

Rice (*Oryza sativa* L.) is one of the leading food crops of the world in addition to wheat and corn. Rice, a staple food for about half of world population, is cultivated in more than 100 countries round the globe. The total area under paddy cultivation worldwide is 158 million hectares with annual production of 700 million tonnes (Anonymous, 2015). Rice production in India has shown a spectacular increase in recent past years and accounts for one-third of the total rice production in the world. In India, rice production has increased from 58.99 million tonnes in 1985-1986 to 106.3 million tonnes in 2013-2014 (Anonymous, 2013). In Jammu and Kashmir, rice is cultivated on an area of 0.27 million hectares with an annual production of 9.0 million tonnes (Anonymous, 2013) and constitutes about 34.5% of total cereal production in the state (Bhat and Shah, 2011).

The convenience food concept is prevalent in the developing world since long. While as its inception in Indian market has been recent. With changing socio-economic pattern of life and increase in the number of working couples, life style logistics, urbanization and concern about the health benefits too has changed. Foods are therefore, expected to meet the new challenges and technologies needed to be evolved based on available raw material and requirements of the society. Extrusion cooking is a well established industrial technology with a number of food processing applications. In addition to the usual benefits of heat processing, extrusion has potential to change the functional properties of food ingredients. During extrusion cooking, raw material undergoes many chemical and structural transformations, such as starch gelatinization, protein denaturation, complex formation between amylose and lipids; and degradation reaction of vitamins and pigments. The advantage of extrusion includes high through output, energy efficiency, normal control, minimum processing time and ability to incorporate a variety of ingredients into the final product.

Several extrusion processing conditions like moisture, thermal energy, mechanical energy inputs and retention time are accounted for the quality of finished products. The control of feed rate, screw speed, barrel temperature and barrel pressure, together with the mentioned critical parameters, determine the crispness, hardness and other quality attributes of final products (Haper, 1981). Extruded foods have become an integral part of daily food intake of the majority of world population. Basically they are prepared from natural ingredients or components according to predesigned plans to produce products with specified quality. Rice flour has become an attractive ingredient in extrusion industry due to its unique attributes such as bland taste, attractive white colour, hypoallergenicity and ease of digestion (Kadan *et al.*, 2003). The basic investigation of extrusion variables on properties of rice extrudate is still in need, though there have been some reports on rice flour mixed with other ingredients (Ilo and Berghofer, 1999).

The quality of rice produced in different parts of India varies significantly due to genetic and environmental factors. In Jammu and Kashmir rice is the staple diet for majority of population and broken rice percentage is about 35% in the State because most of the millers still rely on obsolete equipments to mill the paddy. Extrusion behaviour studies of different varieties of rice shall help in choosing the rice varieties for development of extruded products with better consumer acceptability and good returns to the people directly or indirectly related to its trade. Keeping this in view, the present study was aimed to screen commercially grown rice varieties of Kashmir for their extrusion behaviour and to study the effect of extrusion condition on product characteristics.

MATERIALS AND METHODS

Five rice varieties *viz*., ‘Shalimar Rice-1’, ‘Jhelum’, ‘K-332’, ‘China-1039’ and ‘Pusa Sugandh’, procured from Seed Processing Centre, SKUAST-K, Shalimar were milled to obtain rice in modern rice mill in the Division of Post Harvest Technology, SKUAST-K. The milled rice was grounded in a mill (model 3303, Perten Sewden) to the fineness that passed through 2 mm sieve. Table salt (Tata) and spice mix were procured from local market for use in preparation of extruded products.

Extrusion process

The extrusion experiment was performed *i*n a co-rotating intermeshing twin screw extruder (Clextral BC-21, Firminy, France). The barrel diameter and its length to breadth ratio (l/b) were 2.5 mm and 16:1, respectively. The die plate had one circular hole of 5 mm dia. The extruder was powdered by 8.5 KW motor with speed varying from 0 to 682 rpm. The extruder was equipped with a torque indicator, which showed per cent torque in proportion to be current drawn by the drive motor. Raw materials were metered into extruder with a single screw volumetric feeder (DS and M, Modena, Italy). The moisture content of feed was adjusted by injecting water (~30^{o}C) into the extruder with a pump. A variable speed die face cutter with 4 bladed knives was used to cut the extrudates.

Treatment details

The flour of each rice variety was divided into 9 parts (1.5 kg each) and a total of 45 treatment-combinations were made from the selected varieties. Ten percent spice mix (sugar 4%, salt 2%, ginger powder 0.75%, garlic powder 0.75%, onion powder 1%, chilli powder 0.25%, cheese powder 1% and citric acid 0.25%) was mixed thoroughly and added to each treatment- combinations of flour and mixed for 5-10 min. The material was subjected to extrusion at 3 moisture levels (14, 16 and 18%) and temperature of 4th zone was set at 120, 140 and 160^{o}C. The extrudates were cooled and stored in PET bottles under ambient conditions. The experimental was conducted in a completely randomized design (factorial). Each treatment was replicated three times with 500 g flour as a unit of each replication.

System parameters

Specific mechanical energy (SME): Specific mechanical energy (Wh kg^{-1}) was calculated from rated screw speed (682 rmp), motor power rating, actual screw speed, per cent motor torque and mass flow rate (kg h^{-1}) as per the formula of Pansawat *et al.* (2008)

$$SME = \frac{\text{Actual Screw Speed(rpm)}}{\text{Rated Screw Speed(rpm)}} \times \frac{\%\ \text{motor torque}}{100} \times \frac{\text{motor power rating}}{\text{mass flow rate}} \times 1000$$

Water absorption index (WAI) and water solubility index (WSI) of extrudates: WAI and WSI were determined according to the method developed for cereals (Anderson *et al.*, 1969; Yagci and Gogus, 2008; Stojceska *et al.*, 2008). The ground extrudates were suspended in water and gently stirred at room temperature for 30 min. and centrifuged at 3000 g for 15 min. The supernatants were decanted into an evaporating dish of known weight. WAI was the weight of gel obtained after the removal of supernatant per unit weight of original dry solids. WSI was the weight of dry solids in supernatant expressed as a percentage of the original weight of sample.

$$\text{WAI (g/g)} = \frac{\text{weight sediment}}{\text{weight of dry solid}}$$

$$\text{WSI (\%)} = \frac{\text{weight of dissolved solids in supernatant}}{\text{weight of dry solids}} \times 1000$$

Bulk density: The bulk densities (g mL^{-1}) of extrudates were determined by volumetric displacement procedures (Patil *et al.,* 2007). The volume of expanded sample was measured by using a 100 mL graduated cylinder by rapeseed displacement. The volume of 20 g randomized sample was measured for each test. The ratio of sample weight and the replaced volume in cylinder was calculated as bulk density (w/v).

Expansion ratio: Expansion ratio was determined as per Halek and Chang (1992) by applying a Digital Vernier calliper (Diginatic Solar Mitutoya, Japan) to measure the average thickness of extrudate, 10 randomly chosen pieces of extrudate from each test run of each replicate and calculated as the ratio between thickness of extrudate and die diameter. Volume expansion ratio was average value of six calculations.

$$ER = D/d$$

Where, D = diameter of extrudate; d = diameter of die hole. Ten randomly extrudate diameter was measured and their average was taken as final reading.

Colour: The colour was determined by using Hunter Lab Colorimeter (model SN3001476, Accuracy Micro sensors, New York, USA). The instrument was calibrated with the user supplied black plate calibration standards that were used for zero setting. Minotta supplied white calibration setting were used for white calibration. The samples were uniformly packed in clean petriplates with lids. The instrument was placed on plate and their exposure at different places was conducted. Reading were displayed as L*, *a** and *b** colour parameter according to CIELAB system of colour measurement. L* (luminosity or brilliance) varies from black (zero) to white (100), *a** from green (+100) to red (-100) and *b** from blue (-100) to yellow (+100).

Hardness: The hardness of extrudates was carried out by using texture analyzer (model TA-HD, Stable Microsystems, UK), maximum load of 250 kg, with texture expert system for data collection. The compression probe (50 mm dia., aluminum cylinder) was applied to measure compression force required for sample breakage which indicates hardness. The conditions used in hardness analysis were: measurement of force in compression; force threshold of 1.0 g, pre-test speed of 4.0 mm s^{-1}; test speed of 1.0 mm s^{-1} ; post-test speed of 5.0 mm s^{-1} and rupture distance of 15 mm. Ten extrudates from all test samples were tested and their average was taken as final result.

Statistical analysis

The data was statistically analyzed using analysis of variance as per Snedecor and Cochran (1967), using Minitab software.

RESULTS AND DISCUSSION

Specific mechanical energy (SME)

Both barrel temperature and feed moisture had a significant but negative influence on SME of extruded product (Table 1). The SME values tended to decrease as feed moisture and barrel temperature was increased. SME was significantly higher at 14% mean feed moisture (112 Wh kg^{-1}) followed by 16% (96 Wh kg^{-1}) and least SME value (88 Wh kg^{-1}) was recorded at 18% feed moisture. Further, SME was significantly high at mean barrel temperature of 120^{o}C (108.04 Wh/kg) followed by 140^{o}C (96.93 Wh/kg). Least SME was noticed at 160^{o}C (91.46 Wh kg^{-1}). Among the varieties evaluated, 'Jhelum' showed highest SME value (100.44Wh kg^{-1}) and lower in 'K-332' (98.22Wh kg^{-1}). Higher barrel temperature facilitated the transformation from solid flow to visco-elastic flow and higher moisture produced a lubricating effect resulting in less energy use. Starch gelatinization is positively influenced by SME during extrusion, so higher the SME higher is the degree of gelatinization. Mechanical energy favours gelatinization by promoting rupture of intermolecular hydrogen bond (Gropper *et al*., 2002). The SME ranged from 71-122. Similar results have been reported by Meng *et al*. (2010).

Table 1: Effect of barrel temperature and feed moisture on specific mechanical energy (Wh kg^{-1}) of rice extrudate

Variety / Barrel temp. ►	14% moisture				16% moisture				18% moisture			
	120^{o}C	140^{o}C	160^{o}C	Mean	120^{o}C	140^{o}C	160^{o}C	Mean	120^{o}C	140^{o}C	160^{o}C	Mean
Shalimar Rice-1	122	110	106	112	106	93	87	95	98	87	77	87
Jhelum	120	111	108	113	108	106	85	100	100	85	81	89
K-332	118	112	104	111	104	91	85	93	100	85	85	90
China- 1039	120	110	110	113	110	89	89	96	97	87	81	88
Pusa Sugandh	120	112	108	113	108	93	87	96	95	83	79	86
Mean	118	108	110	112	107	94	87	96	98	85	81	88

$CD_{0.05}$: Variety (V) = 0.55; Moisture (M) = 0.42; Barrel temperature (T) = 0.42;
V x M = 0.95; V x T = 0.95; M x T = 0.74; V x M x T = 1.64

Table 2: Effect of barrel temperature and feed moisture on density (g cc^{-1}) of rice extrudate

Variety \ Barrel temp. ►	14% moisture				16% moisture				18% moisture			
	120°C	140°C	160°C	Mean	120°C	140°C	160°C	Mean	120°C	140°C	160°C	Mean
Shalimar Rice-1	0.18	0.16	0.16	0.17	0.23	0.27	0.22	0.24	0.43	0.45	0.39	0.42
Jhelum	0.15	0.14	0.14	0.14	0.23	0.23	0.23	0.23	0.40	0.38	0.23	0.34
K-332	0.18	0.17	0.17	0.17	0.30	0.28	0.27	0.28	0.46	0.39	0.23	0.36
China- 1039	0.16	0.15	0.15	0.15	0.24	0.23	0.23	0.23	0.54	0.47	0.39	0.47
Pusa Sugandh	0.17	0.16	0.16	0.16	0.31	0.28	0.24	0.25	0.61	0.54	0.38	0.51
Mean	0.17	0.16	0.16	0.16	0.26	0.26	0.24	0.25	0.48	0.45	0.32	0.42

$CD_{0.05}$: Variety (V) = 0.0007; Moisture (M) = 0.0005; Barrel temperature (T) = 0.0005;
V x M = 0.001; V x T = 0.001 ; M x T = 0.0009; V x M x T = 0.002

Density

The density of extrudate was influenced by both feed moisture and barrel temperature (Table 2). At all the temperature levels, a sharp increase in density was observed with increase in feed moisture and slight decrease in density was noticed with increase in barrel temperature. The significantly higher density was observed at 18% moisture (0.42 g L^{-1}) followed by 16% (0.25 g L^{-1}) and less at 14% (0.16 g L^{-1}). Mean barrel temperature of 120°C showed significantly higher density of 0.30 g L^{-1} followed by 140°C (0.29 g L^{-1}). The minimum density was recorded at 160°C (0.24 g L^{-1}). Rice variety 'Pusa Sugandh' showed significantly high density of 0.32 g L^{-1} followed by 'Shalimar Rice-1' (0.28 g L^{-1}), 'China-1039' (0.28 g L^{-1}) and 'K-332' (0.27 g L^{-1}). The minimum density was recorded in 'Pusa Sugandh' with density of 0.24 g L^{-1}. The density was found in between 0.14 and 0.61 g L^{-1}. Feed moisture was found dominant factor affecting extrudate density and expansion which is supported by Faubion *et al.* (1982); Launay and Lisch (1983); Fletcher *et al*. (1985) and Ilo and Berghofer (1999). The high dependence of bulk density and expansion on feed moisture reflects its influence on elasticity characteristics of starch based material. Increased feed moisture content during extrusion changes the amylopectin molecular structure of material, reducing the melt elasticity and thereby decreasing expansion and increasing the density of extrudates. Mercier and Feillet (1975) reported that increase in barrel temperature decreases extrudate viscosity. The reduced viscosity effect would favour the bubble growth during extrusion. Moreover, the degree of superheating of water in extrudate increases at higher temperature which leads to greater expansion (Fletcher *et al.*, 1985; Ilo and Berghofer 1999).

Water solubility index

The water solubility index (WSI) was influenced significantly by feed moisture and barrel temperature (Table 3). WSI increased with increase in barrel temperature and decreased with increase in feed moisture. The significantly higher WSI was recorded in mean feed moisture of 14% (12.51%) followed by 16% (11.38%). Minimum WSI was observed in 18% feed moisture with value of 10.57%. Further, significantly high WSI was observed at mean barrel temperature of 160°C followed by 140°C and lesser at 120°C with WSI of 11.85, 11.55 and 11.21%, respectively.

Table 3: Effect of barrel temperature and feed moisture on water solubility index (%) of rice extrudate

Variety \ Barrel temp. ►	14% moisture				16% moisture				18% moisture			
	120°C	140°C	160°C	Mean	120°C	140°C	160°C	Mean	120°C	140°C	160°C	Mean
Shalimar Rice-1	12.45	12.73	12.95	12.71	11.07	11.49	11.79	11.45	10.33	10.75	10.95	10.68
Jhelum	12.08	12.31	12.50	12.30	11.07	11.31	11.62	11.33	11.06	11.54	11.80	11.47
K-332	13.31	13.62	13.79	13.57	12.37	12.66	12.94	12.66	11.22	11.82	12.13	11.72
China- 1039	12.12	12.74	13.14	12.67	10.81	11.26	11.62	11.23	9.96	10.11	10.94	10.33
Pusa Sugandh	11.18	11.25	11.40	11.28	10.15	10.23	10.35	10.24	9.06	9.42	9.89	9.40
Mean	12.23	12.53	12.76	12.51	11.09	11.45	11.66	11.38	10.33	10.73	11.44	10.57

$CD_{0.05}$: Variety (V) = 0.01; Moisture (M) = 0.01; Barrel température (T) = 0.01 ;
V x M = 0.023; V x T = 0.023 ; M x T = 0.018; V x M x T = 0.040

Table 4: Effect of barrel temperature and feed moisture on water adsorption index (g/g) of rice extrudate

Variety / Barrel temp. ▶	14% moisture				16% moisture				18% moisture			
	120°C	140°C	160°C	Mean	120°C	140°C	160°C	Mean	120°C	140°C	160°C	Mean
Shalimar Rice-1	8.74	7.53	7.01	7.76	9.09	8.54	8.68	8.77	10.14	9.96	9.85	9.98
Jhelum	8.68	8.03	7.63	8.11	9.31	9.13	8.81	9.08	10.44	10.17	9.87	10.16
K-332	8.34	7.14	6.64	7.37	8.27	7.04	6.86	7.39	9.14	8.26	7.57	8.32
China- 1039	7.96	7.24	7.11	7.44	8.47	8.32	8.17	8.32	9.47	8.30	8.14	8.64
Pusa Sugandh	7.13	6.90	6.63	6.89	8.17	8.33	7.45	7.98	9.55	8.85	8.48	8.96
Mean	8.17	7.37	7.00	7.51	8.66	8.27	7.99	8.31	9.75	9.11	8.78	9.21

$CD_{0.05}$: Variety (V) = 0.06; Moisture (M) = 0.05; Barrel temperature (T) = 0.05;
V x M = 0.11; V x T = 0.11; M x T = 0.08; V x M x T = 0.19

Amongst the rice varieties evaluated, ‘K-332’ had significantly higher WSI (12.65%), followed by ‘Jhelum’ (11.70%), ‘Shalimar Rice-1’ (11.61%) and ‘China-1039’ (11.41%). Variety ‘Pusa Sugandh’ had minimum WSI (10.33%). Overall the WSI in snacks ranged from 9.06 to 13.79%. Water solubility index is generally used an indicator for degradation of molecular components. It means the degree of starch conversion during extrusion, which is the amount of soluble polysaccharides released from the starch component after extrusion (Yagci and Gogus, 2008). The change in WSI may be due to extrusion conditions. WSI is related to the presence of soluble molecules that have sometimes attributed to dextrinization (Collona *et al.*, 1989). Similar findings were observed in the effect of extrusion conditions on the physicochemical properties and sensory characteristics of rice based expanded snacks by Kumar *et al.* (2010).

Water adsorption index (WAI)

WAI decreased with increase in barrel temperature but increased with the increase in feed moisture (Table 4). The significantly high WAI was observed in 18% feed moisture, followed by 16 and 14% feed moisture with the value of 9.21, 8.31 and 7.51 g g^{-1}, respectively. The WAI was recorded significantly high in mean barrel temperature of 120°C (8.86 g g^{-1}), followed by 140°C (8.25 g g^{-1}). The least WAI value was observed at 160°C (7.93 g g^{-1}). Rice variety ‘Jhelum’ had significantly high WAI (9.12 g g^{-1}), followed by ‘Shalimar Rice-1’ (8.84 g g^{-1}), ‘China-1039’ (8.13 g g^{-1}) and ‘Pusa Sugandh’ (7.94 g g^{-1}). Least WAI was observed in variety ‘K-332’ (7.70 g g^{-1}). The WAI values ranged from 6.63 to 10.44 g g^{-1}. Water absorption index decreased with increase in barrel temperature, but increased with increase in feed moisture which was in accordance with the results of Yagici and Gogus (2008). The WAI measures the volume occupied by starch after swelling in excess water, which maintains the integrity of starch in aqueous dispersion (Manson and Hoseney, 1986). Gelatinization, the conversion of raw starch to a cooked and digestible material by the application of water and heat, is one of the important effects that extrusion has on starch component of foods. The maximum gelatinization occurs at high moisture and low temperature or vice-versa (Lawton and Henderson, 1972).

Volume expansion ratio

Expansion ratio was significantly influenced by extruder barrel temperature and feed moisture (Table 5). Volume expansion ratio increased with increase in barrel temperature and decreased with increase in feed moisture. Further, the significantly high mean volume expansion ratio was observed at 14% feed moisture, followed by 16% and least in 18% with respective value of 3.34, 2.79 and 2.49. The volume expansion ratio was significantly high in mean barrel temperature of 160°C with mean value of 3.13, followed by 140°C (2.86). The lowest volume expansion ratio was recorded at 120°C with value of 2.64.

Amongst the varieties evaluated, volume expansion ratio was significantly high in ‘China-1039’ (3.09), followed by ‘Shalimar Rice-1’ and ‘Jhelum’ (2.86). Varieties ‘K-332’ and ‘Pusa Sugandh’ had minimum value of mean volume expansion ratio (2.78). The volume expansion ratio

Table 5: Effect of barrel temperature and feed moisture on volume expansion ratio of rice extrudate

Variety / Barrel temp. ►	14% moisture				16% moisture				18% moisture			
	120°C	140°C	160°C	Mean	120°C	140°C	160°C	Mean	120°C	140°C	160°C	Mean
Shalimar Rice-1	3.24	3.37	3.70	3.44	2.25	2.87	3.16	2.76	2.14	2.34	2.71	2.40
Jhelum	3.11	3.29	3.52	3.31	2.67	2.84	2.96	2.82	2.20	2.40	2.79	2.46
K-332	3.12	3.33	3.58	3.34	2.31	2.54	2.75	2.53	2.25	2.34	2.81	2.46
China- 1039	3.15	3.46	3.89	3.50	3.04	3.14	3.22	3.13	2.46	2.66	2.76	2.62
Pusa Sugandh	2.92	3.08	3.31	3.10	2.48	2.75	2.88	2.70	2.25	2.49	2.85	2.53
Mean	3.11	3.31	3.60	3.34	2.55	2.82	2.99	2.79	2.26	2.45	2.78	2.49

$CD_{0.05}$: Variety (V) = 0.01; Moisture (M) = 0.01; Barrel temperature (T) = 0.01;
V x M = 0.02; V x T = 0.02; M x T = 0.02; V x M x T = 0.04

varied between 2.14 and 3.89. The decrease in expansion ratio with increase in feed moisture during extrusion process may possibly be due to higher gelatinization of starch which resulted in more expansion. At higher temperature, the extent of gelatinization was higher thus developing greater pressure inside the extruder and resulting in expansion of extrudate exiting the die. Expansion of extruded cereals or starch based snacks foods is dependent on the extent of starch gelatinization which, in turn, depends on extruder temperature, shear rate and feed moisture (Lawton *et al*., 1972; Chiang and Jonson, 1977; Collona *et al.*, 1984; Guy and Horne, 1988).

Colour

The study on the effect of barrel temperature and feed moisture on colour (L*, a* and b* values) of extruded rice product revealed that barrel temperature, feed moisture and variety significant influenced L*-value (whiteness) of rice extrudate (Table 6). The L*-value increased with increase in feed moisture. The mean L*-value in feed moisture was significantly high in 18% feed moisture followed by 16% and minimum in 14% with respective values of 62.79, 58.58 and 56.56. L*-value showed a decreasing trend with increase in barrel temperature with maximum value (61.16) recorded at 120°C barrel temperature followed by 59.39 at 140°C. Least L*-value was recorded at160°C (57.37). Maximum mean L*-value (62.41) was recorded in 'K-332' which at par with 'Pusa Sugandh'. The L*-value ranged between 53.03 and 68.60.

With increase in feed moisture, a*-value showed a decrease (Table 7). The significantly high mean a*-value was found at 14% (0.58), followed by 16% feed moisture (0.51) and minimum at 14% feed moisture (0.41). The developed product showed increase in redness (a*-value) with increase in barrel temperature. The significantly high mean a*value was observed in products extruded at 160°C barrel temperature (0.59), followed by 140°C (0.50). The least a*value (0.37) was recorded at barrel temperature of 120° C. Products from **'**Jhelum' showed higher mean a*- value (0.65) while least a* value was observed in rice variety 'China-1039' (0.29).

There was insignificant effect of barrel temperature and feed moisture on yellowness (b*value) of rice extrudates (Table 8). The b*value showed gradual increase with increase in feed moisture. The mean b* value was high at 14% feed moisture (14.41), followed by 16% moisture (14.04) and least at 18% feed moisture (13.05). The b* value generally increased with increase in barrel

Table 6: Effect of barrel temperature and feed moisture on colour (L* value) of rice extrudate

Variety / Barrel temp. ►	14% moisture				16% moisture				18% moisture			
	120°C	140°C	160°C	Mean	120°C	140°C	160°C	Mean	120°C	140°C	160°C	Mean
Shalimar Rice-1	57.04	55.22	53.80	55.35	59.21	57.42	55.56	57.40	61.63	60.80	59.10	60.51
Jhelum	57.07	55.15	53.03	55.08	59.01	57.38	52.20	56.20	65.83	64.54	63.61	64.66
K-332	59.01	57.61	55.40	57.34	64.56	62.64	60.58	62.59	68.60	67.73	65.55	67.29
China- 1039	58.18	55.69	52.09	55.32	57.93	56.21	53.72	55.95	60.75	58.61	57.58	58.98
Pusa Sugandh	61.54	58.82	58.71	59.69	62.91	60.88	58.42	60.74	64.22	62.22	61.17	62.51
Mean	58.57	56.50	54.61	56.56	60.72	58.91	56.10	58.58	64.21	62.78	61.40	62.79

$CD_{0.05}$: Variety (V) = 0.18 ; Moisture (M) = 0.14; Barrel temperature (T) = 0.14;
V x M = 0.30; V x T = 0.30; M x T = 0.24; V x M x T = 0.53

Table 7: Effect of barrel temperature and feed moisture on colour (a* value) of rice extrudate

Variety \ Barrel temp.	14% moisture				16% moisture				18% moisture			
	120°C	140°C	160°C	Mean	120°C	140°C	160°C	Mean	120°C	140°C	160°C	Mean
Shalimar Rice-1	0.36	0.62	0.73	0.57	0.28	0.35	0.57	0.40	0.28	0.32	0.43	0.34
Jhelum	0.65	0.87	0.94	0.82	0.47	0.67	0.74	0.63	0.39	0.54	0.62	0.51
K-332	0.50	0.55	0.65	0.57	0.36	0.47	0.52	0.45	0.30	0.41	0.48	0.40
China- 1039	0.30	0.35	0.38	0.34	0.24	0.29	0.34	0.29	0.19	0.24	0.28	0.24
Pusa Sugandh	0.47	0.64	0.76	0.62	0.41	0.60	0.71	0.57	0.38	0.59	0.66	0.54
Mean	0.46	0.61	0.69	0.58	0.35	0.48	0.58	0.47	0.31	0.42	0.49	0.41

$CD_{0.05}$: Variety (V) = 0.009; Moisture (M) = 0.007; Barrel temperature (T) = 0.007; V x M = 0.015; V x T = 0.01; M x T = 0.01; V x M x T = 0.03

temperature. The mean b*value was maximum at 160°C barrel temperature (15.76), followed by 140° C (13.89) and least (12.85) at 120° C. The variety had non-significant effect on b*value, though higher value was in 'Shalimar Rice-1 (15.35)', followed by Pusa Sugandh (14.60). In the final products b*value ranged between 11.92 and 19.91. The L* value showed a decreasing trend with increase in barrel temperature and an increasing trend with increase in feed moisture. An increasing trend was observed in redness (a* value) and yellowness (b*) with increase in barrel temperature and a decreasing trend with increase in feed moisture. Overall, colour was mostly influenced by barrel temperature and, to some extent, by feed moisture. Higher the feed moisture content, brighter was the colour of rice extrudate, which was characterized by high L* value and low a* value. High temperature in combination with low water content favours Maillard reaction between reducing sugar and free amino acid groups resulting in higher yellowness (Anastase *et al.*, 2006). The similar trends were recorded by Anastase *et al.* (2006).

Table 8: Effect of barrel temperature and feed moisture on colour (b* value) of rice extrudate

Variety \ Barrel temp.	14% moisture				16% moisture				18% moisture			
	120°C	140°C	160°C	Mean	120°C	140°C	160°C	Mean	120°C	140°C	160°C	Mean
Shalimar Rice-1	14.75	17.34	19.91	17.33	13.41	14.44	17.24	15.03	12.41	13.31	15.33	13.68
Jhelum	13.49	13.93	15.00	14.14	13.30	13.43	14.45	13.73	12.00	12.97	13.92	12.96
K-332	13.98	14.92	16.47	15.12	12.19	12.98	14.24	13.14	11.21	11.92	13.47	12.20
China- 1039	13.12	14.47	16.63	14.74	12.81	13.00	15.36	13.72	11.74	12.31	14.68	12.91
Pusa Sugandh	13.92	15.85	17.32	15.70	12.71	14.25	16.77	14.58	11.66	13.25	15.65	13.52
Mean	13.85	15.30	17.07	14.41	12.88	13.62	15.61	14.04	11.80	12.75	14.61	13.05

$CD_{0.05}$: Variety (V) = ns; Moisture (M) = ns; Barrel temperature (T) = 2.16; V x M = ns; V x T = ns; M x T = ns; V x M x T = ns

Texture

The effect of barrel temperature and feed moisture on texture of rice extrudate revealed the hardness of extrudate i.e. force was needed to break the product. The force required increased with increase in feed moisture (Table 9). Significantly higher force was required to break the product developed at feed moisture of 18% (121.82 g), followed by 16% (41.12 g). The lowest hardness was observed in 14% (19.52 g). Hardness decreased with increase in barrel temperature. Significantly higher mean force required to break the product was observed in barrel temperature of 120° C (78.62 g), followed by 140°C (64.67 g) and least at 160°C (39.19 g). Significantly higher mean force required was found in variety 'Pusa Sugandh', followed by 'C-1039', 'Shalimar Rice-1' and 'Jhelum' with value of 70.34, 66.30, 58.77 and 54.99 g, respectively. The minimum mean force was in recorded in K-332 (53.73 g). Texture value in the final extruded products ranged from 13.47 to 201. The higher value of maximum peak force required indicates the hardness of sample (Li *et al.*, 2005). Increase in barrel temperature decreased the hardness of sample. However, hardness increased with increase in feed moisture. The increase in hardness with increase in moisture was possibly due to availability of ample water for the formation of harder structure which lead to less expansion of extrudates. At the same time, decrease in hardness with increase in barrel temperature was possibly due to less residual moisture available during extrusion process (Kumar *et al.*, 2010). The decrease in hardness

Table 9: Effect of barrel temperature and feed moisture on texture (g) of rice extrudate

Variety / Barrel temp. ►	14% moisture				16% moisture				18% moisture			
	120°C	140°C	160°C	Mean	120°C	140°C	160°C	Mean	120°C	140°C	160°C	Mean
Shalimar Rice-1	20.63	16.26	13.74	16.88	35.29	33.25	31.09	33.21	151.87	129.10	97.68	126.22
Jhelum	26.72	21.57	13.47	20.59	48.62	31.19	26.89	35.57	155.63	135.15	35.70	108.83
K-332	21.20	19.58	16.54	19.11	50.54	47.23	38.49	45.42	143.91	113.58	32.46	96.65
China- 1039	23.05	19.45	17.23	19.91	54.96	46.92	31.68	44.42	165.97	142.88	94.58	134.48
Pusa Sugandh	23.47	21.99	17.89	21.12	56.27	47.36	37.38	47.00	201.20	144.50	83.02	142.91
Mean	23.01	19.77	15.77	19.52	49.17	41.19	33.11	41.12	163.72	133.04	68.69	121.82

$CD_{0.05}$: Variety (V) = 0.43; Moisture (M) = 0.34; Barrel temperature (T) = 0.34;
V x M = 0.75; V x T = 0.75; M x T = 0.58; V x M x T = 1.31

with increase in barrel temperature and increase with increase in feed moisture has also been reported by Altan *et al.* (2008).

Conclusions: The present investigation revealed that all the test varieties (Shalimar Rice I, Jhelum, K-332, China-1039 and Pusa Sughand), grown in Kashmir valley, were suitable for extrusion process. Feed moisture content of 14 and 16% and barrel temperature of 140 and 160°C were most acceptable process variables. The physicochemical properties of rice-based extrudates on twin-screw extrusion process were dependent on system parameters and process variables. Feed rate, moisture and barrel temperature had significant effect on various extrudate properties.

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