Study of machine parameters in twin-screw extruder for pulses based extrudate

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Abstract: Legumes are prime source of plant proteins, calories and other nutrients. Extrusion technology has been applied to generate analogues of foods made from animal products, as well as snacks using blends of various plant raw materials e.g. oil seeds (soybeans, peanut with a cereal flour). Present work was under taken for producing extruded product from pigeon pea. The legumes viz. pigeon pea and Bengal gram were cleaned and ground to required particle size by multipurpose grinder mill to pass through sieve ASTM No. 20. The moisture content of sample was adjusted to 14% moisture level (w.b.). Before extrusion, the feed was allowed to come to ambient temperature and then remixed, after checking its moisture content. The twin-screw food extruder was used and then different extrudates were prepared using feed rate and feed moisture. The effect in incorporation of dehulled pigeon pea product characteristics was studied. The bulk density and tapping density of pigeon pea flour was found to be 0.481×10^{-3} gm^{-3} and 0.719×10^{-3} gm^{-3} respectively. Then the moisture content of pigeon pea flour was calculated and found to be 9.08% (w.b.) and different sample were prepared of 14% and 20% (w.b.). Now the thousand kernels mass was determined and found to be at average of 30.778 g. The dimensions were taken on the basis of length, width, and thickness and calculated at the average of 4.47, 4.221, and 1.82 mm.

Keywords: extrusion, protein, moisture content, density, dimension

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1 Introduction

In the everyday world, we use adjectives such as crispy, creamy, toothsome, tasty, horrid, and revolting and the like to describe our reaction to a food and nouns such as goodness, freshness, purity, wholesomeness and richness, convey familiar day-to-day concepts which cannot be measured by physical or chemical possibilities. To produce high quality, acceptable, reduced-calorie products and more consideration must be given to the effects of the substitutes on the sensory properties of the finished products (Obiegbuna et al., 2013). As consumers' interest in nutritional issues continue to grow, more definitive studies will become available, clearing up some of the uncertainties regarding the true effectiveness of these alleged bio active agents. Legumes are prime source of plant proteins, calories and other nutrients (Ahnen et al., 2019). The legumes also contribute a substantial anti-nutritional factor, which reduces the digestibility of nutrients present in legumes (Abbas and Ahmed, 2018). Extrusion cooking of legumes increases the digestibility of legume protein (Abd EI-Hady and Habiba, 2003). Although that is offset by loss of essential amino acids inhibitors that are inactivated and in addition, starch and protein digestibility is increased during extrusion cooking.

Extrusion cooking is becoming an increasingly popular food processing unit operation by which cereal, legumes and other raw materials are used to produce various food analogues. This process uses high

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temperature short time (HTST) cooking in addition to be to mix and cause texturing and shaping of food using equipment, which closely resembles the screw extruders used in the processing of thermoplastics (Mościcki and Zuilichem, 2011). The state-of-the-art of protein texturization has been the subject of several reviews. Extrusion provides a high-volume, low-cost alternative to conventional food processing methods (Alam et al., 2016).

Food extrusion is a versatile high temperature, short time (HTST) process, which has become established for continuous manufacture of traditional and new products (Singh et al., 2007; Sudhakar et al., 2021). Extrusion technology has been applied to generate analogues of foods made from animal products, as well as snacks using blends of various plant raw materials (Offiah et al., 2019; Pasqualone et al., 2020; He et al., 2020). Leonard et al. (2020) explained that the rapid rise in viscosity in starch products, which is a function of temperature, is associated with presence of an extrudate outside the granule. For reasons of simplification, the model will be further developed for an ideal process material, e.g., an isothermal Newtonian melt, separated from the feed by an instantaneous melting process.

Extrusion may be defined as forcing a pumpable product through a small opening to shape materials in a designed fashion (Heldman and Hartel, 1999). The extrusion process may occur through use of a piston, a set of rollers, or screw to force the material, usually through a narrow opening, into the desired shape. Food extruders in processing plants work by the same principle, except that typically a screw device is used to pump the food material through a narrow die opening into the desired shape. Table 1 shows the different types of extruders used in the food industry with typical operating conditions and types of food products made.

Table 1 Types of extruders and typical operating conditions

Types of extruders	Feed Moisture (%)	Product Temperature (ºC)	Screw speed ($rmin^{-1}$)	Typical Products
Twin-screw cooking extruder	11-35	80-200	200-500	Puffed snacks, RTE cereals, fabricated chips
High-shear cooking extruder	15-20	120-180	350-500	Puffed snacks, RTE cereals, fabricated starch
Collet extruder	11-16	170-200	300	Puffed snacks
Low-shear cooking extruder	28	90-150	60-200	RTE cereals, setup bases starch
High-pressure forming extruder	25	65-80	40	Cereals pellets, half-products snacks
Pasta press	32	30-52	30	Pasta

Each stage of this closely articulated food system performs a unique set of function that performs raw form materials into consumer-ready to eat products. Thus all inductive investigations are in the process of hypothesis and experiments. The objectives of the present study are as follows:

1. To study the physical properties of dehulled legume.

2. To study the effect of screw speed on the electrical parameters of extruder.

3. To study the machine parameters for different expanded and dhal analogs made from pigeon pea flour alone and with selected cereals using twin screw food extruder.

2 Materials and methods

2.1 Raw material

The experimental pigeon pea was procured from nearby grocery market of Central Institute of Post-Harvest Engineering and Technology (CIPHET), Ludhiana. 5 kg of dehulled pigeon pea and 2 kg of bengal gram were purchased. The grain was cleaned manually using sieve and blower. Average moisture content 9% (w.b.) was considered suitable for pearling of pigeon pea (Opoku et al., 2003).

2.2 Extrusion cooking

The extrudates were prepared in a Laboratory scale BTPL twin-screw extruder and its production shown in Figure1. Initially, the required amount of pigeon pea was taken then fed to the grain pearler for seed coating removal and size reduction. The obtained powder after milling was sieved using ASTM 20 sieve. The dough was prepared from the pigeon pea powder then fed into the extruder to prepare dhal analogue. The relation of twin-screw food extruder between Screw speed, torque, frequency, AC voltage, DC Voltage and current were studied for its no-load condition (Table 2).

Table 2 No load characteristics of twin screw food extruder

Screw speed (rmin^{-1})	Torque (Nm)	Frequency (Hz)	A.C. voltage (V)	D.C. voltage (V)	Current (A)
10	0	0.90	15	586	5.26
20	0	1.83	22	584	5.53
30	0	2.75	29	584	5.09
40	1.07	3.61	36	584	4.72
50	2.34	4.49	42	583	4.45
60	2.75	5.47	50	581	4.15
70	2.54	6.31	52	581	4.10
80	2.46	7.23	64	581	4.01
90	2.42	8.05	71	580	3.95
100	2.42	8.99	78	580	3.91
110	2.27	9.94	86	578	3.84
120	2.38	10.79	93	578	3.09
130	2.24	10.72	100	578	3.86
140	2.56	12.54	107	578	3.83
150	2.40	13.44	115	578	3.84
160	2.59	14.31	122	578	3.82
170	2.66	15.23	130	575	3.82
180	2.61	16.06	137	572	3.83
190	2.62	16.77	144	577	3.78
200	2.56	17.84	151	572	3.76
210	2.68	18.80	159	572	3.77
220	2.70	19.61	165	572	3.82
230	2.73	20.50	173	573	3.77
240	2.75	21.45	181	572	3.77
250	2.74	22.39	188	572	3.73
260	2.99	23.22	195	570	3.75
270	2.95	24.17	203	570	3.73
280	2.90	25.07	211	570	3.69
290	2.91	25.93	216	570	3.70
300	2.95	26.82	225	570	3.68
310	3.07	27.68	232	570	3.71
320	3.07	28.61	239	572	3.71
330	3.23	29.49	246	573	3.71
340	3.29	36.29	253	573	3.69
350	3.38	31.22	260	573	3.70
360	3.31	32.16	269	572	3.69
370	3.42	33.04	276	572	3.71
380	3.47	33.96	284	573	3.70
390	3.56	34.88	291	573	3.68
400	3.60	35.67	297	575	3.69
410	3.60	36.60	305	573	3.69
420	3.61	37.54	312	572	3.67
430	3.81	38.43	320	570	3.66
440	3.69	39.34	327	570	3.67
450	3.65	40.20	335	569	3.68
460	3.71	41.05	341	567	3.65
470	3.77	41.99	350	566	3.67
480	3.86	42.88	357	566	3.66
490	3.91	43.78	364	564	3.68
500	3.98	44.68	371	564	3.70
510	3.97	45.56	378	563	3.67
520	4.02	46.46	386	563	3.69
530	4.03	47.29	393	559	3.65
540	4.15	48.24	400	561	3.66
550	4.18	19.02	407	559	3.67
560	4.21	50.00	415	561	3.62

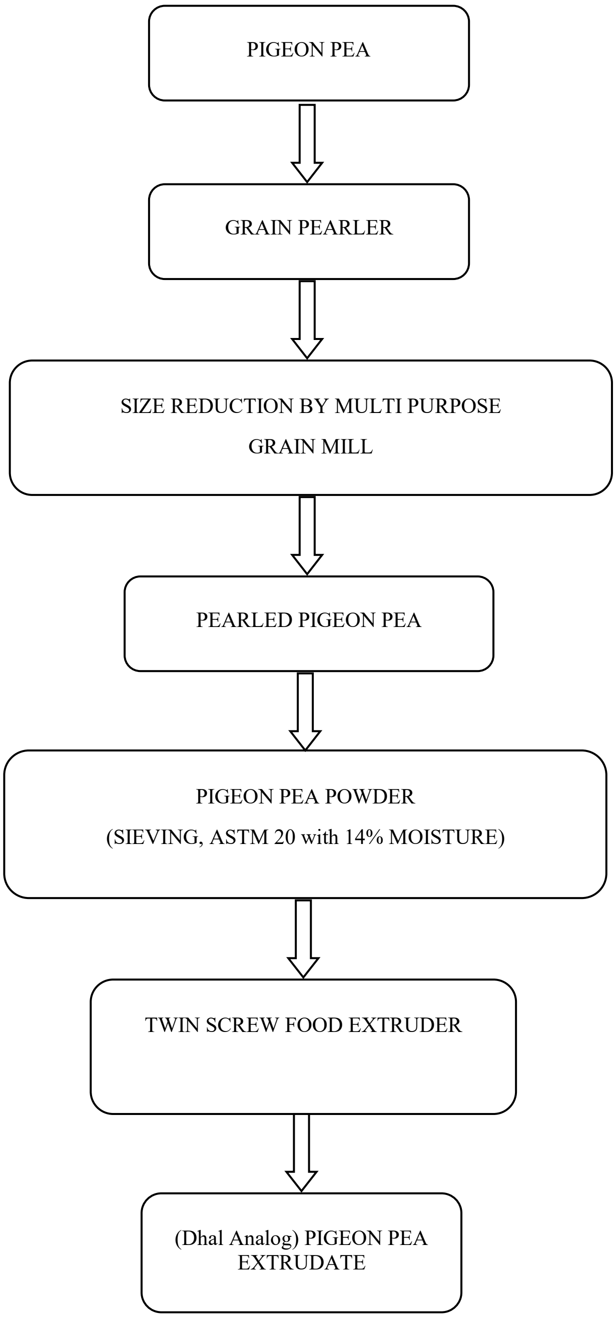


Figure 1 Flow chart for production of Extrudates

2.3 Determination of moisture content

To measure various engineering properties pigeon pea, the grains moisture content was measured by the method described by Sahay and Singh (2001). The grain sample was weighed initially (W_i) then it was kept in hot air oven at the temperature of 105°C for 24 h, with the final weight (W_f), the moisture content was calculated.

In dry basis

$$\text{Moisture Content} = \frac{W_i - W_f}{W_f} * 100 \qquad (1)$$

In wet basis

$$\text{Moisture content} = \frac{W_i - W_f}{Wi} * 100 \qquad (2)$$

where,

W_i -Initial mass of sample, g

W_f -Final mass of sample, g

2.4 Thousand seed mass

Thousand seed mass was determined by the method adopted by Rajićet al.(2003) for wheat and corn. They observed that there was linear rise in thousand grain mass with increase in moisture content as shown in the below relationship:

$$M_{1000} = A + BM \tag{3}$$

where,

M_{1000}-thousand seed mass to be calculated, g

M-seed moisture content, per cent (d.b.)

A-constant indicating weight of seed when moisture content is zero

B-constants

2.5 Measurement of physical and electrical parameters

Physical dimensions of dehulled legume were determined using vernier calliper having precision of 0.02 mm. The readings of electrical parameters were taken from the indicators of the extruder. Digital torque wrench was used to measure the toque.

2.6 Statistical analysis

All the observed data were statistically analyzed by using regression analysis. All the treatments were replicated three times. The effect of operating variables on the response were analyzed by analysis of variance (ANOVA)at 5% level of significance ($p<0.05$).

3 Results and discussion

3.1 Properties of dehulled legume

Legume moisture content is an important parameter for milling operation. Also, the moisture content of flour obtained after milling contributes its moisture for feed preparation in an extruder. The moisture content of dehulled legume obtained using hot air oven method was 9.08 per cent w.b. The bulk density and tapping density of pigeon pea powder was found to be 0.481×10^{-3} gm^{-3} and 0.719×10^{-3} gm^{-3} resp. Now the thousand kernel mass was determined and found to be at average of 30.778 g. The dimension were taken on the basis of length, width, and thickness and calculated at the average of 4.47, 4.221, and 1.82 mm resp.

3.2 Effect of screw speed on electrical parameters

Increase in screw speed of extruder requires more electrical power. The current supplied decreases as the screw speed increases. But, the current supplied reading became almost constant after 100 rmin^{-1} (Figure 2). A polynomial regression model best fits the curve with R^2 value 0.8815.

The torque of the extruder showed an increasing trend towards the increase in screw speed as shown in Figure 3. Logarithmic model best describes the relationship between torque and screw speed. Initially, there is swift increment in torque at around 35 rmin^{-1} but after 60 rmin^{-1} torque increases gradually. The effect of screw speed on torque is significant ($p<0.05$) with R^2 value 0.9831.

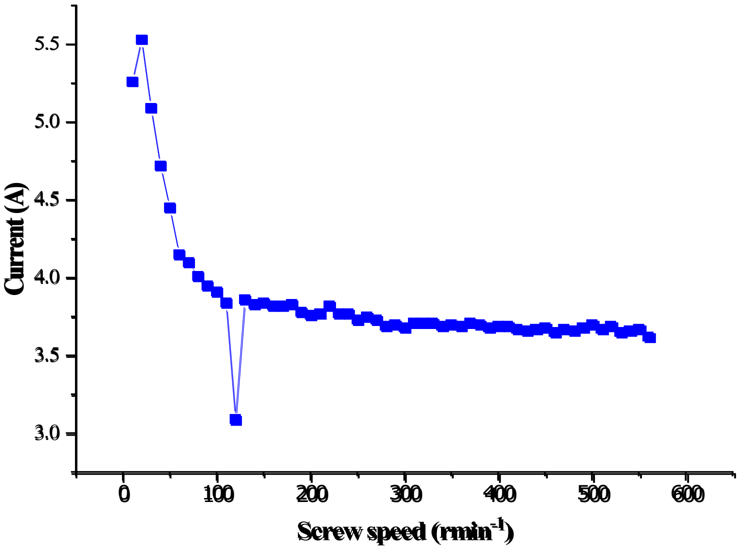


Figure 2 Effect of screw speed on current (Relation between screw speed and current at no load condition of twin screw food extruder)

In case of frequency as shown in Figure 4 there is a positive linear correlation between frequency and sped speed. But a small deviation occurred near at 350 rmin^{-1} speed of extruder. The reason for deviation in trend may occur due to fluctuation in voltage. The effect of screw speed on frequency is highly significant (R^2=0.997) at 5%

level of significance.

The effect of screw speed on torque at no load condition is linearly positive (Figure 4). It was observed that initially torque remains almost constant but suddenly increases at 60 rmin^{-1} then gradually increases. This is because the shear gained by the material was supposed to become proportional to the screw speed, possibly shear thinning effect, and increasing plasticization for higher mixing lowered the viscosity of mass (Das, 2008; Gupta et al., 2016) which overruled the effect of increasing rpm (Faridi and Faubion, 2012) for increasing the torque. The sudden rise in torque beyond 60, probably there was no further reduction in viscosity and the torque increased in the usual way (Raps et al., 2014). This result is similar with study conducted by Das (2008) for corn starch and plasticizer.

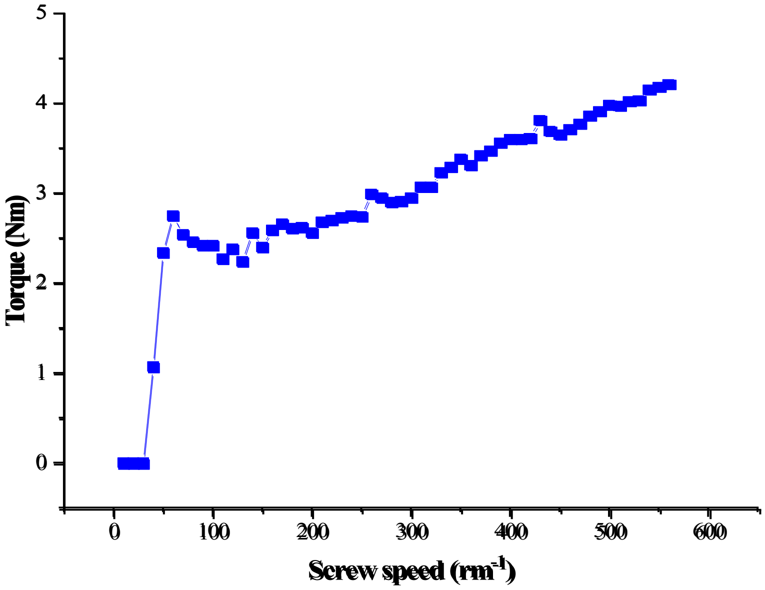


Figure 3 Effect of screw speed on torque (Relation between screw speed and torque at no load condition of twin screw food extruder)

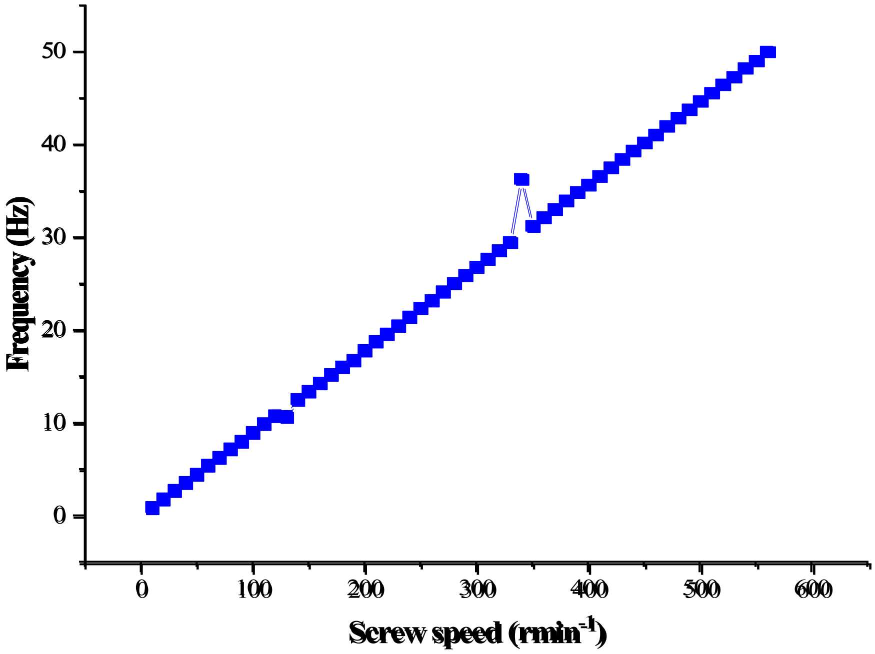
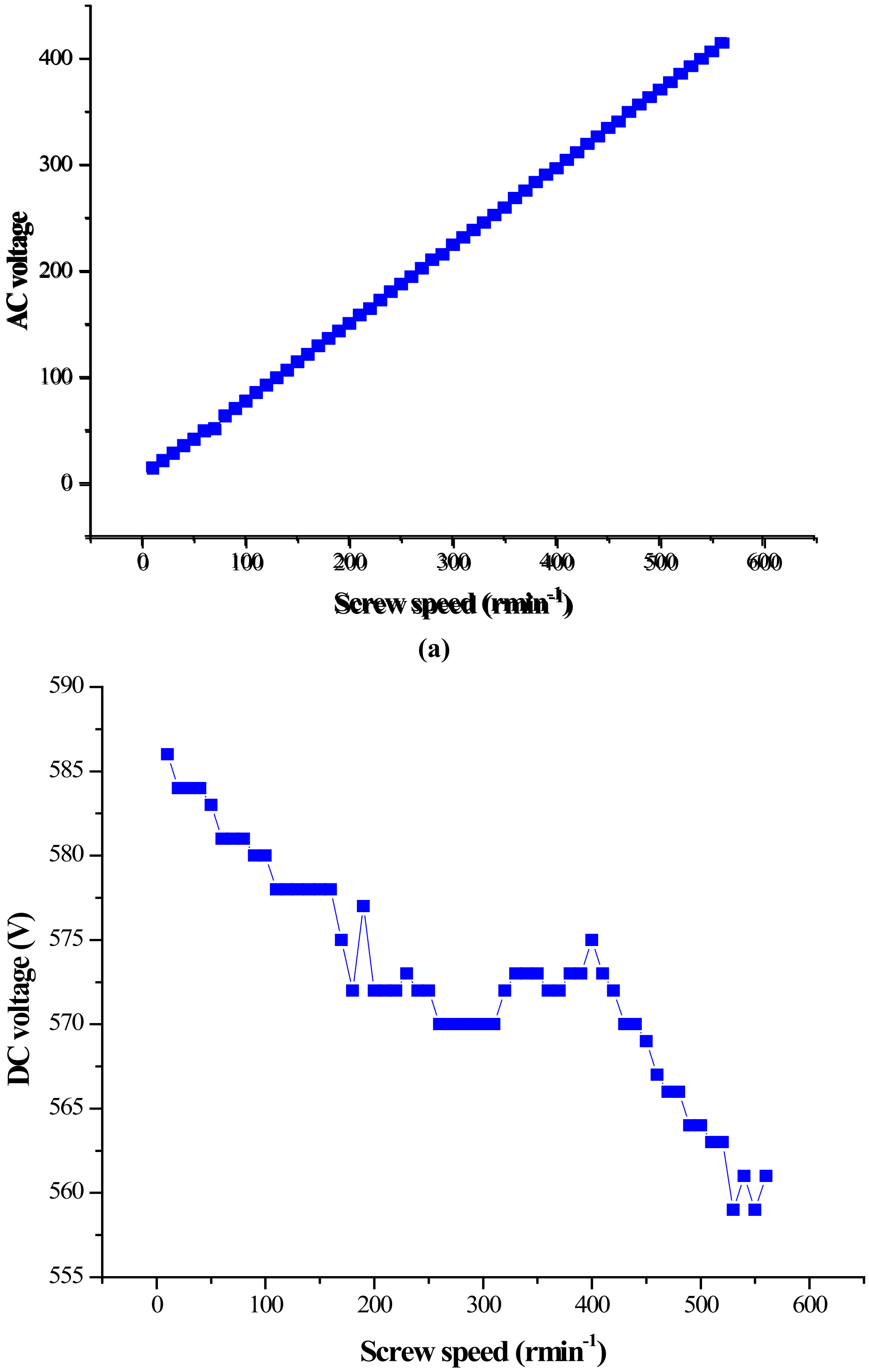


Figure 4 Effect of screw speed on frequency (Relation between screw speed and frequency at no load condition of twin screw food extruder)

Figure 5(a) illustrate that the effect of screw speed on AC voltage supply is highly significant (R^2=0.9999) and a positive linear relationship is obtained. AC voltage increases to a limit of 560V. However, the DC voltage remains constant with increasing screw speed as shown in Figure 5(b).



(a)

(b)

Figure 5 Effect of screw speed on (a) AC voltage (b) DC voltage (Relation between screw speed and voltage at no load condition of twin screw food extruder)

3.3 Machine parameters for different expanded products

The machine parameters such as outlet temperature, feed screw speed, main screw speed, melting zone temperature, die zone temperature, torque, current, frequency and voltages were determined for extrudate samples prepared from varying flour blend ratio as shown in Table 3. The outlet temperature for 100% rice flour is comparatively higher than pure sorghum flour, pigeon pea flour and bengal gram flour. Similarly, feed screw speed, main screw speed and torque were highest in case of rice flour. Although, melting zone temperature and die zone temperature were remain 120°C and 60°C respectively for all samples.

Table 3 Machine parameters of twin screw extruder

Twin screw food extruder observations for different expanded products and dhal analogs										
Sample	A	B	C	D	E	F	G	H	I	J
Outlet temperature (^{o}C)	178.0	143.0	155.0	83.0	157.0	151.0	150.0	143.0	143.0	109.0
Feeder screw speed (rmin^{-1})	26.0	18.0	26.0	34.0	18.0	18.0	31.4	18.0	18.0	20.0
Main screw speed (rmin^{-1})	353.0	355.0	354.0	100.0	352.0	304.0	328.0	327.0	335.0	100.0
Melting zone temp (^{o}C)	120.0	120.0	120.0	100.0	120.0	120.0	120.0	120.0	120.0	70.00
Die zone temp (^{o}C)	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0
Torque (Nm)	27.3	15.2	27.2	23.6	20.5	14.4	18.3	15.1	15.2	2.9
Frequency (Hz)	31.5	30.0	31.5	8.9	31.4	27.2	29.3	29.3	30.0	9.0
Current (A)	6.1	5.2	12.0	8.6	6.2	5.2	5.9	5.2	5.2	3.9
Voltage (AC, V)	263.0	250.0	263.0	7.8	263.0	227.0	245.0	245.0	250.0	78.0
Voltage (DC, V)	552.0	264.0	534.0	570.0	564.0	569.0	669.0	264.0	564.0	570.0

Note: A:100%, rice flour (12% mc); B:50% rice flour+50% sorghum flour (12%mc); C:67% rice flour+ 29% sorghum Flour+ 4% ragi flour (12% mc); D:100% bengal gram (10% mc); E:95% rice flour+ 4% peas flour+ 1% butter (12% mc); F:100% sorghum (10% mc); G:85% rice flour+15% peas flour; H:100% finger millet (10% mc); I: 85% rice flour + 15% finger millet flour; J:100% pigeon gram flour

4 Conclusions

Extrusion provides a high-volume, low-cost alternative to conventional food processing methods. To make this method more cost effective, the machine parameters were studied to know the electrical energy required for preparation of extrudate. It can be concluded that the electrical energy requirement for extrudate from pulse flour depends on the material properties like bulk density and tap density while, for machine parameters it depends on screw speed, torque and temperature. This study may help in electrical energy saving and thus provide benefit to the manufacturers.

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