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Study on the effect of temperature on the physical, color and texture characteristics of lentil extrudates

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Abstract
Lentils are underutilized in food processing due to their antinutritional values, despite having a high nutritional profile. This study aimed to analyze the influence of temperature on the quality parameters of lentil extrudates. Three different temperatures were used for extrusion processing of lentil flour such as 130 ^{0}C, 145 ^{0}C and 160 ^{0}C. The specific mechanical energy was decreasing with the increase in the temperature from 130 ^{0}C to 160 ^{0}C. Expansion and rehydration ratios, bulk density and texture properties of extrudates have a positive effect on increasing temperature. The color change values were negative effect and water absorption index of extrudate after 145 ^{0}C has a negative effect. However, lentil flour extruded at 160 ^{0}C has good quality characteristics. These extrudates are textusrized, so can be used in meat analogue and snack food preparations.

Keywords: food extrusion, lentil extrudate, meat analogue, texture, color

1. Introduction
Lentils are a major leguminous crop grown worldwide with different types like red lentils, green lentils, black lentils, and brown lentils. Lentils are rich in protein with 21 – 31 % depends on variety and type. The biological value of lentil protein is 79%, which is higher than soy protein, pea protein, and chickpea protein (Boye *et al*., 2010) [4]. Masoor is a major lentil type grown and used in India, which contains 26 – 28% protein. It is under-utilized in processing industries, despite having a high nutritional profile due to the presence of antinutritional factors. These antinutritional factors can be decreased through processing methods such as boiling, radio wave heating, microwave heating, autoclaving, milling, extrusion (Hefnawy, 2011; Rathod & Annapure, 2016) [10, 13]

Extrusion is an HTST (High Temperature Short Time) process, which minimizes food degradation and destroys the anti-nutritional factors (Rathod & Annapure, 2016) [13]. In addition to this, the thermal extrusion process makes vegetable protein produce fibrous texture like real meat (Samard & Ryu, 2019) [15], while high starch foods produce highly expanded snack products. Meat extenders are normally prepared from pulse proteins using extrusion cooking (Brishti *et al*., 2020) [5]. These extrudates serve as meat extenders in the production of meat analogues like nuggets, meat balls and burger patties.

Functional properties of these extrudates such as expansion ratio, rehydration ratio, bulk density, water absorption index and textural properties such as hardness, gumminess, resilience, springiness and chewiness are major parameters, which determines the quality of the product. To produce a high quality product, moisture and barrel temperature play a major role (Lin *et al*., 2000) [11]. Especially at low moisture levels, barrel temperature proves to be the main process parameter in the product quality determination (Chen *et al*., 2011) [6]. Research on lentil extrusion is not very common, so all these reasons provide a way to research on extrusion of lentils. This research mainly focuses on the effect of temperature on the quality of lentil extrudates at low moisture extrusion cooking.

2. Materials and Methods
2.1 Raw materials and chemicals
Dehulled masoor and zip lock bags were purchased from local market. Dehulled masoor was ground in a hammer mill and sieved through a flour sieve. Flour was stored in a polyethylene zip lock bag, under a cool and dry place. Drinking water for moisturizing and distilled water was used for analysis purposes.

2.2 Preconditioning of lentil flour

Dehulled lentil flour was moistened with drinking water to 30% moisture. Mixing of water and flour was performed manually. The moistened flour was stored under refrigerated condition overnight. It enables the even mixing of water into the flour.

2.3 Extrusion process

Single screw extruder (D-47055; Brabender GmbH & Co., Duisburg, Germany) was used in all extrusion experiments with spiral screw. Round die of 10mm diameter was used with compression ratio of 3:1. It contains four heating zones, the fourth zone temperature was adjusted to the required level. The temperatures used in this experiment were 130 ^{0}C, 145 ^{0}C and 160 ^{0}C. Manual feeding was done at feed screw speed of 30 rpm. The screw speed of the extruder was adjusted to 80 rpm.

2.4 Specific mechanical energy

Specific mechanical energy (SME) was calculated according to Osen *et al*. (2014) [12] method. Extrusion process conditions were set in the winEx software, after set conditions sample ingredients were fed through feeding hopper. Then mass flow rate was calculated by measuring the length of extruded product in one minute time and torque was recorded in the WinExt software. SME was calculated from torque (T in N m), mass flow rate (MFR in g/min) and screw speed (n in rpm) by the following equation (Osen *et al*., 2014) [12]:

$$\text{SME (kJ/kg)} = \frac{2\pi\ n\ T}{\text{MFR}}$$

2.5 Physical properties of the extrudate

2.5.1 Expansion ratio

Five pieces of extrudates were selected randomly in each experiment. Vernier caliper was used to check the diameter of the extrudate and the expansion ratio was calculated using following equation:

$$\text{Expansion ratio} = \frac{\text{Extrudate diameter}}{\text{Die diameter}}$$

2.5.2 Bulk density

Bulk density was calculated according to Brishti *et al*. (2021). Lentil extrudate was cut into 25mm strands and 4g of extrudate strands was weighed (W). Strands were added into a 50 mL cylinder and filled with yellow millet particles. Extrudate strands were taken off from the cylinder and remaining millet particles were measured (V). Each experiment was carried out in three replicates. Bulk density was calculated using the following equation:

$$\text{Bulk density (g/mL)} = \frac{W}{V}$$

2.5.3 Rehydration ratio

The rehydrated ratio was determined according to Yu *et al*. (2012) [16], lentil extrudate was cut into 35mm strands. 4g of extrudate strands was weighed (W_1) and kept in 100 mL distilled water. The temperature was maintained at 30 ^{0}C for 30 min and water was drained out after 30 min. The rehydrated sample was weighed (W_2) and the rehydration ratio was calculated using the following equation. Each of the experiments was carried out in three replicates.

$$\text{Rehydration ratio (\%)} = \frac{W_2}{W_2 - W_1} * 100$$

2.5.4 Water absorption index

The water absorption index (WAI) of lentil extrudates was determined according to Brishti *et al*. (2021). Lentil extrudate was ground into a fine powder and 3g was mixed into 50 ml of distilled water. Then mixture was stirred for an hour and centrifuged at 5000 rpm for 30 min. After centrifugation, protein particles were separated by discarding the supernatant. Protein particles were reweighed and water absorption index was calculated using the following equation. Each of the experiments was carried out in three replicates.

$$\text{Water absorption index} = \frac{W_2 - W_1}{W_0} *100$$

where, W_0 – Sample weight without centrifuge tube, W_1 – Weight of the tube with the dry sample, W_2 – Weight of the tube with sediment

2.6 Color change analysis

The color values of extrudates were analyzed using Hunter Lab Colorimeter. The color values L*, a* and b* represent the lightness, green/red color and yellow/blue color of the samples respectively. The sample was prepared according to Altan *et al*. (2009). Extrudates were ground using a laboratory grinder and sieved prior to color analysis. Each of the analyses was carried out in three replicates and average values were taken.

$$\Delta E = \sqrt{(L - L_0)^2 + (a - a_0)^2 + (b - b_0)^2}$$

2.7 Texture profile analysis

The textural properties of extrudates were determined according to Chen *et al*. (2010) [7], with slight modifications. The textural properties of lentil extrudate like hardness, chewiness, resilience, cohesiveness, gumminess and springiness are analyzed using TA.XT2 texture analyzer (Stable Micro systems, UK). The extrudate was cooked at 90 ^{0}C for 20 min and water was drained out. The cooked sample was cut into 40×10×10 dimensions. It was compressed using a cylindrical probe (P/35) to half of its original thickness at a speed of 1 mm/s for 5 sec. After this, textural properties were recorded.

2.8 Statistical analysis

Microsoft Excel Office 2019 (Microsoft Corporation, Redmond, WA, USA) was used for statistical analysis.

3. Results and Discussion

3.1 Specific mechanical energy

Specific mechanical energy (SME) is the amount of input work produced from a screw motor applied on raw material being extruded (Chen *et al*., 2010) [7]. SME of lentil extrudates was ranging from 187.43 to 200.33 kJ/kg, mainly at 160 ^{0}C showed less SME. This result shows that an increase in the temperature decreases the SME. Similar results were observed in other authors research (Altan *et al*., 2008; Dogan & Karwe, 2003). The reason for this is an increase in the temperature decreases the viscosity and shear inside the extruder barrel (Altan *et al*., 2008).

3.2 Physical properties
The lentil extrudates with high values of expansion ratio, rehydration ratio, water absorption index and less bulk density extrudates are said to be high quality in the production of snack foods or meat analogues (Brishti *et al*., 2021). Higher values of rehydration ratio and water absorption index show that higher juiciness in the product after cooking, while a higher expansion ratio decreases the bulk density, which promotes rehydration of the product (Brishti *et al*., 2020; Chen *et al*., 2010; Rehrah *et al*., 2009) [5, 7, 14].

3.2.1 Expansion ratio
The expansion ratio is the quality measure, that describes the puffiness and rate of expansion of the extrudate. Among three temperature treatments at 160 ^{0}C (T3) the expansion ratio was found to be high with 1.298 ± 0.016 and at 130 ^{0}C (T1) the expansion ratio was found to be low with 1.236 ± 0.03. These results show that an increment in the temperature can increase the expansion of the product. This is due to high temperatures increases moisture expansion and enhances the bubble size. Although amylose content in lentils favors the expansion by increasing the viscosity (Ghumman *et al*., 2016) [8].

3.2.2 Bulk density
Bulk density indirectly defines the number of void spaces formed inside the extrudate. It is most influenced by protein content and temperature. In this research results at 160 ^{0}C bulk density were found low, which is 0.007317 ± 0.0005, due to the formation of more void spaces, which reduces the weight of extrudate and increases its volume. The bulk density of extrudates was decreasing on increasing the temperature at low moisture contents. The same results were reported in Brishti *et al*. (2021), Hagenimana *et al*. (2006) [9] and Yu *et al*. (2012) [16]. These results due to increment in the temperature caused rapid moisture heating and increase the water bubble size. This process produces large void spaces on moisture flashing out while the product coming out of the die. The findings of the present research showed that temperature increment causes a decrease in the bulk density.

3.2.3 Rehydration ratio
The extruded meat alternatives are hydrated before cooking. Normally these are stored in dried form to increase their shelf life. The rehydration ratio (RR) was found to be high at 160 ^{0}C temperature, which is 253.30 ± 7.97 and low RR was found at 130 ^{0}C, which is 244.37 ± 4.11. The expansion ratio of the extrudate is directly proportional to its rehydration ratio because the increase in the expansion ratio forms more void spaces inside the extrudate and increases the water holding and rehydration capacities (Brishti *et al*., 2020) [5].

3.2.4 Water absorption index
The water absorption index determines the amount of water filled in the void spaces inside the extrudate. The WAI is found to be high at 145 ^{0}C temperature, which is 328.15 ± 2.23 g H_2O. The current study shows WAI was increased from 130 ^{0}C to 145 ^{0}C temperature and decreased after increasing the temperature to 160 ^{0}C. Day and Swanson (2013) reported that the increase in the barrel temperature of navy bean and pinto bean extrudates WAI was increased. In contrast, Ghumman *et al*.'s (2016) [8] research on lentil grit extrusion showed that higher temperatures decrease the WAI, this is due to high temperatures and low moistures increase the starch dextrinization inside the barrel.

3.3 Color change analysis
The color of the extrudates is dependent on three factors such as maillard reaction, product expansion and decomposition of colored compounds in the raw materials (Bisharat *et al*., 2015) [3]. L* value determines the lightness of the sample, which is high in the sample extruded at 130 ^{0}C. At 130 ^{0}C temperature, the ΔE value showed less as 20.51 and at 160 ^{0}C temperature showed as high as 27.01. These results showed that an increase in the temperature decreases the L* value. a* value was increasing as an increase in the temperature. Similar results were obtained by other authors (Andersson, 1991; Ghumman *et al*., 2016) [2, 8]. This may be due to higher temperatures at lower feed moistures enhances the maillard reaction, which produces brown color in the extrudate. Then color change (ΔE) values were increasing gradually as extruder barrel temperature increases. The color change value increases as the increase in the rate of browning reaction and water evaporation. The color of the extrudate plays a major role in the final product processing and consumer acceptance.

3.4 Texture analysis
Texture parameters such as springiness, hardness, cohesiveness, chewiness, gumminess and resilience of three treatments are given in Table 4. Major texture parameters hardness and chewiness are found low as 1528.418 g and 482.129 respectively at 160 ^{0}C, this shows that an increase in the temperature causes lower hardness and chewiness produces a better textured product, where springiness was decreased from 0.82 to 0.699 on increasing temperature. Except for the springiness, other parameters are decreasing as increasing in temperature. These results found may be due to an increase in the barrel temperature forms more void spaces in extrudate on increasing moisture evaporation. Upon rehydration of these high void spaced extrudates make it smooth and less hard.

Table 1: Specific mechanical energy at different temperatures

Tr. No.	Torque (N m)	Screw speed (rpm)	MFR (g/min)	SME (kJ/kg)
T1	12.8	80	32.1	200.334
T2	12.4	80	32.4	192.2765
T3	12.2	80	32.7	187.4398

MFR – Mass flow rate

Table 2: Physical properties of lentil extrudates at different temperature

Tr. No.	Expansion ratio	Bulk density (g/ml)	Rehydration ratio (%)	Water absorption index (g H_2O)
T1	1.236 ± 0.03	0.07435 ± 0.0002	244.37 ± 4.11	305.39 ± 10.12
T2	1.288 ± 0.013	0.07375 ± 0.0003	250.88 ± 1.89	328.15 ± 2.23
T3	1.298 ± 0.016	0.07317 ± 0.0005	253.30 ± 7.97	319.58 ± 6.13

Table 3: Color values of raw material and extrudates

Tr. No.	L*	a*	b*	ΔE
Raw material	73.83	6.43	14.58	
T1	53.56	3.29	14.42	20.51
T2	48.31	3.8	13.66	25.67
T3	46.87	4.81	14.89	27.01

Table 4: Textural properties of lentil extrudate at different temperatures

Property	T1	T2	T3
Hardness (g)	1980.184	1957.681	1528.418
Springiness	0.820	0.832	0.699
Cohesiveness	0.511	0.476	0.451
Gumminess	1012.688	931.464	689.773
Chewiness	830.473	775.329	482.129
Resilience	0.239	0.215	0.210

4. Conclusion

Quality characteristics of lentil extrudates produced from single screw extruder and extruder response were influenced by extruder barrel temperature. Increasing the barrel temperature has a positive effect on several characteristics such as expansion ratio, bulk density and rehydration ratio but a negative effect on water absorption index after 145 ^{0}C. SME of the extrusion process was decreasing with an increase in the temperature, due to a decrease in the viscosity. Textural properties of lentil extrudates were found good at 160 ^{0}C and color change values were increasing as the increase in the barrel temperature, due to high temperatures promotes the maillard browning. The extrudate produced at 160 ^{0}C has good quality characteristics overall and it can be utilized as a snack food or meat analogue adding some spices. Further studies are required on antinutritional factors, protein structure and digestibility of lentil extrudates, which provides a better understanding of the product to the consumers.

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