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Rheological Properties of Sweet Lupine to be used as Extrusion Meat Additives

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Abstract: Sweet lupine has high content of protein, so it can be used as meat additives (texturized lupine) produced by single screw extruder. Rheological properties of sweet lupine samples were measured at different moisture contents (15, 20, 25 and 30%), different temperatures (90, 95, 140, 145, 170 and 175 °C) and shear rates (14.11-77.61 s^{-1}). The results showed that the percentage of moisture (15, 20, 25 and 30%) at 90°C and 95°C and (25 and 30%) at 140°C and 145°C exhibited non-Newtonian pseudoplastic behavior as the apparent viscosity decreased with increasing shear rate. The moisture content (15%) at 140°C, (15% and 20%) at 145°C, (15% and 20%) at 170°C and (15, 20, 25 and 30%) at 175°C exhibited non-Newtonian dilatant behavior as the apparent viscosity increased with increasing shear rate. The apparent viscosity increased very rapidly through different zones of extruder and pressure drop increased with increasing temperature and moisture content.

Keywords: Sweet Lupine, Single Screw Extruder, Rheological Properties, Flow Behavior

1. Introduction

The science of rheology has many applications in the fields of food acceptability, food processing, and food handling. However, foods are complex materials structurally and rheologically and in many cases, they consist of mixtures of solids as well as fluid structural components [1]

Non-Newtonian flow behavior is usually to be expected in food extrusion as previously mentioned by [2]. A major complication is that chemical reaction also occurring during the extrusion cooking process (e.g. gelatinization of starch, denaturation of protein, millard reactions) which strongly influences the viscosity function.

Extrusion technology is extensively used for the preparation of new protein sources, such as oil seeds, leguminous seeds, leaf and single cell proteins. Extrusion cooked texturized protein includes meat extenders in the form of chunks or small granular pieces which are wet milled or produced directly off the extruder. Also, extruders are able to produce a meat analog that has a remarkable similarity in appearance, texture and mouthfeel to meats. The utilization of extrusion cooking through the food industry has shown that a variety of products can be made on extrusion equipment. Some of these products include breakfast cereals, snacks, instant rice, instant pasta, starch modifications and animal feeds [3].

Extrusion cookers used to transform vegetable protein sources directly into varieties of simulated meat analogs that are consumed as it is and have the appearance, texture and mouthfeel of meats. Extrusion technology has developed to the point where texturized vegetable protein can be formed into fibrous matrix almost indistinguishable from meat [4] and [5].

The global trend of non-use of genetically engineered crops such as soybeans, so there is a direction to use other crops that has high protein for the manufacture of meat additives as an example of extruded products. Sweet lupine contains high protein so it can be used as meat additives. Sweet lupines are white – yellow round seeds, the chemical composition of sweet lupine for crude protein 33.3%, fat 11.4%, ash content 4.0%, carbohydrates 43.0%, and moisture content 8.3%, [6], [7] and [8].

The water absorption capacity was 335.9 and 340.1% for bitter and sweet lupine flour respectively [9]. The functional properties of bitter and sweet lupine seeds flour were studied and found that water absorption of bitter and sweet lupine seeds flour were 310 and 314 % respectively [7]. The highest values of water absorption capacity were shown by the yellow species L. luteus 320 % and the lowest by the white lupine L. albus 300% physic functional properties of novel protein ingredients [10].

The fat absorption capacities of bitter and sweet lupine flour were 175.5 and 167.4 % respectively [9], while [11] stated that the fat absorption capacity of sweet lupine seeds was 255.1%. Functional properties of bitter and sweet lupine seeds flour and stated that fat absorption of bitter and sweet lupine flour were 165±1.3 and 166±2.1 % respectively [7].

The aim of this paper was to (1) investigate the rheological behavior of sweet lupine through single screw extruder in order to optimize the moisture content that must may be used through extrusion process, (2) prediction of pressure drop in single screw extruder during the production of lupine as meat additives.

2. Materials and Methods

2.1. Materials

Sweet lupine were purchased from local market.

2.2. Methods

2.2.1. Rheological Measurements of Lupine Samples

Samples of lupine at different moisture contents (15, 20, 25 and 30 %) and controlled temperatures (90, 95, 140, 145, 170 and 175°C) were studied. Samples were placed in a beaker and spindle numberHA-06 was used. Apparent viscosity of lupine samples were performed directly using (Brookfield Programmable DVIII Ultra Viscometer, Brookfield Eng. Labs. Inc., USA) equipped with a thermostatic water bath to regulate the sample temperature during measuring. Shear rate was calculated using the following equation (Brookfield Manual, 1998).

$$\gamma = [\frac{2\pi R_c^2}{60-(R_c^2-R_b^2}]rpm \quad (1)$$

Where, Rc, Container radius, (2.5cm)

Rb, Spindle radius, (0.15cm).

2.2.2. Determination of the Apparent Viscosity of Legumes

The screw and the barrel were modeled as two concentric cylinders with the inner cylinder (screw) rotating inside the stationary outer cylinder (barrel) Fig (1).

$$\mu = k\gamma^{n-1} \quad (2)$$

Where, μ, viscosity, Pa.s

K, consistency index constant

γ, shear rate, s^{-1}

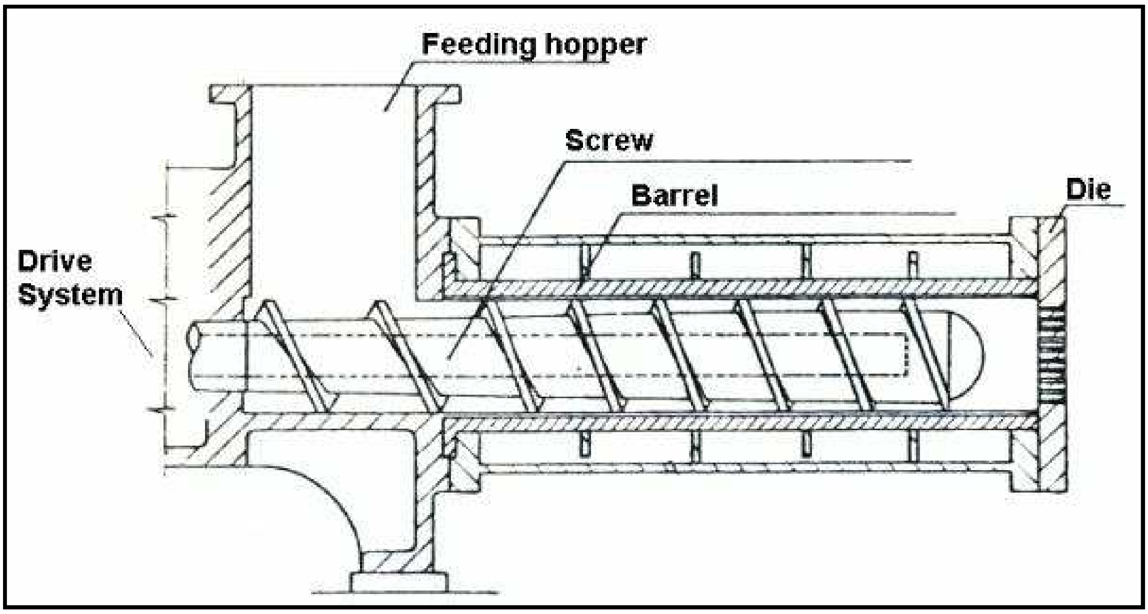

Figure 1. *Screw and barrel of single screw extruder.*

2.2.3. Shear Rates

Shear rate of the extruder screw channel is given by Equation:

$$\gamma = \frac{\pi.D.N}{60.h} \quad (3)$$

Where, γ, Shear rate in screw channel, s^{-1}

D, Screw diameter in mm,

N, Screw speed in rpm,

h, Channel depth in mm

2.2.4. Shear Stress

Shear stress in the extruder screw channel is given by Equation:

$$\tau = \mu \,.\, \gamma \quad (4)$$

Where, τ, is the shear stress, Pa

2.2.5. Determination of Volumetric Flow Rate for the Extruder

The single-screw extruder Fig. (2) relies upon drag flow to convey the fed material through the barrel of the extruder and develop the pressure through the three zones of extruder and the die area. In order for the product to advance along the barrel, it must not rotate with the screw. Drag flow in the extruder was calculated using equation for each of the three zones in extruder (12):

$$Q_d = \frac{\pi NDWH}{2} \quad (5)$$

The pressure flow is generated as the feed material was forced along the barrel of the extruder and through the restricted opening of the die. The pressure flow causes movement backwards down the extruder barrel, causing further mixing of the product (12):

$$Q_p = -\frac{WH^3P}{12\mu L} \quad (6)$$

$$P = \frac{2\mu VL}{H^2} \quad (7)$$

The combination of the two flows (Q_d and Q_p) gives the net flow of the material out of the die

$$Q = Q_d + Q_p \quad (8)$$

Where, Q, Extruder flow rate,
Qd, Drag flow rate in zone,
Qp, Pressure flow rate in zone, bar
D, Screw diameter in zone, m
H, Channel depth in zone, m
W, Channel width in zone, m
N, Rotational rate of screw, rpm
V, Linear velocity of screw, m/s
P, Pressure in zone, bar

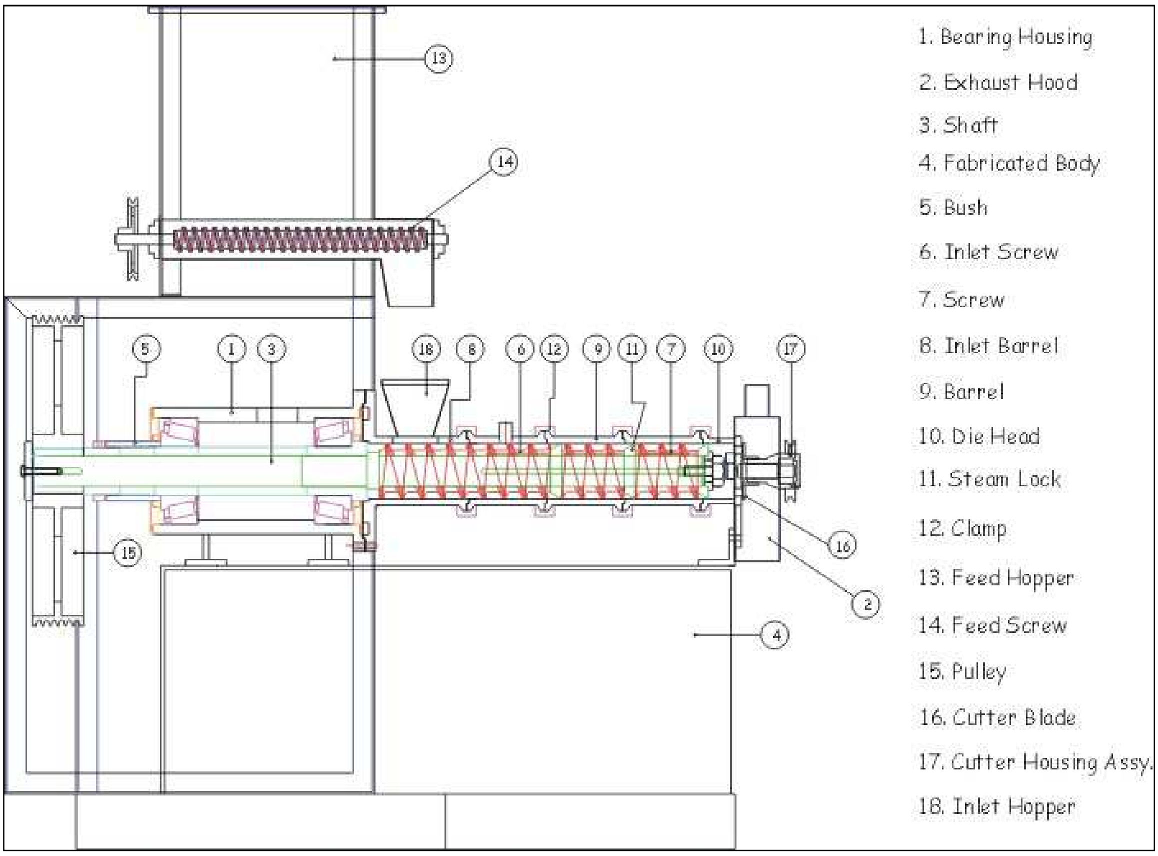

Figure 2. *Basic components of single screw extruder.*

3. Results and Discussion

3.1. Rheological Properties of Sweet Lupine at Different Temperature and Moisture Content in Single Screw Extruder

The effect of shear rate on the apparent viscosity of lupine samples were represented as shown in Figures (1-6) through different zones of extruder (90, 95 °C feeding zone, 140, 145°C kneading zone, and 170, 175°C cooking zone) at different moisture content (15, 20, 25 and 30%). The results observed that samples that contains moisture content (15, 20, 25 and 30%) at 90°C and 95°C exhibited non-Newtonian pseudoplastic behavior, the same trend was observed for samples that contain (25 and 30%) at 140°C and 145°C, as the apparent viscosity decreased with the increasing of shear rate, although the apparent viscosity decreased with increasing moisture content. The results fitted well to power law model equation:

$$\mu = k\gamma^{n-1}$$

$$\log\mu = \log k + (n-1)\log\gamma \quad (9)$$

Figures (3-8) showed samples that contains moisture content 15% at 140°C, (15 and 20%) at 145°C, (15 and 20%) at 170°C and (15, 20, 25 and 30%) at 175°C exhibited non-Newtonian dilatant behavior as the apparent viscosity increased with the increasing of shear rate. This may be due to the fact that at high temperatures the cross-linking reactions occurred, possibly some covalent bonds were formed at high temperature (13). Apparent viscosity decreased with increasing moisture content since moisture is usually the most effective extruder parameter influencing the rheological behavior of the melt for low and intermediate moisture extrusion. Since viscosity of a high moisture extruding system is considerably lower, viscous dissipation in such systems is less. Therefore, the energy required for working the melt in the screw channel would rely mostly on thermal input through the barrel walls rather than friction between molecules as previously discussed by [14].

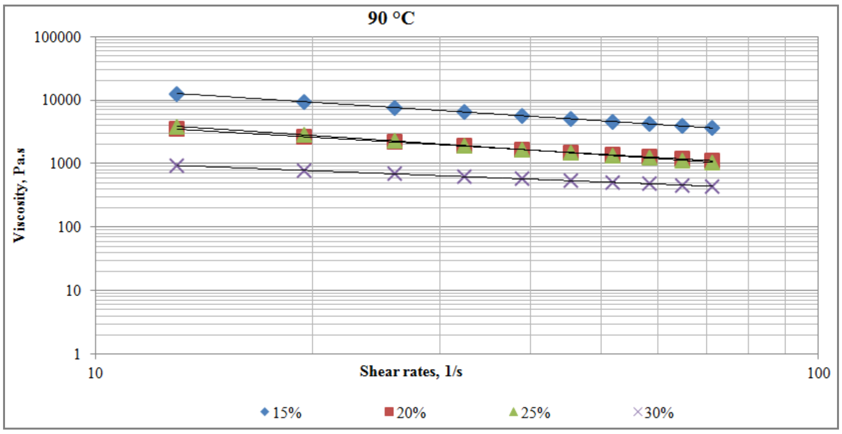

Figure 3. *A log-log plot of viscosity vs shear rate for lupine at different moisture contents in the feeding zone (90 °C).*

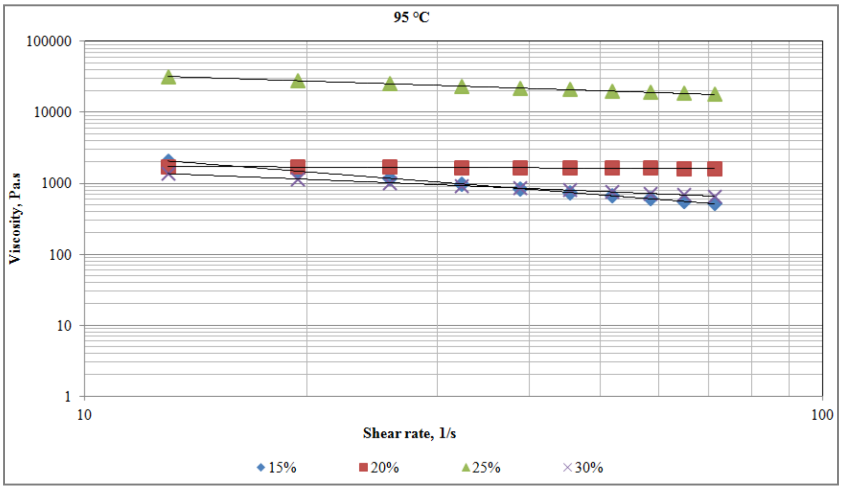

Figure 4. *A log-log plot of viscosity vs shear rate for lupine at different moisture contents in the feeding zone (95 °C).*

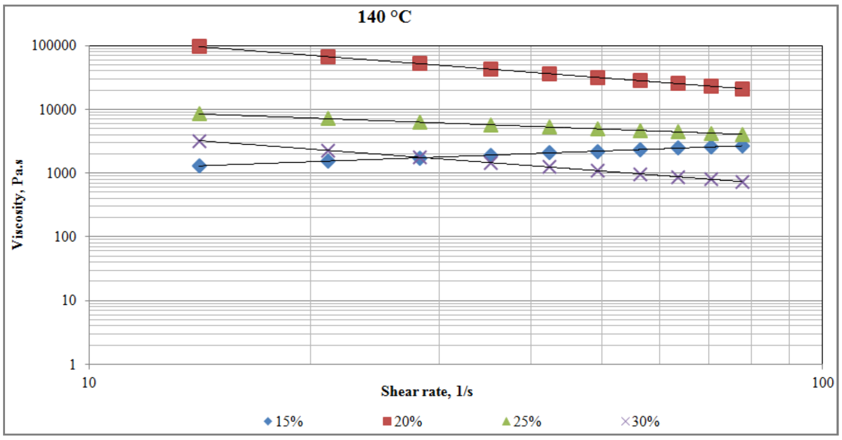

Figure 5. *A log-log plot of viscosity vs shear rate for lupine at different moisture contents in the kneading zone (140 °C).*

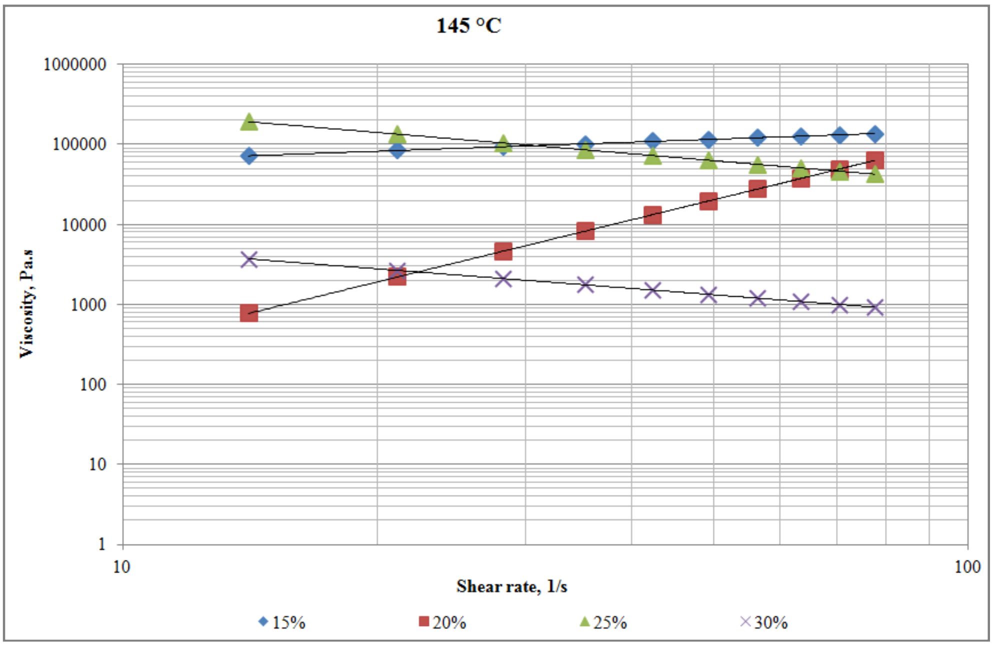

Figure 6. *A log-log plot of viscosity vs shear rate for lupine at different moisture contents in the kneading zone (145 °C).*

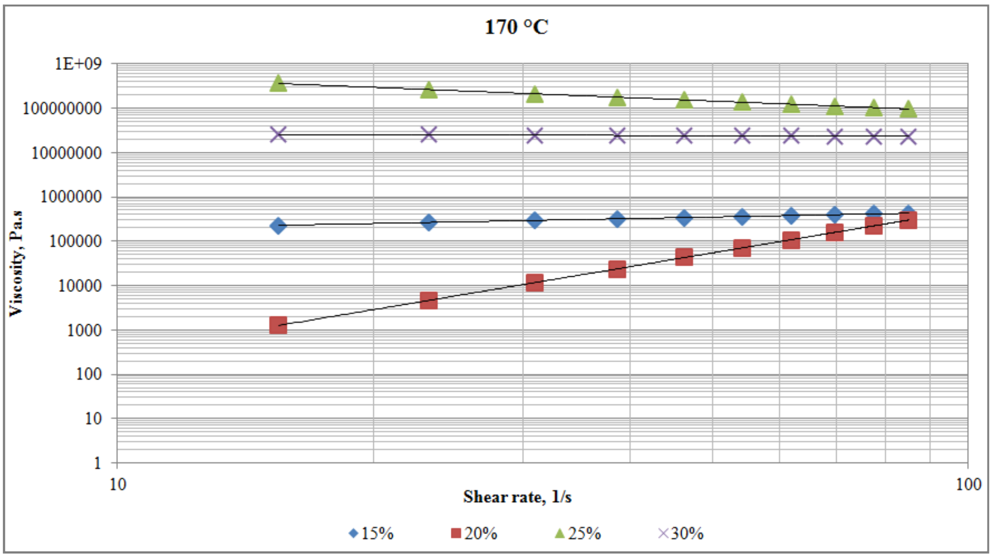

Figure 7. *A log-log plot of viscosity vs shear rate for lupine at different moisture contents in the cooking zone (170 °C).*

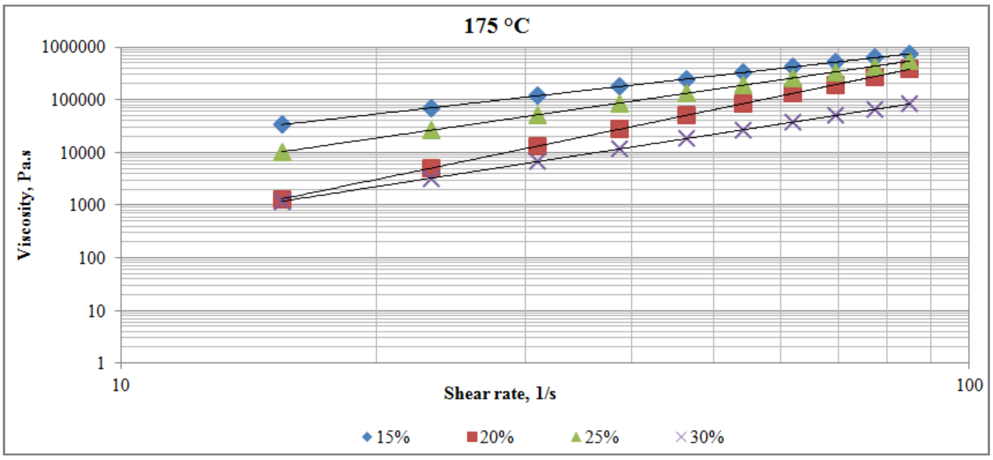

Figure 8. *A log-log plot of viscosity vs shear rate for lupine at different moisture contents in the cooking zone (175 °C).*

The changes in moisture content causes line shift through different zones in the extruder (feeding, kneading and cooking). This can be explained as a result of the interactions between the molecules that generally occur through the breaking and formation of hydrogen and other physico-chemical bonds, (15).

Table (1) presents the parameters obtained by fitting the power law for lupine samples at different moisture contents (15, 20, 25, and 30%) and temperatures (90, 95, 140, 145°C, 170°C and 175°C).

The screw diameter increased through three zones of extruder. The diameter in feeding zone was 7.1 cm, kneading zone was 7.4 cm, and cooking zone was 7.7 cm. From equation 2 and 3, it was found that the shear rate had directly proportional with screw diameter and inversely proportional with channel depth.

So in pseudoplastic behavior, the apparent viscosity decreased with increasing shear rate, and this behavior is useful in feeding zone, where the screw was the smallest. So, viscosity increased with decreasing shear rate. But in the kneading and cooking zones, the screw diameters were increased and the suitable behavior is dilatant in those zones. It was found that the best moisture content was 15% and 20%.

Table (1). *The values of (k) consistency and (n) behavior index for lupine samples at different moisture contents and temperatures.*

Temperature, °C	Power law parameters	Moisture content, %			
		15	20	25	30
90	K	8.200	1.90	2.7	2.8
	N	0.267	0.33	0.236	0.558
95	K	11.6	1.8	7.7	4.1
	N	0.185	0.962	0.655	0.571
140	K	4.1	150.6	218.6	303.1
	N	1.425	0.713	0.868	0.733
145	K	22.6	10.84	852.6	311.956
	N	1.375	1.579	0.614	0.885
170	K	8.431	1.191	6011.5	6303.2
	N	2.366	2.71	0.924	0.941
175	K	2.3	0.145	14.9	1.28
	N	2.815	3.325	2.321	3.093

3.2. Prediction of the Pressure at Different Temperature and Moisture Content in Single Screw Extruder

The pressure drop affected by the viscosity of the lupine at different moisture contents through different zones of extruder was presented in Figs (9-14). The results observed that viscosity increased very rapidly through different zones of extruder and decreased with increasing moisture content. Pressure drop increased with increasing temperature and moisture content, this may be due to that rapid rise in viscosity is one of the most significant changes in extruder, after the initial rise, viscosity starts to decline as the melt is further heated and mechanically sheared [16].

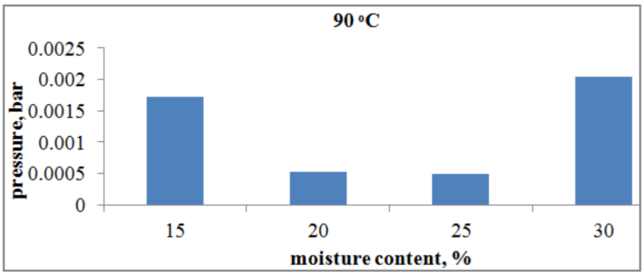

Figure 9. *The pressure drop at different moisture contents in the feeding zone (90 °C)*

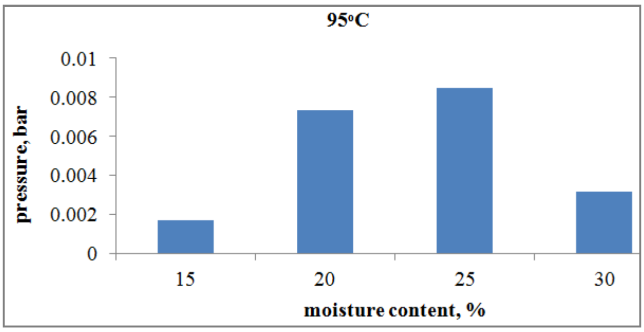

Figure 10. *The pressure drop at different moisture contents in the feeding zone (95 °C).*

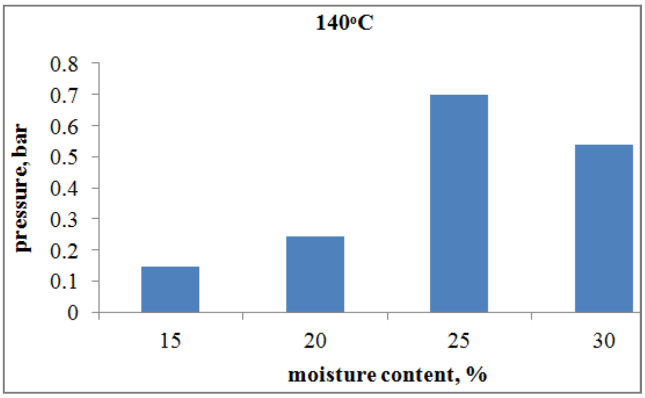

Figure 11. *The pressure drop at different moisture contents in the kneading zone (140 °C).*

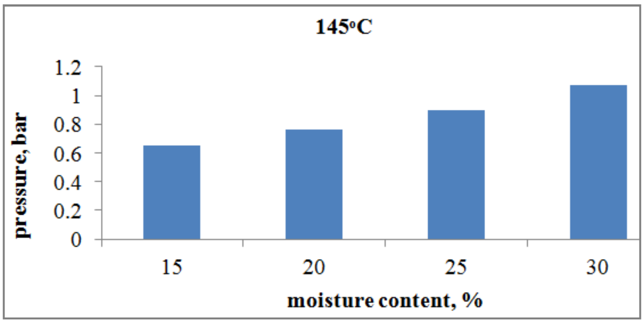

Figure 12. *The pressure drop at different moisture contents in the kneading zone (145 °C).*

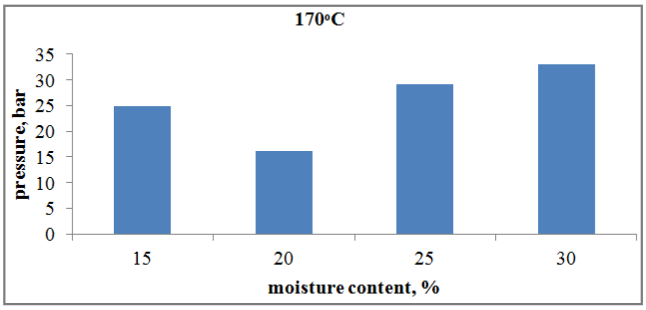

Figure 13. *The pressure drop at different moisture contents in the cooking zone (170 °C).*

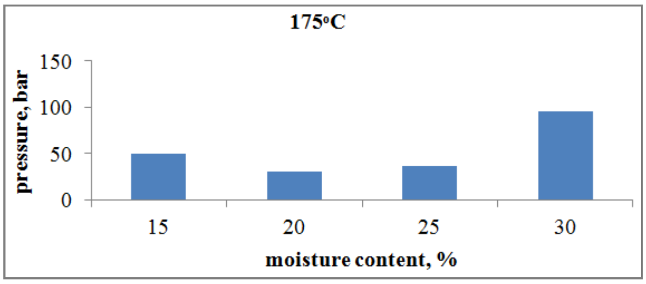

Figure 14. *The pressure drop at different moisture contents in the cooking zone (175 °C).*

4. Conclusion

The global trend of non-use of genetically engineered crops such as soybeans, so there is a direction to use other crops that contain high protein for the manufacture of meat additives as an example of extruded products. Sweet lupine contains high protein, so it can be used as meat additives by single screw extruder. The rheological properties of sweet lupine through single screw extruder to optimize the moisture content that must be used through extrusion process to produce meat additives. The results showed that moisture content (15, 20, 25 and 30%) at 90°C and 95°C and (25 and 30%) at 140°C and 145°C exhibited non-Newtonian pseudoplastic behavior. The moisture content 15% at 140°C, (15 and 20%) at 145°C, (15 and 20%) at 170°C and moisture content (15, 20, 25 and 30%) at 175°C exhibited non-Newtonian dilatant behavior, this may be due to denaturation of protein by the fact that at high temperatures the cross-linking reactions occurred, possibly some covalent bonds were formed at high temperature. Also, the results showed that the pressure drop increased with increasing temperature.

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