PHYSICAL AND MECHANICAL PROPERTIES OF FODDER BEET IN RELATED TO CUTTING PROCESS

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ABSTRACT

The aim of this research work was to determine the physical and mechanical properties of fodder beet that related to cutting process. The physical properties include dimensions, mass and volume of root. The mechanical properties of fodder beet root include static coefficient of friction (μ_s), Firmness (F_{ness}), shearing stress (τ) and shearing energy (Esc).

The μ_s was measured at different moisture contents of root (15, 25, 45, and 85% w.b.) with different friction surface (rubber, plywood, steel and plastic. The F_{ness}, τ and Esc were measured at different moisture contents of root and cutting region.

The results showed that the values of μ_s, F_{ness}, τ and Esc ranged from (0.413 to 0.886), (69.6 to 355.8 N), (0.189 to 0.967 MPa) and (3.31to16.92 mJ mm^{-2}) respectively. All mechanical properties were significantly affected by moisture content and cutting regions.

***Keywords**: Fodder beet, friction, firmness, shear, stress, and shearing energy.*

INTRODUCTION

Fodder beet (*Beta Vulgaris L.*) considered a good source of energy for animal feeding, palatability and digestibility. Fodder beet cultivation may help in overcoming the problem of animal feeding at the beginning of summer season but it still has a weak competitive ability against be seem as winter forage. However, increasing and expanding fodder beet can be realized by finding new and additional areas without changing the prevailing winter crop structure through intercropping with some winter crops (***Abou-Elela and Gadallah, 2012***).

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The increasing demand for animal proteins of the growing population in Egypt is handicapped through the shortage of the carbohydrate components in animal feeds. On the other hand, the horizontal expansion of new reclaimed areas requires the cultivation of crops offering a source for satisfying income to the farmers. Fodder beet can easily fulfill both aims (***Kassab et al., 2012***).

Fodder beet offers a higher yield potential than any other arable fodder crop and when grown under suitable conditions can produce almost 20 t ha^{-1} dry matter yield (***DAF, 1988***) and also yields more than 80 t ha^{-1} and this makes it popular in many countries like New Zealand, Germany, America, Australia, Syria and Egypt (***Shalaby et al., 1989***). It contains 10-15% dry matter and may yield 20 t ha^{-1} of dry matter in one harvest as compared to 13-15 t ha^{-1} from four cuts of grass (***Kiely et al., 1991***).

Knowledge of the physical and mechanical properties of fodder beet is necessary for the design of most equipment such as harvest and cutting. ***Ince et al. (2005***) stated that it was necessary to determine stem physico-mechanical properties such as bending and shearing stress and energy requirements for suitable knife design and operational parameters.

In order to estimate the harvest energy of each crop, physical and mechanical properties of the stem should be determined (***Yiljep and Mohammed, 2005***). Generally, the total shearing strength in harvest plants is an important plant characteristic for designing harvesters like combines and mowers. Shearing energy of the stem indicates how much energy is needed to cut the stem. The lesser is the strength, the more optimized will be energy consumption by the machine. A number of studies have been carried out to decrease shearing strength in different crops (***Announssamy et al., 2000***; ***Hirai, et al., 2002; Shaw and Tabil, 2007***).

Iwaasa et al. (1996) stated that shearing force denotes the required force when animals chew the forage, so it can be regarded as an indicator of feed quality. It is related to voluntary feed intake of ruminants when the plant is utilized as animal feed.

Nazari et al. (2008) found that the shearing stress and the shearing energy of alfalfa stems increased as the moisture content increased. ***Ince et al. (2005)*** found that the shearing stress and the specific shearing energy of sunflower stalk residue increased as the moisture content increased. The maximum shearing stress and specific shearing energy were 1.٠٧ MPa and 10.08 mJ mm^{-2}, respectively.

Chen et al. (2007) showed that shearing force was influenced by variety, moisture content, diameter, chemical composition, and harvesting date for three varieties of maize. Shearing force of maize stem increased with maize maturity, whereas forage quality decreased with increasing of shearing force.

The aim of this research was to investigate some physical and mechanical properties for fodder beet that related to cutting process.

MATERIAL AND METHODS

2.1 Sample preparation - Research plan

The fodder beet (Rota variety - Multi-embryos) was randomly collected from different farms from Kafr El-Sheikh Governorate - Egypt. After harvest the root samples were washed, marked and stored in jute bags in one place in cold storage conditions under roof (at the average temperature of 5 ^oC, relative humidity of 75%), as well as in a room (the average temperature of 20 ^oC, relative humidity of 55%).

The research was conducted in order to determine the static coefficient of friction, firmness, shearing stress and the shearing energy of fodder beet root as a function of moisture content and height regions. To determine the average moisture contents of the fodder stem on the test, the specimens gathered from the field were weighed and dried at 103° C for 24 h (***ASAE, 1999 a***) in the oven and reweighed. The experiments were conducted at a moisture content of 15%, 25%, 45% and 85% w.b.

The research was conducted in order to determine the static coefficient of friction, the firmness, the shearing stress and the specific shearing energy of fodder beet root as a function of moisture content. Moreover, the effect of different material surface on coefficient of friction and the effect of root region (upper, middle and lower) on the firmness, the shearing stress and the specific shearing energy were investigated. The value of independent variables discussed in the study is detailed in Table (1).

Table (1): Dependent and independent variables studied in the research.

Dependent variables	Independent variables	Values
- Friction Coefficient	Moisture content, % w.b.	15, 25, 45, 85 %
	Surface material	Rubber, plywood, steel, plastic,
- Firmness, N	Moisture content, % w.b.	15, 25, 45, 85 %
- Shearing stress, MP_a	Root region	Upper, middle, lower
- Shearing energy, mJ mm^{-2}		

2.2. Physical properties

2.2.1. Tuber dimensions

The fodder tuber, in terms of the two principal axial dimensions, that is (in cm): Diameter and length.

2.2.2. Tuber mass

The mass (*m*) of fodder tuber was recorded by using a digital balance, with an accuracy ±0. 1 g.

2.2.3. Tuber volume

In order to determine fruit volume (***V***) a simple technique which applies to large objects such as fruit and vegetables is the platform scale. The liquid volume is computed by determining the mass of the displaced water and dividing by the known density of the water. The mass of the displaced water is the scale's reading with the object submerged minus the mass of the container and water. Weight of the displaced water which will be used in the following expression to calculate volume (***Mohsenin, 1986***):

$$\text{Volume (cm}^3\text{)} = \frac{\text{Weight of displaced water (cm}^3\text{)}}{\text{Water density (g/cm}^3\text{)}} \qquad \textbf{(1)}$$

2.3. Mechanical properties of fodder beet

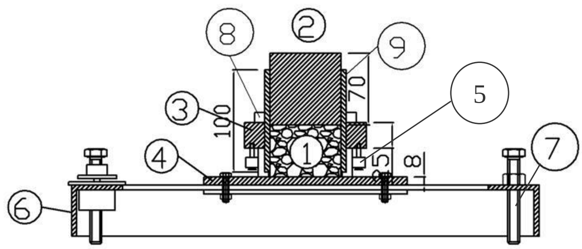
2.3.1. Static friction coefficient

Static friction coefficient of is the ratio of force required to start sliding the sample over a surface divided by the normal force, i.e. the weight of the sample (***Mohsenin, 1986***). The static coefficient of friction of fodder beet tuber against different materials, namely plywood, plastic, steel and rubber was determined with different moisture content for fodder beet root. The designed device by ***Ibrahim (2008)***, Fig. (1) was used to determination of static friction force. The static coefficient of friction was calculated as follows:

$$\mu_S = \frac{F_T - F_E}{W} \qquad \textbf{(2)}$$

Where

μ_S	:	Static friction coefficient;
F_T	:	Force required starting motion of filled wooden frame, N;
F_T	:	Force required to start motion of empty wooden frame, N;
W	:	Weight of the sample, N.



Dims. in mm

1-Sample	**2**- Piston	**3**- Carriage
4- Sliding surface	**5**- Rolling wheels	**6**- Base
7- Adjustable screw	**8**- Adjustable nut	**9**- Cylinder

Fig. (1): The designed device for measuring the friction force.

2.3.2. Firmness

The firmness (F_{ness}) of tuber is the measurements of root skin resistance to puncture (***Mohsenin et al., 1986***). Firmness was measured by a digital force gauge (NIDEC-SHIMPO-CORPORATION, JAPAN) supported by the stand (Fig. 2). An 8 mm diameter probe with a radius of curvature of 5 mm was used as referred by ***Peng and Lu (2006) and Jha et al. (2010)***. The firmness was measured in three positions: upper, middle and lower tuber with different moisture content for fodder beet root. Roots were placed on the tester base. All the measurements were done keeping perpendicular direction of the test plunger. In the compression process the root skin became deformed until the moment of its puncture. The maximum value of force F (N) causing puncture of the root skin was recorded**.**

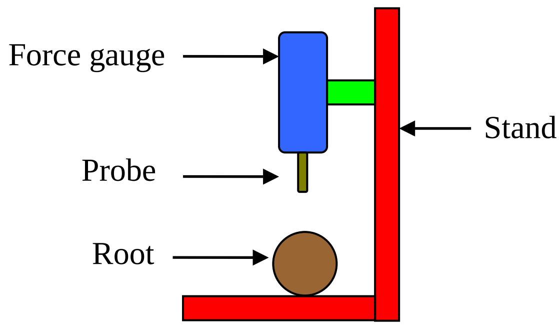


Fig. (2): Test device used to measure the firmness

2.3.3. Shearing stress

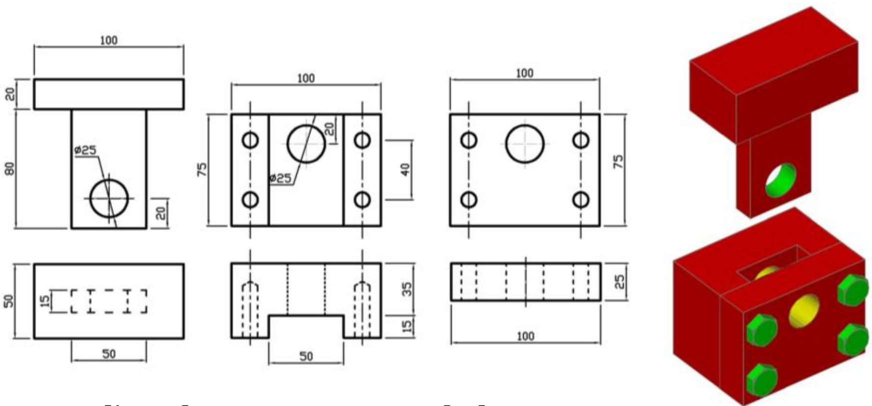
The ultimate shear strength is maximum shear stress that can be sustained by a material before rupture caused by a flexural load. This test carried according to (***ASAE, 1999 b***). The test carried out by using shear testing fixture that consisting a double shear block arrangement.

2.3.3.1. Sample preparing

Cylindrical samples with a diameter of 25 mm were cut from the centre fodder beet using a cork borer and then trimmed to a height of 25 mm. The core samples were taken perpendicular to the major axis of the tubers and from the upper, middle and lower region with different moisture content for fodder beet root.

2.3.3.2. Shearing test

In order to determine the shearing force of fodder beet, an experimental shearing apparatus was manufactured. The shear strength was measured in double shear using a shear box (Fig. 3) consisting essentially of to fixed parallel hardened steel plates 15 mm apart, between which a third plate can slide freely in a close sliding fit. Hole diameter of 25 mm was drilled through the plates to accommodate. Shear force was applied to the cylinder specimens by mounting the shear box. The test was carried out between the standard Instron stainless steel polished platens of a model Instron Universal Testing Machine (Instron, USA) using a 1 kN load cell.



Loading plate **Supported plates**

Fig. (3): The shear force measuring device.

The test was carried out at room temperature (20–21^{o}C). Shear force was applied to the specimens by mounting a shear box in the compression testing machine. The sliding plate was loaded at a rate of 10 mm min^{-1} and, as for the shear test. The load–displacement behaviour was recorded with Instron recorder obtained up to the specimen failure. The shear failure stress (or ultimate shear strength) was calculated from the expression:

$$\tau = \frac{F}{2A} \qquad \textbf{(3)}$$

Where;

τ : Shear stress, MP_a

F : Shear force at failure in N,

A : Initial cross – sectional area in mm^2.

2.3.4. Shearing energy

The shearing energy was calculated by using the integrating the area under the shear force and displacement curve (***Chattopadhyay and Pandey, 1999; Chen et al., 2004***). For this case, the area under the curve was divided into the basic geometrical shapes and the calculation of the area under the curve was made with the help of the force and displacement data by using a standard computer program (Microsoft Excel 2003). The specific shearing energy was found as:

$$E_{SC} = \frac{E_S}{A} \quad \textbf{(4)}$$

Where;

Esc : specific shearing energy, mJ mm^{-2}

Es : shearing energy in mJ,

A : Initial cross – sectional area in mm^2.

2.4. Statistical analysis

Statistical analysis was carried out using a randomized complete block procedure of the MStat-c statistical package. Duncan multiple range comparison were used to identify means that were different at probabilities of 5 % (***Snedecor and Cochran 1976***).

RESULTS AND DISCUSSIONS

3.1. Physical properties of fodder beet

Some physical properties of fodder beet root (length, diameter, mass and volume) are shown in table (2).

Table (2) shows the dimensions of fodder beet root. The mean root length was 27.3 cm, mean root diameter was 23.7 cm, mean mass was 3870 g and mean volume was 3465 cm^3.

Table (2): Some physical properties of fodder beet tuber.

	Max.	Min.	Mean	Stand. Dev.
Length (cm)	28.6	25.5	27.3	1.4
Diameter (cm)	24.5	22.8	23.7	0.8
Mass (g)	4234	3518	3870	332.7
Volume (cm^3)	3636	2858	3465	361.5

3.2. Mechanical properties of fodder beet

The mechanical properties of fodder beet included static coefficient of friction (μ), firmness (F_{ness}), shearing stress stress (τ) and shearing energy (E_{SC}).

3.2.1. Static coefficient of friction

Figure (4) shows the static coefficients of friction for root on galvanized steel, wood, steel and plastic surfaces at different moisture contents. It was observed that the static coefficient of friction increased linearly with the increase of the moisture content of root on test surfaces. While the highest value (0.886) for the static coefficient of friction was recorded for rubber surface at 85 % moisture content, the lowest value (0.413) was recorded for plastic surface at 15 % moisture content. ***Beyhan et al. (1994)*** expressed that the relationship between friction surface and moisture content for granular agro-materials are important in terms of the static coefficient of friction. Similar results on effect of grain moisture on static coefficient of friction have been reported by ***Kibar et al. (2010)*** for rice.

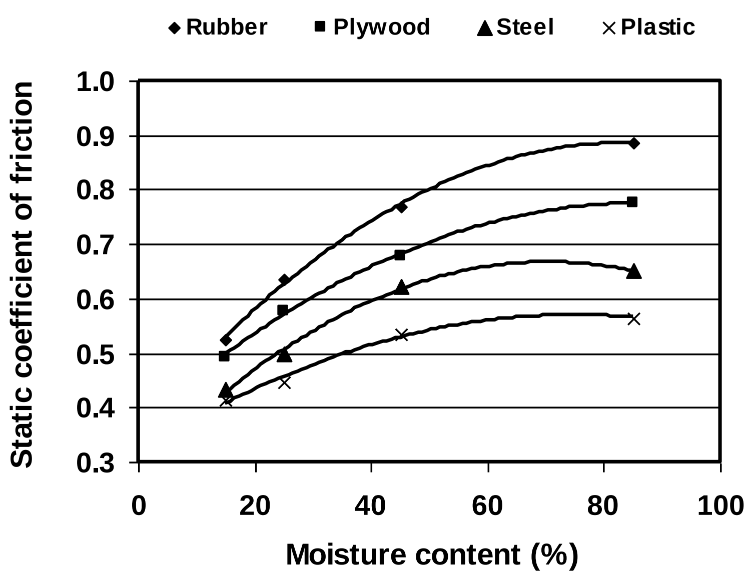


Fig. (4): The effect of moisture content and surface material on friction coefficient of fodder beet.

The values of the static coefficient of friction were significantly affected by moisture content and surface material at the 0.05 probability level as shown in table (3).

Table (3): The effect of moisture content and surface material on friction coefficient of fodder beet.

Moisture content (w.b. %)	Static coefficient of friction	Surface	Static coefficient of friction
15	0.466 [d]	**Rubber**	0.703 [a]
25	0.540 [c]	**Plywood**	0.631 [b]
45	0.650 [b]	**Steel**	0.551 [c]
85	0.719 [a]	**Plastic**	0.490 [d]
F-test	*	**F-test**	*

NS and *: Non-significant, significant at P > 0.05, respectively. Means with the same letters are not significantly different at P<0.05.

The results of the regression analysis carried out between the coefficient of friction and moisture content for all the structural surfaces tested with their corresponding correlation coefficients are presented in table (4).

Table (4): Regression equations for predicting coefficient of friction from moisture content for fodder beet root.

Surface	Regression equation	(R^2)
Rubber	$\mu_s = -8 \times 10^{-5} M_C^2 + 0.0127 M_C + 0.3557$	0.998
Plywood	$\mu_s = -5 \times 10^{-5} M_C^2 + 0.0094 M_C + 0.3686$	0.998
Steel	$\mu_s = -8 \times 10^{-5} M_C^2 + 0.0109 M_C + 0.2814$	0.996
Plastic	$\mu_s = -5 \times 10^{-5} M_C^2 + 0.0068 M_C + 0.316$	0.991

μ_s = coefficient of friction; M_C = Moisture content (w.b. %).

3.2.2. Firmness

Firmness varied between 69.6 and 355.8 N at different moisture content and regions. Figure 5 presents an increasing relationship between the firmness and moisture content for all regions as reported by ***Rashidi* et al., 2010**. The highest firmness was obtained as 355.8 N in the upper region at a moisture content of 85 %, while the lowest firmness was found to be 69.6 N in the lower region at a moisture content of 15 %. The firmness decreased towards the lower regions of the root as shown in Fig. (5).

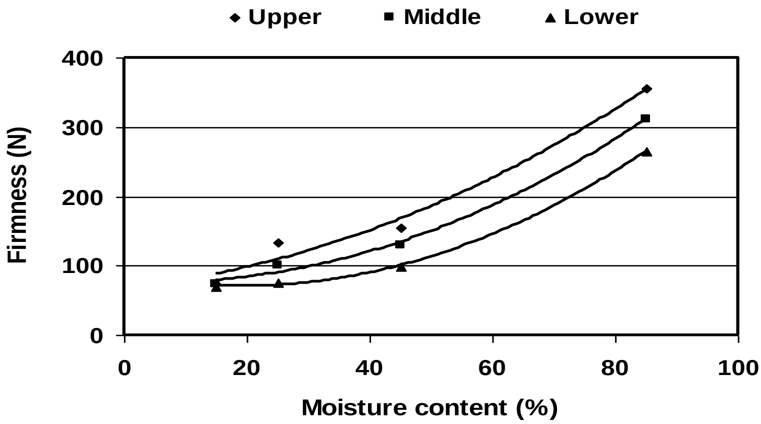


Fig. (5): The effect of moisture content on firmness according to the regions.

In addition, according to the Duncan's multiple range tests, the values for the firmness in the lower region were found to differ from those for the middle and upper regions. The relationship between moisture content and firmness can be expressed by the following equation (table 5).

Table (5): Regression equations for predicting firmness from moisture content for fodder beet root.

Region	Regression equation	(R^2)
Upper	$F_{ness} = 0.0290\ M_C^2 + 0.8896\ M_C + 68.765$	0.974
Middle	$F_{ness} = 0.0371\ M_C^2 - 0.4033\ M_C + 77.378$	0.982
Lower	$F_{ness} = 0.0447\ M_C^2 - 1.7033\ M_C + 86.782$	0.975

F_{ness} = Firmness (N); M_C = Moisture content (w.b. %).

The values of the firmness was significantly affected by moisture content and cutting regions at the 0.05 probability level as shown in tables (6) and (7).

Table (6): The effect of moisture content and surface material on friction coefficient of fodder beet.

Moisture content (w.b. %)	Firmness (N)	Shearing stress (MPa)	Shearing energy (mJ mm^{-2})
15	72.6 [d]	0.197 [d]	3.45 [d]
25	103.3 [c]	0.281 [c]	4.91 [c]
45	127.8 [b]	0.347 [b]	6.08 [b]
85	310.9 [a]	0.845 [a]	14.79 [a]
F-test	*	*	*

NS and *: Non-significant, significant at P > 0.05, respectively. Means with the same letters are not significantly different at P<0.05.

Table (7): The effect of region on firmness, shearing stress and shearing energy.

Cutting region	Firmness (N)	Shearing stress (MPa)	Shearing energy (mJ mm^{-2})
Upper	179.8 ^{a}	0.489 ^{a}	8.55 ^{a}
Middle	153.9 ^{b}	0.418 ^{b}	7.32 ^{b}
Lower	127.2 ^{c}	0.346 ^{c}	6.05 ^{c}
F-test	*	*	*

NS and *: Non-significant, significant at P > 0.05, respectively. Means with the same letters are not significantly different at P<0.05.

3.2.3. Shearing stress

Shearing stress varied between 0.189 and 0.967 MPa at different moisture content and regions. Figure 6 presents an increasing relationship between the shearing stress and moisture content for all regions as reported by most previous researchers (***McRandal and McNulty, 1980; Annoussamy et al., 2000***). The highest shearing stress was obtained as 0.968 MPa in the upper region at a moisture content of 85 %, while the lowest shearing stress was found to be 0.189 MPa in the lower region at a moisture content of 15 %. The shearing stress decreased towards the lower regions of the root as shown in Fig. (6). The values of the shearing stress was significantly affected by moisture content and cutting regions at the 0.05 probability level as shown in tables (6) and (7).

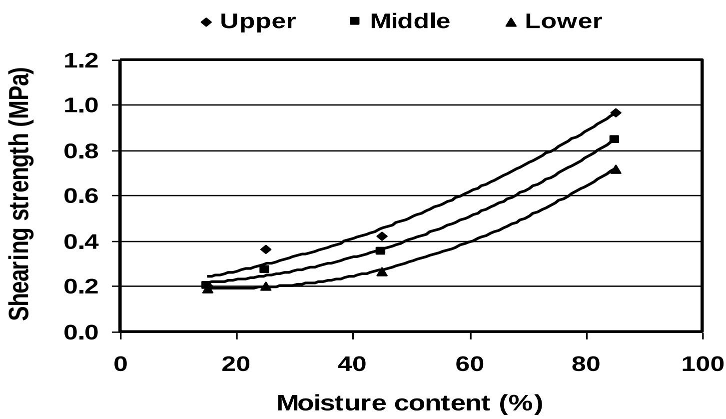


Fig. (6): The effect of moisture content on shearing stress according to the regions.

In addition, according to the Duncan's multiple range tests, the values for the shearing stress in the lower region were found to differ from those for the middle and upper regions. The relationship between moisture content and shearing stress can be expressed by the following equation (table 8):

Table (8): Regression equations for predicting shearing stress from moisture content for fodder beet root.

Region	Regression equation	(R^2)
Upper	$\tau = 0.00008\ M_C^2 + 0.0024\ M_C + 0.1869$	0.978
Middle	$\tau = 0.00010\ M_C^2 - 0.0011\ M_C + 0.2103$	0.995
Lower	$\tau = 0.00010\ M_C^2 - 0.0046\ M_C + 0.2358$	0.999

τ = Shear stress (MPa); M_C = Moisture content (w.b. %).

3.2.4. Specific shearing energy

The specific shearing energy requirement increased quadratic (second-order) with increases in the moisture content for all regions (Fig. 7). This effect of moisture content was also reported by ***Annoussamy et al. (2000)*** for wheat straw and by ***Chen et al. (2004)*** for hemp stalk. The values of shearing energy varied from 3.31 to 16.92 mJ mm^{-2} in low moisture contents had lowest values and high moisture contents had highest values. The reason for this difference may be expressed due to the viscous damping effect of moisture as reported by ***Persson (1987***). The specific shearing energy also decreased towards the lower regions. Its values varied between 3.54 –16.92, 3.51–14.83, and 3.54 –16.92 mJ mm^{-2} for the upper, middle and lower regions, respectively, at the different moisture contents studied (Figure 8). It was greater in the upper regions because of the accumulation of more mature fibers in the root. The values of the shearing energy was significantly affected by moisture content and cutting regions at the 0.05 probability level as shown in tables (6) and (7).

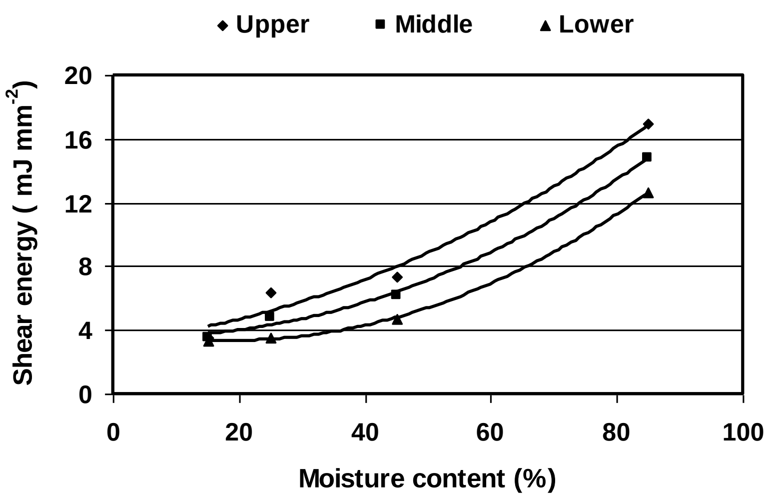


Fig. (7): The effect of moisture content on specific shearing energy according to the regions.

According to the Duncan's multiple range test results, these values are different from each other for the distinct root regions. The relationship between moisture content and shearing energy can be expressed by the following equation in table (9):

Table (9): Regression equations for predicting specific shearing energy from moisture content for fodder beet root.

Region	Regression equation	(R^2)
Upper	$E_{SC} = 0.0014\ M_C^2 + 0.0423\ M_C + 3.2705$	0.978
Middle	$E_{SC} = 0.0018\ M_C^2 - 0.0192\ M_C + 3.6798$	0.995
Lower	$E_{SC} = 0.0021\ M_C^2 - 0.0810\ M_C + 4.1274$	0.999

E_{SC} = Specific shearing energy (m J mm^{-2}); M_C = Moisture content (w.b. %).

CONCLUSION

The obtained results of physical and mechanical properties fodder beet root can be summarized as follows:

1. Static coefficient of friction varied between 0.413 and 0.886 at different moisture content and friction surfaces.
2. The values of the static coefficient of friction were significantly affected by moisture content and surface material.

3. Firmness varied between 69.6 and 355.8 N at different moisture content and cutting regions.
4. Shearing stress varied between 0.189 and 0.967 MPa at different moisture content and cutting region.
5. The shearing energy varied from 3.31 to 16.92 mJ mm^{-2} at different moisture content and cutting region.
6. All studied mechanical properties increased with increasing moisture content.
7. The values of the firmness, Shearing stress and shearing energy were significantly affected by moisture content and cutting regions.

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الملخص العربى

الخواص الطبيعية والميكانيكة لبنجر العلف والمتعلقة بعملية القطع

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يهدف هذا البحث إلى تقدير الخواص الطبيعية والميكانيكية لجذور بنجر العلف (صنف روتا) المنزرع في مصر، لما تمثله هذه الخواص من أهمية في عمليات الحصاد والتداول والتقطيع، لمعرفة متطلبات عملية تقطيع بنجر العلف لاستخدام كعلف للحيوان.

وقد تم تقدير كل من الخواص البعدية للدرنة, حجم الدرنة, كتلة الدرنة, وأيضا الخواص الميكانيكية للدرنة مثل معامل الاحتكاك, معامل الصلابة, إجهاد القص, الطاقة اللازمة للقص. وذلك مع محتوى رطوبى مختلف (١٥، ٢٥، ٤٥، ٨٥ % على اساس رطب). ومعامل الاحتكاك مع أسطح مختلفة (المطاط، الخشب، الحديد، البلاستيك)، معامل الصلابة, إجهاد القص, الطاقة اللازمة للقص خلال مناطق القطع المختلفة من درنة بنجر العلف.

و قد بينت الدراسة ما يلي:

١. توجد فروق معنوية بين رطوبة بنجر العلف والخصائص الميكانيكية: معامل الاحتكاك, معامل الصلابة, إجهاد القص, الطاقة اللازمة للقص.

٢. وجد أن معامل الاحتكاك, معامل الصلابة, إجهاد القص, الطاقة اللازمة للقص تزيد بزيادة المحتوى الرطوبى.

٣. معامل الاحتكاك يترواح من ٠,٤١٣ إلى ٠,٨٨٦، حيث كانت القيمة الصغرى كانت مع المحتوى الرطوبى ١٥ % والسطح البلاستيكى، والقيمة العليا كانت مع المحتوى الطوبى ٨٥% والسطح المطاطى.

٤. معامل الصلابة يترواح من ٦٩,٦ إلى ٣٥٥,٨ نيوتن، حيث كانت القيمة الصغرى مع المحتوى الرطوبى ١٥ % ومنطقة القطع السفلية، والقيمة العليا كانت مع المحتوى الطوبى ٨٥% ومنطقة القطع العلوية.

٥. اجهاد القص يترواح من ٠,١٨٩ إلى ٠,٩٦٧ ميجا بسكال، حيث كانت القيمة الصغرى مع المحتوى الرطوبى ١٥ % ومنطقة القطع السفلية، والقيمة العليا كانت مع المحتوى الطوبى ٨٥% ومنطقة القطع العلوية.

٦. طاقة القص تترواح من ٣,٣١ إلى ١٦,٩٢ مللى جول مم$^{-٢}$، حيث كانت القيمة الصغرى مع المحتوى الرطوبى ١٥ % ومنطقة القطع السفلية، والقيمة العليا كانت مع المحتوى الطوبى ٨٥% ومنطقة القطع العلوية.

٧. تم التوصل الي معادلات رياضية للتنبأ بالقيم المختلفة للخواص الميكانيكية لبنجر العلف مع المتغيرات المختلفة تحت الدراسة.

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