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CONVENTIONAL COEFFICIENT OF ELASTICITY FOR SUGAR BEET ROOTS*

M. Bzowska-Bakalarz

Institute of Agricultural Mechanization, University of Agriculture, Głęboka 28, 20-612 Lublin, Poland

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A b s t r a c t. One of the more important mechanical characteristics of sugar beet roots is the conventional coefficient of elasticity. It is a modulus describing elasticity - a basic parameter classifying quality of raw material that is strictly connected with the tissue turgor. A static experiment on compression was carried out using Instron testers on a range of sugar beet varieties grown with differentiated doses and types of nitrogen fertilizers, and tested in differentiated periods. The present studies were conducted in 5 stages, and at each of them the influence of different factors on the values of the conventional elasticity coefficient obtained was considered. The conventional elasticity coefficient does not belong to the variety characteristics of sugar beet roots. Influence of the nitrogen type and dose depended on meteorological conditions within the vegetation period and during storage root. With the increase in the degree of wilting (z) the conventional coefficient of elasticity lower. The values of the elasticity coefficient are significantly dependent on the alignment of bundles of sieve tissue in relation to the direction of force application, and on the type of tissue. Coefficients obtained for the speeds higher than 10 mm/min should distinguished and called instantaneous.

K e y w o r d s: sugar beet, root, coefficient of elasticity

INTRODUCTION

One of the more important mechanical characteristics of sugar beet is the conventional coefficient of elasticity [1-5, 11]. It is a modulus describing elasticity - a basic parameter classifying quality of raw material that is strictly connected with the tissue turgor. It is also important from the point of view of cutrag transportation in extractors [2-5,10,11].

MEASUREMENT SCOPE AND METHODS

A static experiment on compression was carried out in the Institute of Agrophysics of the PAS using Instron 1253 and 6022 testers on a range of sugar beet varieties grown with differentiated doses and types of nitrogen fertilizers, and tested in differentiated periods with 10 repetitions for each of the the study combinations. The present studies were conducted in 5 stages, and at each of them the influence of different factors on the values of the conventional elasticity coefficient obtained was considered. In order to estimate variability *n* the distribution of the coefficient values in roots, the studies were carried out in three measuring zones differing in their position in the root and in the alignment of the sieve tissue [1].

During the first stage of the present studies (period 1981-1983) the aim was to evaluate mechanical parameters of the fresh root tissue. The cylindrical samples (length and diameter: 20 mm) were compressed between two parallel plates [2]. Conventional coefficient of elasticity was then calculated from the $F(\Delta l)$ in the range of forces at which the curve did not appear as a non-linear one; linearity of the curve can be seen close to the limit of biological resistance (the breaking point), and the forces close to it. The values of E_U coefficient were determined according to the concept of the secant coefficient for compressing forces

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experimentally determined at the upper value of the force F_0=490.5 N.

At the second stage of the experiment (1986) the study material also contained the roots stored for one and two months. The conventional coefficient of elasticity was then calculated at the experimentally chosen force F_0=392.4 N.

During the third stage (1988) the scope of the study was narrowed to one sugar beet variety, but coefficient of elasticity of the plant roots grown at various types and doses of nitrogen fertilizers were determined. Various speeds of deformation were applied in order to estimate, at least approximately, the speed range at which the compression test could be treated as static. In the I and II study period the elasticity coefficient was determined for the force of F_0=400 N, and in the III period, since the value of breaking stresses was low, it was calculated at the force F_0=250 N. The fourth stage was additional verification results of experiment using Zwick 1445 tester [2].

In the fifth study period (1990) a static compression trail was carried out on free samples and samples placed in cylinders (in order to estimate the Poisson coefficient) [2]. The use of cylinders eliminated expansion of samples sideways, which created conditions for uniaxial deformations in the state of triaxial stress application [2]. The values determined were as follows: conventional coefficient of elasticity E_U, edometric coefficient of elasticity E_e. The E_U and E_e coefficients were determined from the $F(\Delta l)$ curve gradient in the force range from 0 N to 400 N (free samples at the I and II stage, samples in cylinders at the II stage), and in the range 400-1000 N (samples in cylinders at the I study stage), at which no non-linearity of function is observed. The elasticity coefficient determined for the samples in cylinders (triaxial stress conditions) does not meet the values of elasticity coefficient for free samples. The former represents rather an edometric equivalent of the compressibility that is determined in edometers for the studies on soil [6].

SUMMARY OF RESULTS

During the compression trials the course of the relation $\delta(\Delta l)$ is similar to the course of the same relation in elastic body. For that reason it is possible to calculate conventional elasticity coefficient describing the relation between stress and root tissue deformation with adequate approximation (Table 1).

The conventional elasticity coefficient E_U does not belong to the variety characteristics of sugar beet root. Nitrogen dose in fertilizers influenced the level of the conventional elasticity coefficient only at the II stage of this experiment (fresh roots); when at the highest level of nitrogen fertilization with ammonia nitrate lower values of the coefficient were observed. At the III stage of this experiment (1988) a significant influence of the nitrogen type and dose on the coefficient values was noted only in the case of roots stored for 2 months. The highest coefficient was noted in plants fertilized with urea at the dose of 140 kg/ha. With the increase in the degree of wilting (z) the conventional coefficient of elasticity increased. Roots stored for 1 month showed the coefficient values lower (from 4 to 40%) than fresh roots.

At the III study period (roots stored for 2 months) the values of coefficient were even lower because of the low resistance of wilted roots (z=18%). The year 1986 was exceptional in this respect, as in this year due to the very good conditions of storage (balanced degree of root wilting: from 3.8 to 6%) no significant differences in the values of breaking stresses was recorded, and the stored roots were characterised by similar coefficient values as fresh roots.

The values of the elasticity coefficient are significantly dependent on the alignment of bundles of sieve tissue in relation to the direction of force application (zone A and B), and on the type of tissue (zone C). The highest value of the elasticity coefficient was noted for the samples collected from the bottom part of the root (zone C), a lower one the A zone, and the lowest in the B zone. At the III, and IV study stage differences between at the A and B zones were blurred, but the tendency for a

Table 1. Conventional coefficient of elasticity E_U (MPa)

Study object		Average E_U (MPa)			LSD (MPa)	The estimation of error
I Stage of investigation						
Variety	AJ 3	10.55				
	PN Mono 1	10.72			-	
	PS Mono 4	10.39				
Fertilization N (kg/ha)	160	10.67				
	280	10.43			-	S_e=1.121 MPa
Zone	A	10.51				w=11.9%
	B	9.57	•0.94		0.38	
	C	11.58	•2.01			
Years	1981	10.45				
	1983	10.65			-	
Year 1993 (Höppler consistometer investigation)						
Variety	AJ 3	8.59				
	PN Mono 1	8.94			-	
	PS Mono 4	9.12				
Fertilization N (kg/ha)	160	8.87				S_e=1.415 MPa
	280	8.89				w=15.9%
Zone	A	8.86 }				
	B	8.34 }				
	C	9.44	•0.84			
II Stage of investigation						
Variety	AJ Polycama	11.51			-	
	PN Mono 1	11.43				
Fertilization N (kg/ha)	0	11.71				
	120	11.61			0.34	
	280	11.09	•0.57			
Zone	A	11.39				S_e=1.405 MPa w=12.2%
	B	10.31	•1.08	•1.33	0.34	
	C	12.72	•2.41			
Study date	I	11.57				
	II	11.15	•0.42		0.34	
	III	12.69	•0.54			
III Stage of investigation						
Zone	A	9.81 }				
	B	9.51 }			0.35	
	C	10.44	•0.84			
Fertilization N (kg/ha)	0	10.12				
	140 Gk	9.69			-	
	140 M	9.96				S_e=1,071 MPa
	260 Gk	9.69				w=10,8%
	260 M	10.15				
Study date	I	9.92			-	
	II	9.91				
Speed v_b (mm/min)	10	9.64			0.24	
	300,0	10.20	•0.84			

T a b l e 1. Continuation

Study object		Average E_U (MPa)		LSD (MPa)	The estimation of error
		Roots stored for 2 months			
Zone	A	8.359			
	B	8.925		-	
	C	8.802			
Fertilization N	0	9.058			S_e=1.503 MPa
(kg/ha)	140 Gk	6.681	•	1.076	w=17.2%
	140 M	10.394	•		
	260 Gk	7.906			
	260 M	9.437			
Speed v_b	10	8.523			
(mm/min)	300.0	8.868	-		
Zone	A	9.11			
	B	8.73		0.56	S_e=1.055 MPa
	C	9.45	•0.72		w=11.6%
Study date	I	9.54	•0.89		
	II	8.65		0.38	

Study object		I period		II period		III period	
Speed	0.5	9.336		7.641		6.51	
(mm/min)	2.0	9.158		7.846	•0.354	5.54	
	10.0	9.739		9.097	•0.903	5.61	•1.86
	300.0	9.921		10.00		7.74	
	LSD (MPa)		-		0.796		1.472
	S_e (MPa)		1.192		0.914		1.505
	w %		12.5		9.4		23.6

Study object		Average E_U (MPa)		LSD (MPa)	The estimation of error
		IV Stage of investigation			
Zone	A	9.21			
	B	8.71		1.00	S_e=1.286 MPa
	C	9.54			w=14.1%
Study date	I	11.62	•4.94	0.66	
	II	6.68			
		V Stage of investigation			
Zone	A	9.41			
	B	8.68		1.00	S_e =1.250 MPa
	C	10.23	•1.185		w=11.8%
Study date	I	9.45	•2.46	1.50	
	II	11.91			
		E_e			
Zone	A	52.73	•2.46	7.02	
	B	59.87			S_e=9.23 MPa
	C	59.11			w=26.1%
Study date	I	38.39	•37.7	4.77	
	II	76.09			

T a b l e 1. Continuation

Study object		The compression coefficient G (MPa)	Volumetric coefficient K (MPa)
Zone	A	3.220	40.111
	B	1.477	46.213
	C	3.505	41.687
Study date	I	3.257	31.818
	II	4.036	80.364

• - significant difference, LSD - the least significant difference at α=0.05, S_e - standard deviation for error.

lower value of the coefficient in the B zone when compared to the A zone was preserved.

One of the typical rheological phenomena is the influence of the deformation speed on the elasticity coefficient. There are instantaneous coefficient (obtained at high speed) and relaxing coefficient (at the speeds close to 0). Conventional coefficient of elasticity for fresh roots differed significantly in relation to deformation speeds, but the tendency: the higher the speed - the higher the coefficient, was preserved. An increase in the degree of wilting up to 14.5% (II study period) resulted in the coefficients obtained at low speeds (0.5, 2.0 mm/min) lower, at the speed of 300 mm/min - higher. For the wilted roots (III study period coefficients obtained at the speed levels of 0.5, 2.0, 10 mm/min did not differ significantly, and were lower than the coefficient for the speed level of 300 mm/min. Coefficients obtained for the speeds higher than 10 mm/min should distinguished and called instantaneous. The values of the conventional elasticity coefficient E_U and Poisson coefficient (ν) determined during the static compressibility trials allowed also for the calculation of G and K coefficients. The volumetric coefficient (K) expresses material resistance to a considerable extension during compression, and the compression coefficient (G) is related to the size of shearing angle.

DISCUSSION

Elastic deformation of the beet root tissue can be considered the index of root consistency [3,4,10,11]. Special research methods of calculating the elasticity coefficient allowing to estimate the condition of beets stored before processing were established and normalized. Vukow [11], Ostrowski [10], and Grabka [5] carried out an experiment of bending 20 samples cut out from the roots and calculated an average elasticity coefficient as a function of the constant bending force and differentiated longitudinal deformations of the samples. They proved that the value of that coefficient mostly depended on the tissue turgor [11] and the influence of formalin used during extraction [5]. Vukow [11] marked off the following groups of roots: plastic (fresh) with the elasticity coefficient of 7-14 MPa, elastic (overdried) with the coefficient of 4.2-7.0 MPa, soft (whithered) with the coefficient of 1.8-4.2 MPa, and very soft with the coefficient of 1.8 MPa. The authors [3,4,11] emphesize that the drastic decrease of the value of the elasticity coefficient is supported by freezing and defrosting of roots as well as by tissue denaturation. Decreasing the elasticity coefficient below 0.8 MPa indicates that the tissue is flabby and does not transmit the sap. Measurements of the elasticity coefficient at the bending trial were carried out only for the extreme storing conditions, as the listed sources indicate. The simplicity of measurement and the possibility of receiving the statistical average of coefficients from several cylinder samples of the tissue at the same time, makes this method useful for industrial laboratories. In the described experiments, however, the changeability of the elasticity coefficient deriving from the cultivation conditions, storage time, species kind, or anatomical composition of the root, were not determined.

The best and most frequently used form of deformation while estimating elasticity coefficients of separate single samples of the root tissue is one-axis compression. This sort of putting weight allows to estimate the value of the elasticity coefficient most unmistakably, because it creates and controls the conditions, in which the elastic deformation is estimated according to the Hook Law. The course of the relationship of stress and deformation of the root tissue is similar to the one of elastic bodies [1-3,7,11]. The value of the coefficient is the coefficient of proportion between the stress and the deformation value. If the conditions of the static trial of compression are kept, the results received by using this method are comparable despite of the technique and research tools used. The results of the research carried out on a group of following tissues: parenchyma and conducting, using the Hoppler consistometer [7], are also comparable to the results received on the INSTRON machine [1,2]. The results of the research carried out on different instruments can also be compared in terms of values, under the condition that the samples cut out consist of the same group of tissues [8]. There is a correlation between elasticity coefficients of single tissues (e.g., parenchyma) and groups of them [7].

Some scientists have recently been trying to estimate the elasticity coefficient by selecting proper rheological models describing the processes of relaxation and crawling, but the values of those coefficients are not treated as parameters characterizing the condition of beet roots [2,8,9].

According to the papers of mentioned authors, the research described in this work is an important contribution to the information about factors influencing the value of elasticity coefficient of beets.

CONCLUSIONS

The analysis of the results allows us to draw the following conclusions:

1. The conventional elasticity coefficient does not belong to the variety characteristics of sugar beet roots.

2. Nitrogen dose in fertilizers influenced the level of the conventional elasticity coefficient E_U only at the II stage of this experiment (fresh roots) and III stage (roots stored for 2 months). Influence of the nitrogen type and dose depended on meteorological conditions within the vegetation period and during root storage.

3. With the increase in the degree of wilting (z) the conventional coefficient of elasticity lowers. Long period of roots storing and unfavourable conditions of storage additionally lowered the value of the conventional elasticity coefficient (the low resistance of wilted roots).

4. The values of the elasticity coefficient are significantly dependent on the alignment of bundles of sieve tissue in relation to the direction of force application (zone A and B), and on the type of tissue (zone C). The highest value of the elasticity coefficient was noted for the samples collected from the bottom part of the root (zone C), a lower one the A zone, and the lowest in the B zone.

5. Coefficients obtained for the speeds higher than 10 mm/min should distinguished and called instantaneous.

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