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DETERMINATION OF PHYSICAL CHARACTERISTICS OF ROOT VEGETABLES WITH PUNCTURE TEST

ODREĐIVANJE FIZIČKIH OSOBINA KORENASTOG POVRĆA POMOĆU TESTA PRODIRANJA

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ABSTRACT

The aim of this research was to analyze the physical characteristics of root vegetables: carrot, parsley, parsnip and celery. These root vegetables are sold fresh on the market which is why it is important to specify its shape, structure and root texture. Carrot, parsley and parsnip were grown in ridge cultivation and celery was grown on the flat ground. The yields of root and leaf, as well as the dry matter were measured. Root physical characteristics were tested by the puncture test. The puncture force was measured by TMS-PRO instrument (Food technology) having the cylindrical punch diameter of 6 mm. The puncture test was performed for every root at three measuring points located at the point of maximum diameter: sideways into the whole root and at the cross section of xylem and phloem. Critical points were determined on the puncture curve: puncture point ('yield point'), maximum and average value of the puncture force for the distance of 10 mm, as well as the slope of the puncture force. Also, the shape of the puncture curve was analyzed with respect to the depth of the cylindrical punch penetration. The puncture test showed statistically significant and clearly expressed differences in the measuring points of the carrot, parsnip, parsley and celery which confirmed the heterogeneous structure of the tested root vegetables. The measured quantitative values of the puncture force are very important in the technological sense since they can contribute to the design of the machinery used for mechanical harvesting and processing.

Key words: *puncture force, carrot, parsnip, parsley, celery, phloem, xylem.*

REZIME

Zadatak istraživanja bio je ispitivanje fizičkih osobina korenastog povrća: mrkve, peršuna, paštrnaka i celera. Navedeno korenasto povrće je namenjeno za realizaciju na tržištu u svežem stanju, te je iz tog razloga posebno značajno poznavanje njegovog oblika, strukture i teksture korena. Mrkva, peršun i paštrnak gajeni su u sistemu mini gredica, a celer je proizveden na ravnom zemljištu. Izmeren je prinos korena i lista, kao i sadržaj suve materije. Pomoću testa prodiranja (puncture test) ispitivane su fizičke osobine korena. Za merenje sile prodiranja korišćen je merni instrument TMS-PRO (Food technology), sa prečnikom probojca 6 mm. Za svaki koren, na mestu maksimalnog prečnika izveden je test prodiranja (puncture test) na tri merna mesta: bočno prodiranje u ceo koren i na poprečnom preseku na mestu ksilema i floema. Na krivi prodiranja određene su karakteristične tačke: tačka prodiranja ("yield point"), maksimalna i srednja vrednost sile prodiranja za pređeni put od 10 mm, kao i nagib sile prodiranja. Takođe je analiziran i oblik krive prodiranja u zavisnosti od pređenog puta probojca. Ispitivanjem fizičkih osobina pomoću testa prodiranja (puncture test) utvrđene su statistički značajne i jasno izražene razlike po mernim mestima za koren mrkve, paštrnaka, peršuna i celera, čime je dokazano postojanje heterogene strukture ispitivanih materijala. Kvantitativne izmerene vrednosti sile prodiranja imaju veliki tehnološki značaj pri projektovanju linija mašina za mehanizovano ubiranje kao i postrojenja za doradu.

Ključne reči: *sila prodiranja, mrkva, paštrnak, peršun, celer, floem, ksilem.*

INTRODUCTION

The instruments can measure physical but not sensory characteristics. There are several reasons why food physical characteristics are measured: engineering process design, determination of structure and texture. It has been generally accepted that the texture represents a sensory characteristic since only humans can measure food texture. Solid food such as apple or carrot shows the highest correlation between the sensory firmness and puncture test (*Bourne, 2002*). The structural and texture characteristics of food depend on the integrity of the cell wall components (*Sila et al., 2006*). The texture of fresh, cooked and dehydrated carrots were determined by measuring the maximum puncture force with the puncture test which involved the use of cylindrical punch with diameter of 2 mm at the speed of 1 mm/s and puncture depth of 2.5 mm (*Brown et al., 2008*). After applying the puncture test *Bajkin et al.,* (*2011*) determined quantitative differences in the structure of the carrot root between xylem and phloem. The differences between carrot root xylem and phloem cause texture differences (*Llorka et al., 2001*). Physical characteristics of root vegetables can also be determined by measuring the compression force and the extrusion. The compactness and firmness of carrot root texture were evaluated when carrot was fresh and during its hydrothermal treatment by measuring the compression force up to 50% of the reduction in thickness of a sample with the dimensions of 15 x 15 x 10 mm, and 100 g of extrusion (*Borowska et al., 2004*). The research was intended for determining the puncture force with respect to the tested crops and measuring points. The obtained values of the puncture force for different crops have practical purpose for the design of the machinery used for mechanical harvesting and processing of root vegetables. The differences between the puncture forces obtained at different measuring points are the consequence of root structure and texture.

Nomenclature:

F (N)	– puncture force,
F/l (N/mm)	– slope of puncture curve,
D (mm)	– root diameter,
L (mm)	– root length,
M (g)	– root mass,
N (-)	– number of leaves,
Y (t/ha)	– yield,

Subscripts

r – root,
l – leaf,
yp – yield point,
max – maximum value,
av – average value.

MATERIAL AND METHOD

The root vegetables used for this research were grown on Bag farm in Bačko Gradište. Carrot, parsley and parsnip were grown in ridge cultivation and celery was grown on the flat ground. The testing of physical characteristics was performed for the carrot hybrid 'Bolero F1', parsnip cultivar 'Berlinski dugi', parsley hybrid 'Eagle F1' and celery habrid 'Diamant F1'. Root and leaf yields were determined on the plot in November 2010, and after that the physical characteristics were analyzed in the Laboratory for Biosystematics Engineering, Department of Agricultural Engineering at the Faculty of Agriculture in Novi Sad. The dimensions were measured by movable measuring device with the accuracy of 0.1 mm and the mass was measured by electronic scale with the accuracy of 0.1 g. The cross section of the tested roots clearly showed two parts: inner (xylem) and outer (phloem). *Poničan et al.,* (*2004*) suggest that the following physical characteristics of root vegetable should be measured: length (L), maximum diameter (D_{max}), xylem diameter (D_x) and root mass (M) because they determine the quality of fresh root on the market (*EU No 730/99*). Physical characteristics of root were tested with the puncture test (*Bourne, 2002*) by using the TMS-PRO measuring instrument, Food Technology Corporation (*www.foodtechcorp.com*). During the puncture test a cylindrical punch that was 6 mm in diameter was used; it had the speed of 30 mm/min and total depth of penetration of 10 mm. The puncture test was performed for every root at three measuring points located at the point of maximum diameter: sideways into the whole root and at the cross section of xylem and phloem. Critical points were determined on the curve and they showed the dependence between the puncture force and penetration depth: 'yield point' (F_{yp}) and maximum puncture force (F_{max}), but the average value of puncture force (F_{av}) for the penetration depth of 10 mm and puncture curve slope (F/l) were also determined. The puncture curve slope was calculated for the interval which was defined based on the penetration depth of the cylindrical punch. The starting point was the penetration depth of 3 mm and the end point was the 'yield point' (*Alvo et al., 2004*). Also, the shape of the curve showing dependence between the puncture force and penetration depth of the cylindrical punch was also analyzed. The curve categorization was made based on the puncture force after the 'yield point' had been reached (*Bourne, 2002*). The obtained data was processed by Statistica 10 program. Arithmetic mean of carrot root dimensions and mass, as well as the critical points of the puncture force were tested by the F-test analysis of variance and LSD test. The interdependence and influence of the vegetable root diameter on the puncture force was determined by simple correlation coefficients (*Li, 1975*). All the tests were performed at 5% significance threshold.

RESULTS AND DISCUSSION

Root mass and dimensions (length, maximum diameter, diameter and xylem diameter), and leaf length, number of leaves and leaf mass were measured in the laboratory conditions. Biological root yield (Y_r) and leaf yield (Y_l) (Tab. 1) were measured in the field conditions. The yield of parsnip leaf mass was not measured because it was damaged.

Table 1. Dimensions, mass and biological yield of the tested vegetables

Vegetables		Carrot	Parsnip	Parsley	Celery-root
Root	L_r (mm)	199.40	191.20	194.00	106.60
	D_{max} (mm)	37.60	45.80	44.20	88.40
	D_x (mm)	14.60	19.80	29.40	80.40
	M_r (g)	157.52	102.71	106.16	436.24
	Y_r (t/ha)	54.34	37.90	41.11	49.2
Leaves	L_l (mm)	372.00	-	228.00	364.60
	N_l (-)	5.20	-	14.60	12.40
	M_l (g)	22.06	-	26.76	69.58
	Y_l (t/ha)	10.53	-	6.29	13.75

The carrot root yield was 54.34 t/ha and the leaf yield was 10.53 t/ha. The best yields during the years with favorable conditions can be over 60 t/ha (*Ponjičan, 2009*). Parsnip yield was 37.9 t/ha which was within the limits of average values that range from 20-70 t/ha (*Lazić et al., 2001*). Parsnip yield was considered as low with respect to the applied production technology. Parsley gave high root yield of 41.11 t/ha. The expected values range from 25-40 t/ha (*Lazić et al., 2001*). Parsley leaf yield was also high and it was 6.29 t/ha. The acceptable parsley leaf yield ranges from 3-4 t/ha. Celery root yield of 49.2 t/ha was also high since the average values range from 30-40 t/ha (*Lazić et al., 2001*). The celery leaf yield was 13.75 t/ha which was within the expected values of 10-15 t/ha (*Lazić et al., 2001*). The moisture content was measured by thermogravimetric method in the drier (*Babić Lj, and Babić M, 2000*) and the following results for the dry matter content were obtained: 10.53% for carrot, 14.09% for parsnip, 14.93% for parsley and 8.64% for celery.

Puncture force relative to the tested crop and measuring point

Precise determination of differences in the structure of individual root parts of root vegetables can be best achieved by the puncture test (*Bourne, 2002; Bajkin et al., 2011*). The values obtained for different crops and different measuring points are given in the Table 2.

*Table 2. The parameters tested by the puncture test with respect to the measuring point and tested crop**

Crop	Tested parameters	Measuring point		
		Sideways	Xylem	Phloem
Carrot	F_y (N)	68.00 a	56.45 a	56.87 a
	F_{max} (N)	85.32 a	77.25 a	64.54 b
	F_{av} (N)	59.91 a	60.89 a	49.47 b
	F/l (N/mm)	36.19 a	30.88 ab	28.02 b
Parsnip	F_y (N)	49.49 b	89.66 a	36.11 b
	F_{max} (N)	66.43 b	106.69 a	43.06 c
	F_{av} (N)	36.19 a	30.88 ab	28.02 b
	F/l (N/mm)	38.34 b	81.49 a	33.25 b
Parsley	F_y (N)	56.36 a	48.56 a	-
	F_{max} (N)	75.76 a	52.46 b	-
	F_{av} (N)	52.20 a	40.41 b	-
	F/l (N/mm)	16.07 a	19.71 a	-
Celery	F_y (N)	84.11 a	61.20 b	-
	F_{max} (N)	98.76 a	65.41 b	-
	F_{av} (N)	66.02 a	42.73 b	-
	F/l (N/mm)	29.92 a	20.25 b	-

* The tests were performed in rows by LSD-test at the significance threshold of 5%.

With respect to phloem, xylem point of the carrot root showed statistically higher values for maximum (F_{max}) and average (F_{av}) puncture force. Statistically significant differences in the puncture curve slope were determined between the sideway measuring point and phloem measuring point. The measuring points on the parsnip root showed the greatest differences. Xylem point showed statistically higher values for the 'yield point' (F_y), maximum puncture force (F_{max}) and puncture curve slope (F/l). Puncture force in phloem was not measured for parsley due to its small width. During the measuring of maximum (F_{max}) and average (F_{av}) puncture force statistically considerably higher values were obtained at the sideway measuring point in comparison to xylem. Differences between the measuring points were even greater for the celery root. Values obtained sideways were statistically considerably higher for all the tested parameters in comparison to the measuring performed in xylem. Typical shapes of the puncture curve were obtained for the measuring points on the root for all tested crops and their representative values are given in Figure 1.

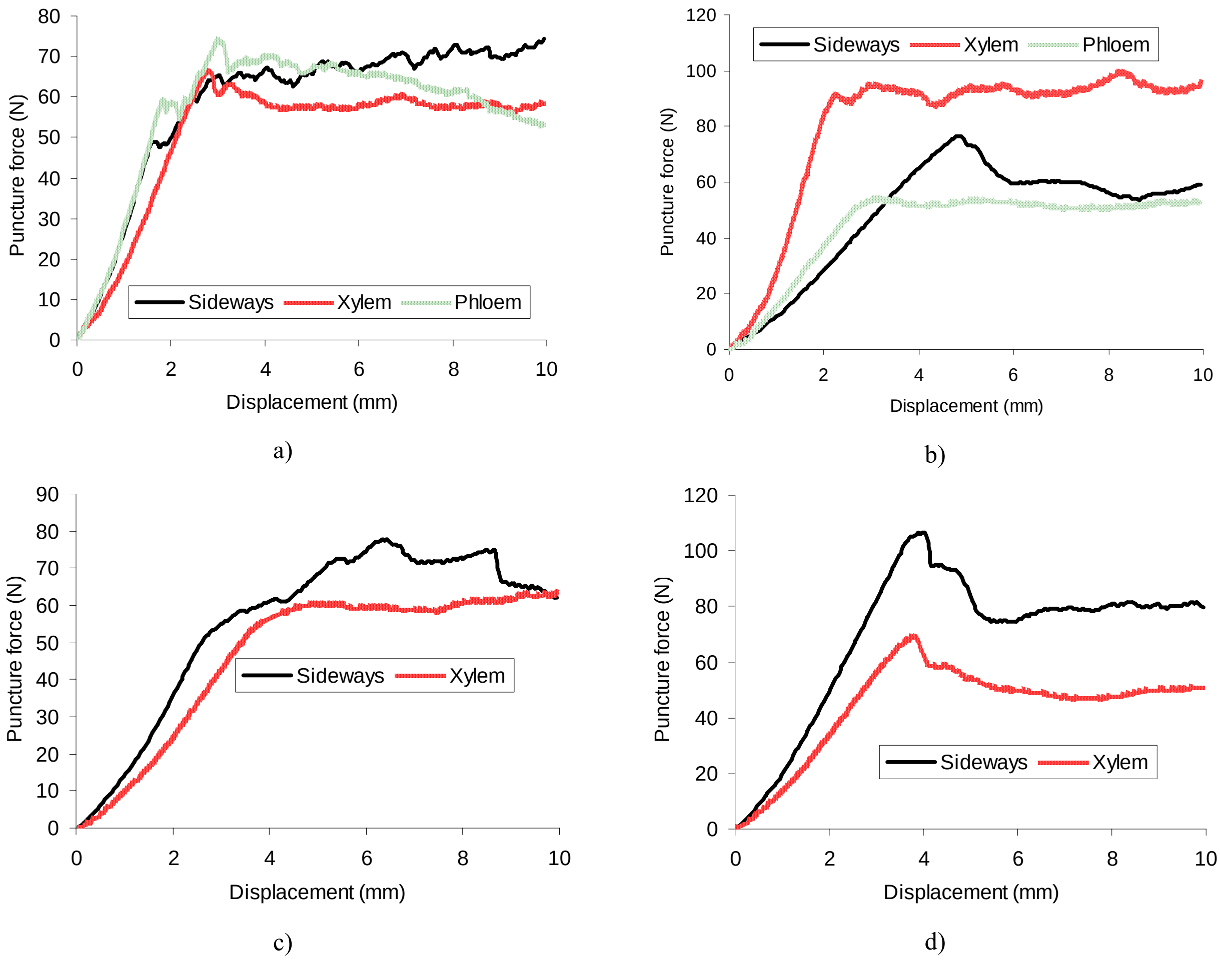

Fig. 1. Typical puncture curves with respect to the measuring point on the root: a) carrot, b) parsnip, c) parsley and d) celery

The presented curves for the carrot root vary considerably for different measuring points, because the values had different values after the 'yield point' was reached. With the measurement performed sideways the resistance increased (type A), while xylem and phloem points had decreasing values (type C) or the values remained unchanged (type B).

The obtained values of the puncture force for parsnip root showed more differences and the curve shape is of type C. The highest values were measured in xylem. Sideway measurement is expressed by type B curve and measurement performed in phloem does not show clearly the critical 'yield point' (type D).

The critical 'yield point' is also not clear for parsley. The sideway measuring in the beginning showed higher values which started decreasing after the displacement and became equal to the value obtained in the xylem. The first phase of measuring at the xylem point recorded abrupt value increase while in the second phase the increase was slower.

Higher values of puncture force were obtained for the sideway measuring of the celery root with respect to the xylem point. After the critical 'yield point' had been reached, the values first started decreasing (type C) and later the value remained constant. Different shapes of puncture curves are the consequence of differences in the structure of some root parts (*Bajkin et al., 2011*). The analysis of critical points (yield point and maximum value), average value, curve slope and shape of the puncture curve for carrot, parsnip, parsley and celery showed obvious differences for different measuring points which confirmed the heterogeneous structure of the tested root vegetables. The measured values are very important in the technological sense since they determine the design of the machinery used for mechanical harvesting (*Bajkin, 1994*) and processing (*Borowska et al., 2004*).

Regression analysis of the root diameter and puncture test parameters

Statistically significant and negative values of correlation coefficient for root diameter and tested parameters (not presented in this paper) were determined for the xylem measuring point on carrot, parsley and celery, while parsnip showed positive values of the correlation coefficient. Other measuring points did not show statistically significant differences in the values of the correlation coefficient for root diameter and observed puncture force parameters. Statistically high values of correlation coefficient were determined for the observed critical points on the puncture curve and average puncture force values. This confirms that all tested values are relevant for the assessment of the structure and texture of root vegetables. The highest correlation coefficient values were recorded for average and maximum puncture force at all measuring points and for all tested crops (carrot 0.89-0.92, parsnip 0.87-0.99, parsley 0.98-0.99 and celery 0.67-0.95). The analyzed forces (F_y, F_{max} and F_{av}) and curve slope (F/l) had statistically significant values of correlation coefficient only in the case of celery (0.73-0.89). The slope of puncture curve is a suitable and reliable parameter for the evaluation of the condition of agricultural crops which are most commonly of heterogeneous structure (*Alvo et al., 2004*).

CONCLUSION

The tests of physical characteristics performed with the puncture test, as well as the determination of the critical points (yield point and maximum value), average value, curve slope and shape of the puncture curve for carrot, parsnip, parsley and celery showed evident differences in the measuring points which confirmed the heterogeneous structure of the tested root vegetables. The obtained quantitative values are very important in the technological sense because they determine the design of the machinery used for mechanical harvesting and processing. Negative correlation between the root diameter and observed puncture force parameters was determined in xylem for carrot, parsley and celery, while the test performed with parsnip showed positive correlation. The highest correlation coefficient values were recorded between the average and maximum values of the puncture force.

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