Biblid: 1821-4487 (2012) 16; 1; p 6-9
UDK: 631.3:52-33:635.1

Original Scientific Paper
Originalni naučni rad

DETERMINATION OF SHEAR FORCE OF ROOT AND LEAF MASS IN ROOT VEGETABLES
ODREĐIVANJE SILE REZANJA KORENA I LISNE MASE KORENASTOG POVRĆA

Ondrej PONJIČAN, Anđelko BAJKIN, Dragi RADOMIROVIĆ, Mirko BABIĆ, Milivoj RADOJČIN
Faculty of Agriculture, 21000 Novi Sad, Trg Dositeja Obradovića 8, Serbia
e-mail: ponio@polj.uns.ac.rs

ABSTRACT

The aim of this research was to determine the shear force of root and leaf mass depending on the basic physical properties of root vegetables: carrot, parsley, parsnip and celery. TMS-PRO (Food technology) measuring instrument and TMS flat shear blade set (Warner-Bratzer shear test) were used for measuring the shear force. Dependence of instant shear force on the shearing distance was determined in the laboratory conditions. Also, maximum shear force (F_{max}) and average shear force (F_{av}) were determined and specific shear force (F_{sp}) was calculated per unit of sheared part. As it was expected, the correlation between maximum shear force and root diameter (0.49-0.80) was high and positive. Calculation of specific shear force per unit of sheared part was general and objective indicator of shear force. The measured quantitative values of shear force are of technological importance for the design of machines for mechanical harvesting and processing plants.

Key words: *shear force, root, leaf, carrot, parsnip, parsley and celery.*

REZIME

Zadatak istraživanja bio je određivanje sile rezanja korena i lisne mase u zavisnosti od osnovnih fizičkih osobina korenastog povrća: mrkve, peršuna, paštrnaka i celera. Za merenje sile rezanja korišćen je merni instrument TMS-PRO (Food technology), i TMS set za rezanje ravnom oštricom (Warner-Bratzer shear test). U laboratorijskim uslovima određena je zavisnost trenutne sile rezanja od pređenog puta. Određena je maksimalna sila rezanja (F_{max}) i srednja sila rezanja (F_{av}), i izračunata specifična sila rezanja (F_{sp}) po jedinici površine. Prema očekivanju, visoka i pozitivna korelacija utvrđena je između maksimalne sile rezanja i prečnika korena (0.49-0.80). Izračunavanjem specifične sile rezanja po jedinici odrezane površine dobija se opšti i nepristrasan pokazatelj sile rezanja. Izmerene su i izračunate vrednosti specifične sile rezanja korena mrkve (7.77 N/cm^2), prešuna (31.59 N/cm^2) paštrnaka (49.94 N/cm^2) i celera (8.61 N/cm^2), kao i lisne mase mrkve (17.93 N/cm^2), peršuna (10.60 N/cm^2) i celera (8.01 N/cm^2). Kvantitativne izmerene vrednosti sile rezanja imaju veliki tehnološki značaj pri projektovanju linija mašina za mehanizovano ubiranje kao i postrojenja za doradu.

Ključne reči: *sila rezanja, koren, list, mrkva, paštrnak, peršun, celer.*

INTRODUCTION

It is generally accepted that the texture is a sensory feature since only people can measure textural characteristics of food (*Bourne, 2002*). There are several important reasons for measuring physical and mechanical characteristics of food such as engineering process design and determination of structure and texture. Structural and textural characteristics of fruit and vegetables depend on the components of wall cells and their compactness (*Sila et al., 2006*). Instruments can be used for determining mechanical properties only. Academically, quantitative measurement of texture is essential for the study of chemical and physiological mechanisms of texture. Commercially, quantitative measurement of texture is essential in order to ensure the quality of produce at packout (*Abbott, 2004*). The color, flavor, texture, and the nutritional value of fruit and vegetable products are factors critical to consumer acceptance and the success of these products (*Barrett et al., 2010*). From the aspect of product quality preservation it is necessary to be familiar with stress limits (load limits) in order to prevent any damage of products (*Bajkin, 1994; Babić and Babić, 2007*). The most widely used texture measurement for fruits and vegetables, after manual squeezing of course, is the Magness-Taylor fruit firmness test, which measures the maximum force to puncture the product in a specified way (*Abbott, 2004*). Puncture test was used for determining the texture of phloem and xylem of carrot root (*Bajkin et al, 2011a*). Statistically, significantly higher values of maximum puncture force (F_{max}) of root carrot were measured in xylem (76.6 N) in comparison to phloem (66.9 N). *Bajkin et al,* (*2011b*) determined physical and mechanical characteristics of root vegetables (carrot, parsnip, parsley and celery). The analysis of maximum puncture force showed statistically significant differences between xylem and phloem for carrot (77.3 and 64.5 N) and parsley (106.7 and 43,06 N). The values of maximum puncture force in xylem were 52.7 N for parsnip and 65.4 N for celery. The values of maximum sideway puncture force were 85.3 N for carrot, 66.4 N for parsley, 78.8 N for parsnip and 98.8 N for celery. The Kramer shear or shear-compression test is widely used in the processed foods industry, but it is less commonly used by horticulturists (*Abbott, 2004*). Kramer shear test is used for meat and fish, as well as for fruits and small vegetables, cereals and snacks such as the crisps. Measuring cell consists of ten parallel steel blades which are drawn through guide slots into a rectangular container filled with tested sample. Simultaneous measurement at different measuring points excludes the effect of inequality of texture. Besides Kramer shear test, Warner-Bratzer shear test (*Rosca and Rosca, 2011*) is also widely used in practice. Warner-Bratzer test gives information about the toughness and tenderness of meet product and vegetables. Sample shearing is performed by interchangeable shear blades fited into the frame. It is used for objective determination of fresh fruit and vegetable textures in food processing industry. Most frequently used blades are flat and "V" shaped blades.

The texture of horticultural products is tested by puncture test, compression test and shear test (Warner-Bratzler shear test), (*Rosca and Rosca, 2011*). For shear test the sample diameter should be standardized since it can affect the values of shear force (*Bourne, 2002*). In practice, the most important value is maximum shear force value.

In order to obtain a detailed analysis of the texture of root vegetables used in food industry the task of this research was to determine quantitatively the shear force of root and leaf mass. The measured quantitative values of shear force are of technological importance for the design of machines for mechanical harvesting and processing plants. Also, it was important to observe the influence of dimensions of tested sample on the obtained shear force values.

Nomenclature:

F (N) – shear force
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
max – maximum value
av – average value
sp – specific

MATERIAL AND METHOD

Shear force was measured for the same samples that were used for puncture force measuring (*Bajkin et al., 2011b*). The root vegetables used for this research were grown on Bag-Decco farm in Bačko Gradište. The testing of physical characteristics was performed for the carrot hybrid 'Bolero F1', parsnip cultivar 'Berlinski dugi', parsley hybrid 'Eagle F1' and celery hybrid '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.

Mechanical characteristics of root texture were tested with the Warner-Bratzer shear test (*Rosca and Rosca, 2011*) by using the TMS-PRO measuring instrument, Food Technology Corporation (*www.foodtechcorp.com*). Flat blade was used for the shear test. The software of the measuring instrument had six steps:
1. ZERO value of load and displacement,
2. RUN @ 60 mm/min until load = 0.50 N,
3. CLEAR DATA,
4. ZERO value of load and displacement,
5. RUN @ 30 mm/min until displacement = 300.00 N or break % = 80%,
6. ASSIGN displacement to V0.

Each measuring was performed in 15 repetitions. The shearing distance as well as the maximum (F_{max}) and average (F_{av}) shear forces were measured. Specific shear force (F_{sp}) was calculated according to the ratio between average shear force (F_{av}) and root (D_r) or leaf mass (D_l) diameter at the shearing point, equation 1.

$$F_{sp} = \frac{F_{av}}{D}, \text{ (N/cm}^2\text{)} \qquad (1)$$

The moisture content was measured by thermogravimetric method in the drier (*Babić and Babić, 2000*).

Regression analysis was used to determine the interdependence between characteristic shear forces (Fmax and Fav), root diameter (D) and leaf mass characteristics: leaf length (Ll), number of leaves (Nl) and leaf mass (Ml). The obtained data were processed by Statistica 10 program (www.statsoft.com). All the tests were performed at 5% significance threshold.

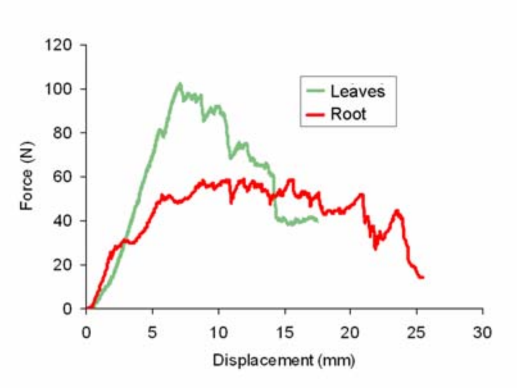
RESULTS AND DISCUSSION

The yields of carrot root, parsley, parsnip and celery were 54.34 t/ha, 41.11 t/ha, 37.9 t/ha and 49.2 t/ha, respectively (*Bajkin et al., 2011b*). The yields of carrot root and celery were within the high yield limits that can be achieved in intensive production. Particularly high yield was achieved with parsley (*Lazić Branka et al., 2001; Ponjičan, 2009*). Low parsnip yield was the consequence of high sowing density and leaf mass rottening. The reason for high sowing density was to obtain smaller root diameter and better placement of fresh parsnip on the market. Parsley and celery leaves are also used in food industry. Parsley leaf yield was 6.29 t/ha and for celery it was 13.75 t/ha. Total yields of parsley and celery leaves, which had to be additionally cleaned, were high. Root dry matter contents were: 10.53% for carrot, 14.09% for parsnip, 14.93% for parsley and 8.64% for celery. Besides the elasticity and displacement modules, stress at which material is broken should also be determined. Insight into the shear force, tearing force, breaking force, picking force and alike is necessary for the design of machinery implements (*Babić and Babić, 2007*). The values of shear force of root and leaf mass of carrot, parsley, parsnip and celery were measured by Warner-Bratzler shear test (*Rosca and Rosca, 2011*) (Table 1).

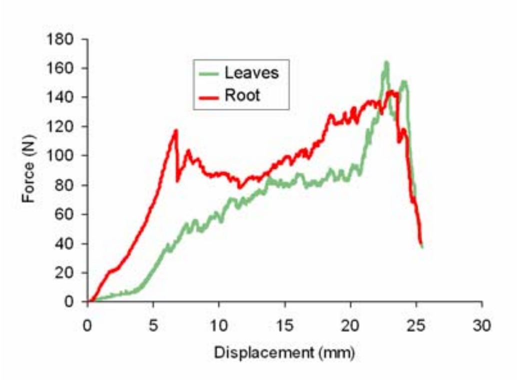
Table 1. Maximum (F_{max}), average (F_{av}) and specific (F_{sp}) shear force of root and leaf for tested root vegetables

Measured parameters		Vegetables						
		Carrot		Parsley		Parsnip	Celery	
		Root	Leafs	Root	Leafs	Root	Root	Leafs
F_{max}	Mean (N)	**73.01**	**79.83**	**130.84**	**114.16**	**226.07**	**133.77**	**133.24**
	S.D. (N)	9.44	19.15	29.31	30.35	37.40	23.65	24.27
	C.V. (%)	12.93	23.99	22.40	26.58	16.54	17.68	18.22
F_{av}	Mean (N)	**51.89**	**43.29**	**81.14**	**60.11**	**112.24**	**89.17**	**66.19**
	S.D. (N)	7.27	9.05	13.67	9.18	34.22	14.20	19.90
	C.V. (%)	14.02	20.90	16.85	15.28	30.49	15.93	30.07
F_{max}/F_{av}		1.41	1.84	1.61	1.90	2.01	1.50	2.01
F_{sp}	Mean (N/cm^2)	**7.77**	**17.93**	**31.59**	**10.60**	**49.94**	**8.61**	**8.01**
	S.D. (N/cm^2)	1.45	4.07	17.91	1.85	29.38	1.68	2.68
	C.V. (%)	18.70	22.67	56.70	17.41	58.83	19.54	33.52

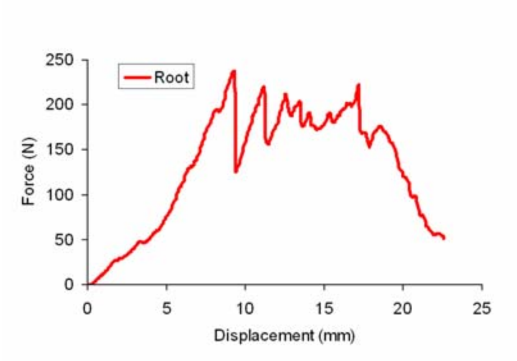
The highest values of maximum shear force (F_{max}) were measured for parsnip (226.07 N), almost equal values were obtained for celery and parsley (133.77 and 130.84 N), and the lowest value was measured for carrot (73.01 N). The highest maximum shear force (F_{max}) of leaf mass was determined for celery (133.24 N), then for parsley (114.16 N), while the carrot had the lowest value (79.83 N). The values of average shear force (F_{av}) and the values of maximum shear force (F_{max}) were equally dependent. The highest average shear force (F_{av}) of root was measured for parsnip (112.24 N) and the lowest was measured for carrot (51.89 N). Celery had the highest value of average shear force (F_{av}) of leaf mass (66.19 N), and the same value was the lowest for carrot (43.29 N).



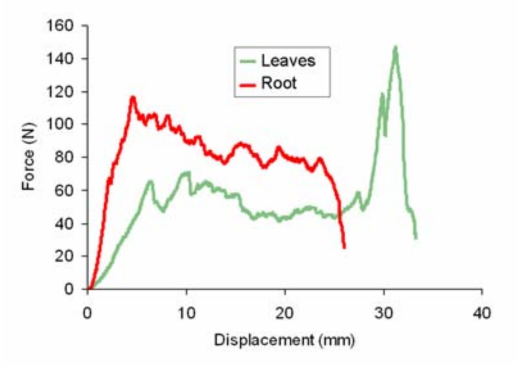
a)



b)



c)



d)

Fig. 1. Typical curves of root and leaf shearing: a) carrot, b) parsley, c) parsnip and d) celery

During the root shearing, highest specific shear force (F_{sp}) was measured for parsnip (49.94 N/cm^2). Parsley also had a high value of this force (31.59 N/cm^2). Considerably lower values were determined for celery (8.61 N/cm^2) and carrot (7.77 N/cm^2). The highest specific shear force (F_{sp}) at leaf mass shearing was measured for carrot (17.93 N/cm^2), while considerably lower and similar values were measured for parsley (10.60 N/cm^2) and celery (8.01 N/cm^2). During the root shearing, ratio between maximum shear force (F_{max}) and average shear force (F_{av}) was 1.41 for carrot, 1.50 for celery, 1.61 for parsley and 2.01 for parsnip. This ratio showed higher values during the leaf mass shearing: 1.84 for carrot, 1.90 for parsley and 2.01 for celery. Figure 1 shows the change in shear force of root and leaf depending on the tested root vegetables.

During the carrot testing, higher maximum shear force (F_{max}) was measured for leaf mass (79.83 N) in comparison to the shear force of root (73.01 N). By comparing specific shear force (F_{sp}) of leaf mass (17.93 N/cm^2) it was also determined that the value was higher in comparison to the shear force of the root (7.77 N/cm^2). Instant shear force value of carrot root depended on the change in the root diameter (Fig. 1a). The highest shear force of leaf mass was recorded at the beginning of shearing. For parsley, similar values of maximum shear force (F_{max}) were measured for root (130.84 N) and leaf mass (114.16 N). By comparing specific shear force (F_{sp}) considerably higher value was measured for the root (31.59 N/cm^2) in comparison to the leaf mass (10.60 N/cm^2). For parsnip (Fig. 1b), shear force of root had high values at the beginning and at the end of shearing. F_{max} for parsley leaf mass shearing occurred at the end of the shearing process. In comparison to the other tested crops, parsnip had higher values of maximum shear force (F_{max} = 226.07 N) and specific shear force (F_{sp} = 49.94 N/cm^2) of root. Change in the shear force of parsnip (Fig. 1c) was dependent on the change in the sample diameter with clearly expressed peaks. For celery, similar values of maximum shear force (F_{max}) were measured for root (133.77 N) and leaf mass (133.24 N), which was also the case with specific shear force (F_{sp}) measured for root (8.61 N/cm^2) and leaf mass (8.01 N/cm^2). Maximum shear force (F_{max}) was recorded at the beginning of the celery root shearing and at the end of the leaf mass shearing process (Fig. 1d).

Regression analysis (Tab. 2) showed high and positive values of determination coefficient between maximum shear force (F_{max}) and average shear force (F_{av}) which ranged from 0.56-0.89.

*Table 2. Regression analysis of shear test for carrot, parsnip, parsley and celery roots**

Vegetable	Parameter	Mean	S. D.	F_{av}	F_{max}
Carrot	D_r (mm)	29.53	4.02	**0.79**	**0.80**
	F_{av} (N)	51.89	7.27	-	**0.88**
	F_{max} (N)	73.01	9.44		-
Parsley	D_r (mm)	20.33	6.54	0.50	**0.56**
	F_{av} (N)	81.14	13.67	-	**0.88**
	F_{max} (N)	130.84	29.31		-
Parsnip	D_r (mm)	18.67	6.62	0.63	0.49
	F_{av} (N)	112.24	34.22	-	**0.89**
	F_{max} (N)	226.07	37.40		-
Celery	D_r (mm)	88.40	4.71	-0.24	-0.18
	F_{av} (N)	83.43	18.34	-	**0.56**
	F_{max} (N)	133.64	23.15		-

* Bold values were statistically significant at 5% significance threshold

Out of the measured parameters of root physical properties (length, diameter and mass), the highest values of determination coefficient were recorded for the root diameter (D_r). Statistically significant values of determination coefficient were recorded for the root diameter (D_r) and maximum shear force (F_{max}) for carrot (0.80) and parsley (0.56). High interdependence was not determined for celery because the shear force was tested on a rectangular sample.

High and positive correlation (0.37-0.86) between maximum shear force (F_{max}) and average shear force (F_{av}) was determined during the leaf mass shearing. The highest correlation values between the observed shear forces of leaf mass (F_{av} and F_{max}) and physical properties of root and leaf mass were determined for root diameter (D_r), number of leaves (N_l) and leaf mass (M_l), Table 3.

*Table 3. Regression analysis of shear test for leaf masses of carrot, parsley and celery**

Vegetable	Parameter	Mean	S. D.	F_{av}	F_{max}
Carrot	D_r	37.60	3.05	**0.93**	**0.96**
	N_l	5.20	1.64	0.48	0.01
	M_l	22.06	7.89	**0.94**	0.87
	F_{av}	43.29	9.05	-	0.86
	F_{max}	79.83	19.15		-
Parsley	D_r	44.20	4.60	0.63	0.65
	N_l	14.60	4.72	0.73	-0.12
	M_l	26.76	8.76	0.84	0.46
	F_{av}	60.11	9.18	-	0.56
	F_{max}	114.16	30.35		-
Celery	D_r	88.40	5.13	-0.31	-0.57
	N_l	12.40	1.14	**0.96**	0.58
	M_l	69.58	22.53	-0.57	0.43
	F_{av}	66.19	19.90	-	0.37
	F_{max}	133.24	24.27		-

* Bold values were statistically significant at 5% significance threshold

Statistically significant values of determination coefficient were obtained for carrot, for the root diameter (D_r) (0.93 and 0.96) and leaf mass (M_l = 0.94), and for celery it was for the number of leaves (N_l = 0.96).

During the performance of shear test, the most significant parameter is determination of F_{max} (*Bourne, 2002*). Also, the simplicity of measuring equipment used for determining maximum shear force (F_{max}) should be emphasized. During the shear test, the samples should be standardized and of equal dimensions. Sample standardization is difficult to achieve during the measuring of mechanical properties in horticulture (*Babić and Babić, 2007*). This research proved the existence of high correlation between the root sample diameter (D_r) and maximum shear force (F_{max}) which ranged from 0.49-0.80. The uses of modern instruments which can measure and calculate average shear force (F_{av}), as well as the process of shearing off, give accurate and general data on shear force of the given crop. Furthermore, this research also proved the existence of high correlation between maximum shear force (F_{max}) and average shear force (F_{av}) which ranged from 0.56-0.89. This means that average shear force can be considered as highly significant and objective method of determining the shear force. However, high correlation (0.50-0.79) between average shear force (F_{av}) and D_r was also determined. The parameter of specific shear force (F_{sp}), calculated according to the average shear force (F_{av}) and sheared part, was introduced in order to eliminate the influence of sample diameter.

Specific shear force (F_{sp}), calculated according to the Warner-Bratzer shear test, gives general and objective indicator of shear force which is equal to the one obtained by Kramer shear test for intended materials. Determination of specific shear force (F_{sp}) is very important in the practice of designing tools for processing industry.

CONCLUSION

Removal (shearing) of leaf mass is frequent practice during harvesting, while root of root vegetables is shredded during the processing. Therefore, it is necessary to be familiar with the intensity and the flow of shear force, as well as with its dependence on basic root physical properties (dimension and mass) and on the type of root vegetable. Warner-Bratzer shear test is used for determining the shear force of root vegetables. Force and its maximum values depend on the root diameter. Besides maximum shear force (F_{max}) and average shear force (F_{av}), the calculation of specific shear force (F_{sp}) was also given in this paper because it is objective indicator of shear force per unit of sheared part and it does not depend on the sample diameter. The measured quantitative values of shear force are of technological importance for the design of machines for mechanical harvesting and processing plants.

ACKNOWLEDGMENT: The research presented in this paper was financed by the Ministry of Education and Science, Republic of Serbia. Grant no. TR 31058, 2011-2014.

REFERENCES

Abbott, J.A. (2004). Textural quality assessment for fresh fruits and vegetables. Advantages in experimental medicine and biology, (54), 265-279.

Babić, Ljiljana, Babić, M. (2000). Drying and storing. (Sušenje i skladištenje in Serbian) University of Novi Sad, Faculty of Agriculture, Novi Sad, 306.

Babić, M., Babić, Lj. (2007). Physical properties of agricultural materials (Fizičke osobine poljoprivrednih materijala in Serbian), University of Novi Sad, Faculty of Agriculture, Novi Sad, authorized script, 38.

Bajkin, A. (1994). Mechanization in vegetable production (Mehanizacija u povrtarstvu in Serbian). University of Novi Sad, Faculty of Agriculture, Novi Sad, 363.

Bajkin, A., Ponjičan, O., Babić, M., Radomirović, D., Dedović, N., Radojčin, M. (2011a). Interaction between carrot root dimensions and puncture force. Journal on Processing and Energy in Agriculture, 15(2), 59-62.

Bajkin, A., Ponjičan, O., Babić, M., Radomirović, D., Dedović, N., Radojčin, M. (2011a). Determination of physical characteristics of root vegetables with puncture test. Journal on Processing and Energy in Agriculture, 15(3), 130-133.

Barrett, D.M., Beaulieu, J.C., Shewfelt, R. (2010). Color, flavor, texture, and nutritional quality of fresh-cut fruits and vegetables: desirable levels, instrumental and sensory measurement, and the effects of processing. Critical reviews in food science and nutrition, 50(5),369-389.

Bourne, M.C. (2002). Food Texture and Viscosity: Concept and Measurement. Second Edition, Academic Press, An Elsevier Science Imprint.

Lazić, Branka, Đurovka, M., Marković, V., Ilin, Ž., (2001). Vegetable (Povrtarstvo in Serbian). University of Novi Sad, Faculty of Agriculture, Novi Sad,: 472.

Ponjičan, O. (2009). Analysis of parameters of mini-bed forming machine for production of root vegetables (Analiza parametara mašine za formiranje mini gredica pri proizvodnji korenastog povrća in Serbian). Ph.D. Thesis, Faculty of agriculture, University of Novi Sad, Serbia.

Rosca, A., Rosca, Daniela (2011). Instrumental texture analysis – an objective measuring method for quality assurance in food industry. University Of Craiova, 41 (52), 361-367.

Sila, D.N., Smout, C., Elliot, F., Van Loey A., Hendrikx, M. (2006). Non-enzymatic depolymerization of carrot pectin: Toward a better understanding of carrot texture during thermal processing, Journal of Food Science, 71(1), E1–E9.

STATISTICA (Data Analysis Software System), v.10 (2011) Stat-soft, Inc, USA (www.statsoft.com)

Food Technology Corporation (www.foodtechcorp.com)

Received: 06.04.2012. Accepted: 10.04.2012.