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Physical and mechanical properties of the black turnip root flesh

Agnieszka Starek[1], Elżbieta Kusińska[2], Tomasz Guz[2]

[1]*Department of Biological Bases of Food and Feed Technologies, University of Life Sciences, Głęboka 28, 20-612 Lublin, Poland, e-mail: agnieszka.starek@up.lublin.pl*

[2]*Department of Engineering and Food Machinery, University of Life Sciences, Doświadczalna 44, 20-280 Lublin, Poland, e-mail: elzbieta.kusinska@up.lublin.pl, tomek.guz@up.lublin.pl*

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Abstract. The paper presents the results of measurement of the basic physical properties of black turnip and the results of studies on the impact of sampling site on the textural properties of its pulp. Selected texture indices, i.e. hardness, elasticity, cohesiveness and chewiness, were determined using the TPA double compression test. The tests were carried out on samples taken from well-defined root layers (upper layer, middle layer, lower layer) and zones (A, B, C) of black turnip, because of its structural heterogeneity. The samples were compressed at the longitudinal and transverse direction of the fibers relative to the compressing device movement. The results obtained were statistically analyzed using the Statistica 10.0 program. The research has shown that the site of sampling and the direction of fiber positioning have a significant impact on the value of all the black turnip texture parameters.

Key words: black turnip, physical properties, sampling site.

INTRODUCTION

The processing of fruit and vegetables is an important sector of food economy in Poland. This sector is quite innovative in relation to products. More and more often attention is paid to new, tasty varieties or health promoting aspects of vegetables. The quality of the supplied raw materials is important for the processing enterprises, because they directly affect the quality of processed products [9, 29].

However, for the proper processing of the raw material it is necessary to precisely determine its mechanical properties. During the description of the mechanical characteristics of materials using strength tests, the compression test is most often used because it is the closest to the simulation of biting and chewing. Among many sets of the samples used in the compression tests, samples loaded between parallel plates, i.e. the texture profile analysis (TPA) test, is most often mentioned. Current methods of textural analysis, based on fairly technically advanced research instruments, allow for objective evaluation of the properties of the raw materials studied [11, 28, 34, 31, 2, 33].

The available data on the physical properties of raw materials, despite numerous scientific studies in this field, are still of limited value due to the heterogeneity of plant-based materials. Therefore, the characteristics of the raw material should take into account its geometric features, surface conditions, porosity, fiber orientation and the procedure of sample collection as well as a precise description of the process parameters. In addition, the description of the material should include comprehensive data on cultivation conditions, variety, moisture, maturity and pre-treatment [17, 4, 15].

Among the lists of publications and scientific works describing vegetable tests, mainly the mechanical properties of potato tubers, carrot roots and sugar beet are the object of broader analyzes and investigations [5, 13, 16]. There are occasional reports of the results of studies on commercial vegetables from the *Brassica* family.

Black radish, most often called turnip (Brassica rapa subsp. Rapa), has a thickened root, with a hot taste, very similar to the taste of radish. The bottom part is usually bright, whereas in the upper part it is red, dark red or almost black (in different cultivars) [16, 1, 3]. Its stem is elevated, erect, and branching. It has the height of 60-120 cm. Lower leaves are lyre-shaped and hairy, green in color, upper leaves are ovate, serrated, and blue. The highest leaves with their entire base cover the stem [20, 7].

The content of vitamin C in black radish is slightly larger than in radishes. There are also relatively high concentrations of vitamins B1 and B2 in it. Black radish contains a lot of protein, sugars and mineral salts. Like other vegetables from the cruciferous family, it is rich in indoles - active antioxidants counteracting the destructive action of oxygen free radicals in the body. In the black turnip root there are sulfur compounds (glucosinolates) [18, 6, 19]. These compounds act antiseptically in the gastrointestinal tract and airways [10, 32]. The healthiest is eating turnip or its juice in raw form. Thermal treatment decreases the content of valuable components. In receiving the juice, the pharmaceutical industry takes care of us, because such juice contained in ampoules can be bought as a dietary supplement [25, 26]. Turnip also contains substances with very strong antibacterial, antiviral and antifungal activity [32]. Furthermore, it is used in cosmetics [27]and may be added to salads [21]. You can also bake turnip, cook, stuff it, or mix it with mashed potatoes, soups and stews [24].

Undertaking research on black turnip, apart from a high cognitive value, has many possible practical applications.

MATERIALS AND METHODS

The raw material used for the research was black turnip (Murzynka cultivar). The material for testing was collected from the second day to the seventh day from the date of harvest. Vegetables were stored in a ventilated room at the temperature of 4°C and 95% relative humidity.

DETERMINATION OF DENSITY, MOISTURE CONTENT AND EQIUVALENT DIAMETER

Density, i.e. the quotient of the weight of the examined vegetable and its volume, was calculated from formula (1). The weight of the vegetables was determined using a laboratory scale (model WLC 1,2 / A2 / C / 2 from RADWAG). In order to determine the volume, water was poured into a measuring cup and the vegetable was immersed in it. To obtain the measurement result from the final volume, the initial volume of water was subtracted. The density determination was made on 15 pieces of black turnip root and the arithmetic mean value was calculated:

$$\rho = \frac{m}{V}, \tag{1}$$

where:
ρ - density [$kg \cdot m^{-3}$],
m - weight of vegetable [kg],
V - volume of vegetable [m^3].

The moisture content was measured using the drying method consisting in drying the fragmented samples at 105°C in a SLW 53 STD laboratory dryer, according to PN-90 / A-75101/03 [23]. The moisture determination was carried out in triplicate for each of the five roots.

The moisture content value was calculated from the formula:

$$W = \frac{b_w - c_w}{b_w - a_w} \cdot 100\ [\%], \tag{2}$$

where:
W – moisture content [%],
a_w - weight of the dish [g],
b_w - sample cell weight before drying [g],
c_w - sample cell weight after drying [g].

In order to determine geometrical features of the black turnip, the vegetables were stripped of leaves and other hard parts. Using the formula (3) [8], the equivalent diameter d_z was determined, which was calculated as the diameter of the sphere with the volume equal to the volume of the irregular particle d_k:

$$d_z = d_k = \sqrt[3]{\frac{6m}{\pi\rho}}, \qquad (3)$$

where:
d_z - equivalent diameter [m],
m - particle mass [kg],
ρ - particle density [kg • m-3].

The measurement of the equivalent diameter was made on 15 pieces of black turnip root.

MEASURING GUIDELINES FOR PROFILE TEXTURAL ANALYSES

Due to the diverse and different structure of black turnip, cutting out the samples for research was carried out in a strictly defined way. Figure 1 shows the appearance of the structure of vegetables after cutting a) along and b) across the fibers and marking the sample cutting locations.

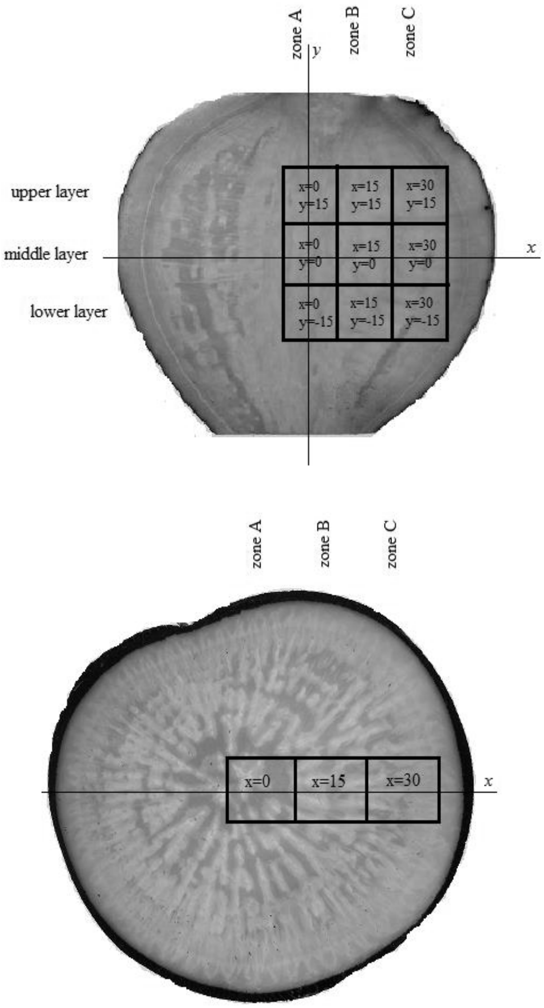


Fig. 1. Structure of black turnip tissue after cutting: a) along, b) across the fibers

It was assumed that the root of the black turnip is symmetrical with respect to the y axis. The above figure shows that the structure of the raw material is heterogeneous. The vegetable has bast fiber layers that are separated by soft flesh. On the longitudinal section of black turnip (Fig. 1a) it is clearly visible that high fiber density occurs in the upper layer, and on the cross-section, where the radial fiber distribution is shown (Fig. 1b), near the skin.

The samples were prepared as follows: each vegetable was divided into three layers (upper, middle and lower) with the thickness of 15 mm. Then, a 45x15x15 mm rectangular prism was cut from each layer, divided into three zones A, B and C (15 mm wide). Cubes with the side of 15 mm were obtained. To ensure the accuracy of cutting out samples, a metal template was developed and prepared with four parallel spaced knives with the spacing of 15 mm.

In order to be able to perform statistical analysis, the mathematical location of the means of individual samples was determined. The x-y coordinate system was assumed, which intersected at point 0. The y axis coincided with the vertical axis of zone A and the x-axis with the horizontal axis of the middle layer. The vertical axes of the samples located in zone B and C were separated from the y axis by 15 and 30 mm, respectively, and the horizontal axes of the upper and lower layers were 15 and -15 mm away from the x-axis respectively. The x and y coordinates concerned cube centers.

A TPA double compression test was carried out on a TA.XT plus texture from Stable Micro Systems cooperating with a computer having Texture Exponent 32 software, using for this purpose 9 samples in the form of cubes with the side length of 15 mm cut from 10 roots, put on the measuring table with longitudinal alignment (sample a) and transverse fibers (sample b) (Fig. 2).

During the tests, a cylindrical mandrel with the diameter of 25 mm was used, which compressed the sample to 50% of the height at the head speed of the device 0.83 mm • s-1.

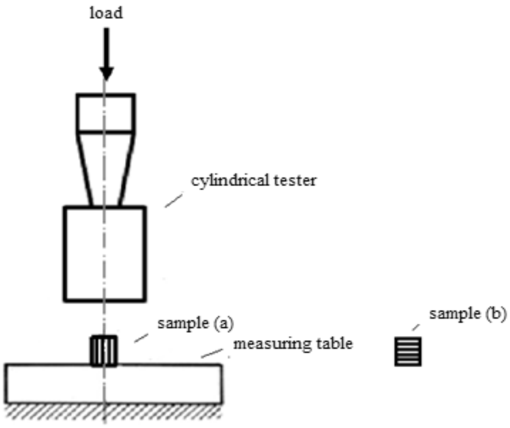


Fig. 2. Scheme of the system for carrying out the TPA test

Analysis of obtained measurements in the form of texturograms in the system of two coordinates, force-deformation, allowed to determine textural parameters (Fig. 3).

The following texture determinants have been specified:

- hardness H (N), i.e. the maximum force during the first compression cycle,
- elasticity (-), which is characterized by the degree of shape recovery; is the quotient of the deformation of the sample during the second and first compression (Spr = L2 / L1),
- cohesiveness (-), characterizing the strength of internal bonds holding the product, it is the quotient of fields under the diagram of the force of the second and first compression of the sample (Coh = W2 / W1),
- chewiness Ch (N), which is a measure of the strength required to chew the bite of food to such an extent that it is ready to be swallowed; it is defined as the product of hardness, cohesiveness and elasticity.

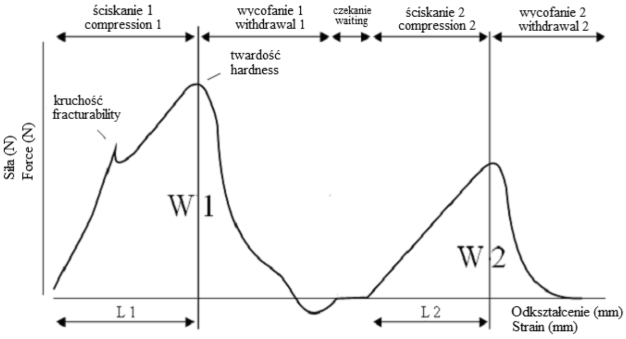


Fig. 3. An example graph obtained during the double compression test (TPA)

STATISTICAL ANALYSIS OF TEST RESULTS

The obtained results were subjected to statistical analysis using statistical package Statistica 10.0. In order to investigate the significance of differences between the site of collection and individual texture determinants, a multivariate ANOVA analysis was carried out. The inference was made at the significance level of 0.05. Detailed analyses of mean confidence intervals were made using the Tukey's test. Using regression analysis, equations describing texture parameters were derived depending on where the sample was taken and the fibers were laid.

RESULTS AND DISCUSSION

Among the conditions enabling the achievement of high repeatability of results and their proper analysis is the thorough knowledge of the physical properties of the tested material. The most important physical properties of vegetables include: geometrical features (for irregular particles the equivalent diameter is determined), density, moisture content [22]. A comparison of average values of selected physical features is given in Table 1.

Table 1. Density, moisture content and equivalent diameter of black turnip

Density [kg·m^{-3}]	Moisture content [%]	Equivalent diameter [m]
1066,499±1,257	68,933±0,791	0,081±0,003

Black turnip is characterized by high density and low moisture content compared to other spherical vegetables [4, 5].

The results of the influence of the sampling site of kohlrabi pulp on the values of texture determinants are presented in Figures 4-7. The various letters given at the mean values in the diagrams indicate the existence of significant differences between them.

It was observed that the value of hardness (Fig. 4 and Table 2) reached the highest level in the upper layer, then it decreased, and increased again in the lower layer. Based on the results obtained, functional trends of hardness changes were developed for both the positions of the black turnip flesh samples. The highest value was observed in the root tissues vegetables taken from zone A (from the upper layer). The value of the parameter was 265 N (with the pulp arranged along the fibers) and 320 N with the transverse arrangement of the fibers. However, the lowest values were recorded in the middle layer in zone A - 145 N (for tissues with longitudinal alignment of fibers) and 164 N (for tissues placed transversely).

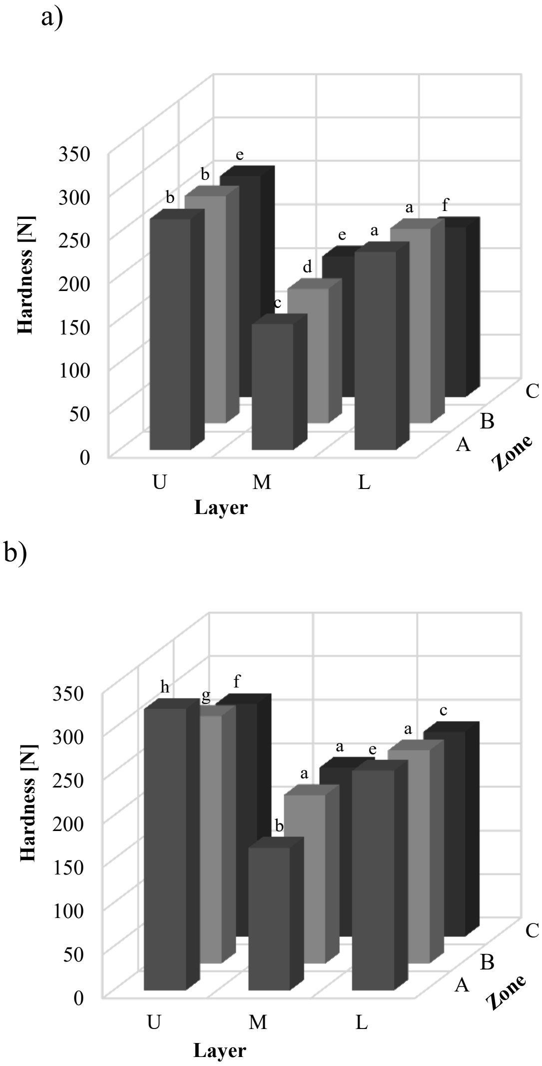


Fig. 4. The dependence of hardness of black turnip pulp on the sampling site at the fiber arrangement: a) longitudinal, b) transverse

Table 2. Significance of Tukey's differences between the hardness of black turnip flesh samples taken from specific places

Hardness [N]		
Place of sampling	Fiber arrangement	
	longitual	transverse
AU	265,58[ij]	322,8[l]
AM	144,56[a]	163,63[c]
AL	228,02[e]	252,03[h]
BU	261,76[i]	283,71[k]
BM	154,70[b]	193,23[d]
BL	224,02[e]	244,38[g]
CU	253,77[h]	266,77[j]
CM	161,68[c]	193,67[d]
CL	194,95[d]	234,87[f]

The elasticity of black turnip flesh differs from the hardness (Fig. 5). The upper layer was characterized by the lowest values, in the middle layer there was an increase in elasticity and then a decrease.

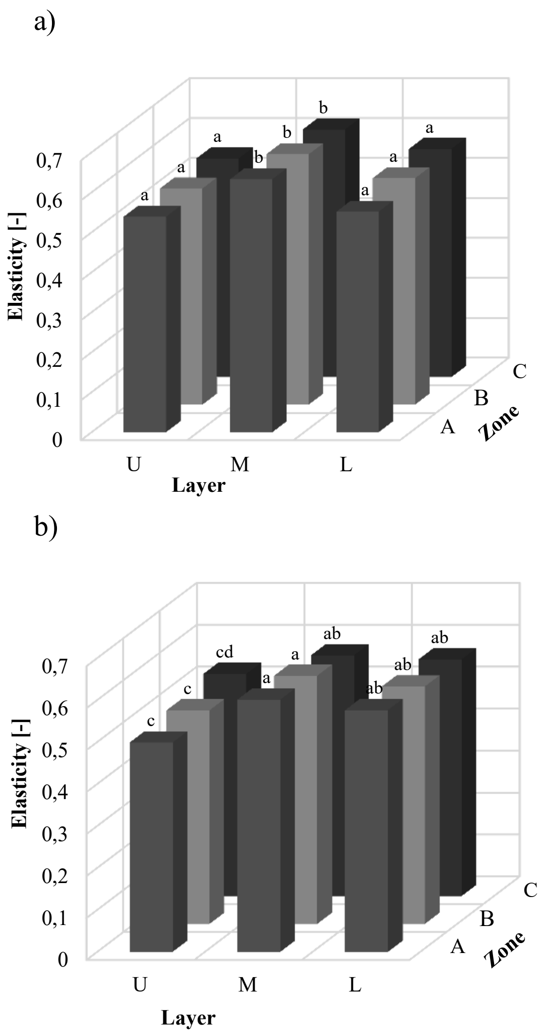


Fig. 5. The dependence of elasticity of black turnip pulp on the sampling site at the fiber arrangement: a) longitudinal, b) transverse

After the statistical analysis no significant differences were found in the elasticity values of samples taken from different zones. The parameter values in each layer with the highest values (middle layer) and the lowest ones (upper layer) were similar to each other and contained in the following ranges: 0.62 - 0.63 and 0.54 - 0.55, respectively.

Mean elasticity values with homogeneous groups ($p \leq 0.05$) listed in Table 3 also indicate that there are no statistically significant differences between longitudinal and transverse fiber placement.

Table 3. Significance of Tukey's differences between the elasticity of black turnip flesh samples taken from specific places

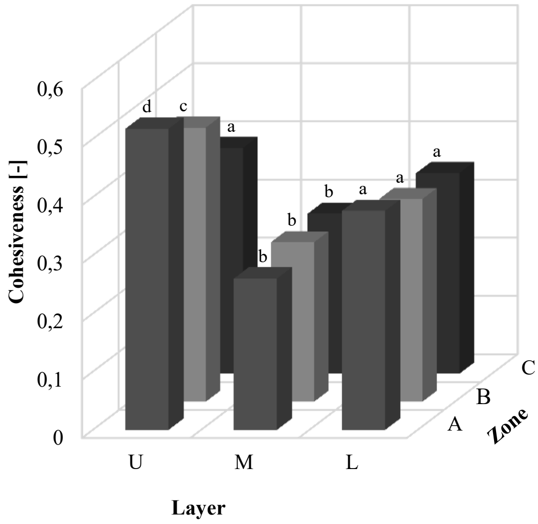
Elasticity [-]		
Place of sampling	Fiber arrangement	
	longitual	transverse
AU	0,54[abc]	0,5[a]
AM	0,63[h]	0,6[efgh]
AL	0,55[bcde]	0,58[cdehg]
BU	0,54[abcd]	0,51[ab]
BM	0,63[gh]	0,59[defgh]
BL	0,57[cde]	0,57[cde]
CU	0,55[abcd]	0,53[abc]
CM	0,62[fgh]	0,57[cdef]
CL	0,57[cdef]	0,56[cde]

The results of studies on changes in the cohesiveness of the parenchyma of the examined vegetables are shown in Figure 6. The highest average cohesiveness value was noted for the samples taken from the upper zone A - 0.52, and the lowest for tissues cut from the middle zone of zone A - 0.26 for the raw material squeezing was arranged along the fibers. The cohesiveness values were lower with the lateral position of the fibers. The significance of Tukey's differences (Table 4) shows that significant differences occur with samples taken from the bottom layer. The value of the parameter for the material taken from zone A (longitudinally) was 0.38, from zone B 0.35 and from zone C 0.34, and for the tissues laid across the fibers it was, respectively, 27%, 22% and 14% higher.

In the next part of the research, changes in chewiness were considered (Fig. 7, Table 5).

This parameter reached the highest level during the study of the upper layer of the parenchyma in zone A during longitudinal alignment of fibers (84 N), and the lowest in the middle layer of zone A, the value of which was by as much as 72% lower. Regardless of the arrangement of the material samples during the double compression test, the pulp was characterized by the slightest puzzlement from the zone of the nearest vegetable skin (zone C). For the bottom layer (with longitudinal fiber arrangement), the determinant value was 38 N, for the middle layer 28 N and for samples coming from the black turnip core 54 N.

a)



b)

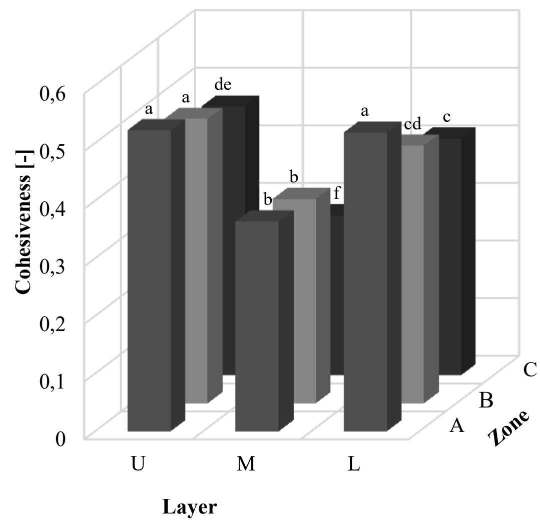


Fig. 6. The dependence of cohesiveness of black turnip pulp on the sampling site at the fiber arrangement: a) longitudinal, b) transverse

Table 4. Significance of Tukey's differences between the cohesiveness of black turnip flesh samples taken from specific places

Cohesiveness [-]		
Place of sampling	Fiber arrangement	
	longitual	transverse
AU	0,52[g]	0,52[g]
AM	0,26[a]	0,36[b]
AL	0,38[bc]	0,52[g]
BU	0,47[ef]	0,49[fg]
BM	0,27[a]	0,35[b]
BL	0,35[b]	0,45[de]
CU	0,39[bc]	0,47[ef]
CM	0,28[a]	0,28[a]
CL	0,34[b]	0,41[cd]

Table 5. Significance of Tukey's differences between the chewiness of black turnip flesh samples taken from specific places

Chewiness [N]		
Place of sampling	Fiber arrangement	
	longitual	transverse
AU	74,08[jk]	83,99[l]
AM	23,74[a]	35,74[bc]
AL	47,41[ef]	75,19[k]
BU	66,62[hij]	71,15[ijk]
BM	26,54[a]	40,52[cde]
BL	44,24[de]	61,8[gh]
CU	53,97[f]	65,87[hi]
CM	27,54[a]	30,71[ab]
CL	38,33[bcd]	54,42[fg]

a) b)

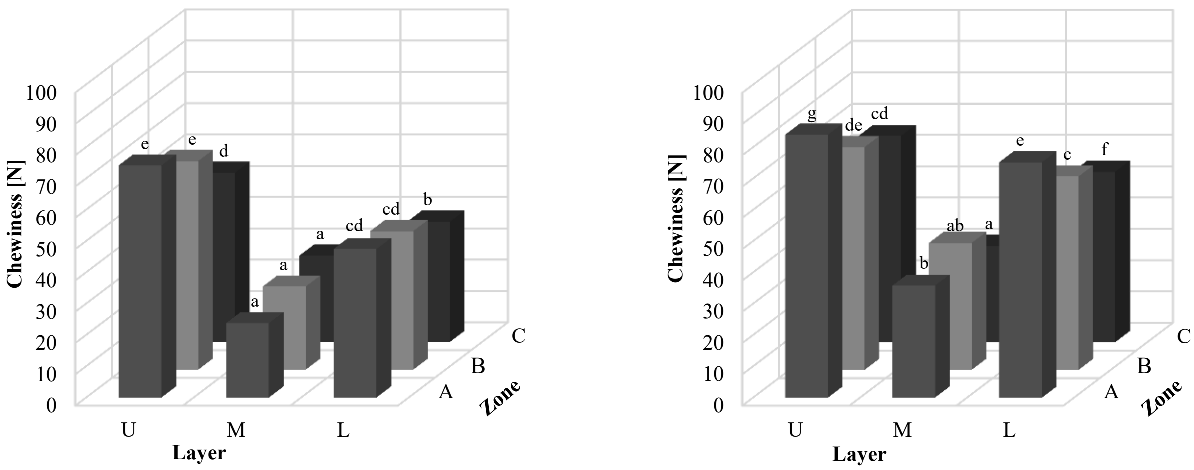


Fig. 7. The dependence of chewiness of black turnip pulp on the sampling site at the fiber arrangement: a) longitudinal, b) transverse

Table 6 presents regression equations describing the impact of sampling from a specific zone and layer on individual texture determinants of black turnip flesh.

Table 6. Regression equations and R^2 determination coefficients describing the determinants of black turnip flesh texture when laying the longitudinal and transverse fibers depending on the coordinates of the sample collection

Texture determinants	Fiber arrangement	Regression equation	R^2
Hardness [N]	longitual	$Hd = 0{,}375y^2 - 0{,}0113x^2 + 1{,}490y + 157{,}897$	0,96
	transverse	$Hd = 0{,}373y^2 - 0{,}484x + 1{,}577y + 190{,}778$	0,89
Elasticity [-]	longitual	$El = -0{,}00033y^2 - 0{,}00069y + 0{,}626$	0,51
	transverse	$El = -0{,}0022y^2 - 0{,}0019y + 0{,}589$	0,47
Cohesiveness [-]	longitual	$Coh = 0{,}00061y^2 - 0{,}0016x + 0{,}003y + 0{,}293$	0,80
	transverse	$Coh = 0{,}00064y^2 - 0{,}003x + 0{,}0012y + 0{,}374$	0,87
Chewiness [N]	longitual	$Ch = 0{,}125y^2 - 0{,}0092x + 0{,}719y + 29{,}4$	0,86
	transverse	$Ch = 0{,}147y^2 - 0{,}488x + 0{,}329y + 42{,}981$	0,89

where: x - distance from the measuring point from the coordinates [mm], y - distance from the measuring point from the abscissa [mm].

The equations are valid for the values of x (in the range of 0 ÷ 30 mm) and y (in the range of -15 ÷ 15 mm) and were determined at the significance level of differences $\alpha \leq 0.05$.

CONCLUSIONS

The conducted research and analysis of the results allow to formulate the following conclusions:

1. The sampling site and direction of fibers of the black turnip pulp had a significant influence on the values of texture markers tested.
2. The samples of black turnip flesh had the highest hardness and chewiness in the upper layer, while the lowest in the middle layer.
3. The sampling site and direction of fibers in the tissue samples of the black turnip flesh did not significantly affect the value of elasticity.
4. The cohesion of black turnip was the highest in the upper layer during the compression of samples with transversely oriented fibers.

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