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Modification of the textural properties of Jerusalem Artichoke tubers using different thermal treatments

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Abstract. The aim of the study was to determine the effect of thermal treatment in a convection-steam oven on the textural properties of Jerusalem artichoke tubers. The thermal treatment was continued for 5, 10, 15, 20, and 30 minutes at various levels of steam addition (0, 20, 60, and 100%). The thermal treatment in the convection-steam oven was shown to have a significant effect on the hardness, chewiness, and cohesiveness of the product. The thermal processing methods analysed in this study did not exert a significant effect on the elasticity of the Jerusalem artichoke tubers. With an increase in the heating time, the mean values of the material hardness and chewiness declined and the cohesiveness of Jerusalem artichoke tubers increased. Application of higher volumes of steam resulted in a reduction of the mean values of hardness and chewiness of the product accompanied by a simultaneous increase in the mean cohesiveness values.

Key words: textural properties, TPA test, thermal treatment.

INTRODUCTION

The quality of plant raw materials is mainly assessed by the determination of their mechanical properties and chemical composition. The basic element determining mechanical properties is the plant tissue structure or, more specifically, the condition of cell walls. In the processing of agricultural materials, the structure of the raw material is destroyed e.g. by thermal energy supplied in the heating process. The mechanical properties are altered by unit processes taking place during processing, e.g. internal and external heat transfer as well as internal and external mass (water) transfer. This is associated with changes in the size and arrangement of cells, biochemical transformations (loss of vitamins and nutrients, etc.), and linear and volumetric shrinkage of the material [9].

In food technology, raw materials are subjected to various treatments, e.g. thermal processes involving heat transfer (e.g. pasteurisation or sterilisation) and changes in the weight (e.g. drying or freezing). The highest energy consumption in the food industry is noted during thermal treatment of materials. Hence, there are attempts to shorten the thermal treatment time maximally and simultaneously retain the highest possible quality of the product. Additionally, prolonged heating time can result in deterioration of the performance properties of the material. Modification of the properties of food products is largely associated with adjustment thereof to consumer preferences. The attractiveness of a food product to the buyer lies not only in its appearance but also in its taste values, which depend on the flavour, smell, and texture of the material. Textural properties and, hence, product quality are directly determined by mechanical traits [12].

The determination of textural properties is based on sensory or instrumental analyses. The former involve the sense of smell, taste, hearing, and touch. Instrumental analysis consists in a number of mechanical tests based on the impact of compression, breaking, stretching, or shearing forces [5].

The choice of an appropriate method depends primarily on the type of problem to be analysed. Plant materials contain considerable amounts of water and exhibit viscoelastic properties. Creep and stress relaxation tests are very often used to determine the properties of this type of materials. Compression tests provide the greatest number of data about analysed materials. The modulus of elasticity calculated from the tangent to the initial section of the measurement curve can be a measure of material freshness. Compression tests are an important source of information about the mechanical resilience as well as the consumption and storage quality of raw materials and products. The properties of food products are most typically determined by the Texture Profile Analysis (TPA) test. A high correlation was found between the results of sensory and instrumental analyses, in particular those of model analyses [8, 9].

As reported by many authors, e.g. Garcia-Segovia et al. [3], Iborra-Bernad et al. [4], Marzec et al. [6], Nguyen et al. [7], and Wierzbicka and Półtorak [11], thermal treatment of plant materials induced changes in their textural properties. The range of these alterations depends on both the type of the thermal treatment (mode of heat transfer) and the process parameters used (time, temperature, heating environment). Hence, an attempt was made in this study to determine changes in the textural properties of Jerusalem artichoke tubers subjected to the thermal treatment in a convection-steam oven (at different volumes of steam addition).

MATERIAL AND METHODS

The study material was tubers of the Jerusalem artichoke (*Helianthus tuberosus* L.) variety Albik grown in the Lublin Province. Healthy tubers without mechanical damage and with similar shapes and sizes were chosen for the analyses. The investigations were carried out immediately after harvest.

The thermal treatment was applied to the Jerusalem artichoke tubers in a Houno A/S convection-steam oven at the temperature of 100°C. The heating time was set at 5, 10, 15, 20, and 30 minutes. The raw material was thermally treated with addition of various volumes of steam, i.e. 0, 20, 60, and 100%.

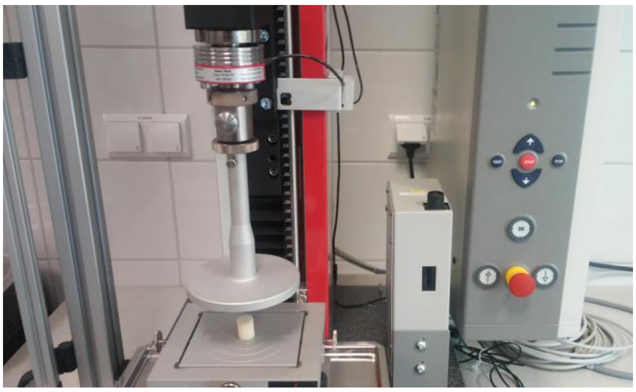


Fig. 1. Zwick/Roell Z0.5 strength-testing machine

The mechanical properties of the Jerusalem artichoke tubers were measured with the TPA test using the Zwick/Roell Z0.5 strength-testing machine (Fig. 1). Material samples were placed singly on the lower stationary plate of the machine and pressed twice by a flat cylindrical 100-mm diameter attachment. The force axis was parallel to the vertical axis of the sample. The material was pressed to 50% of the initial height at a velocity of 0,83 mm·s^{-1}. The tests consisted in recording the value of the force required for compression of the product – F [N], displacement of the measuring head – d [mm], and measurement time – τ [s]. The measured parameters presented in force-displacement and force-time graphs (Fig. 2) were analysed with testXpert II software.

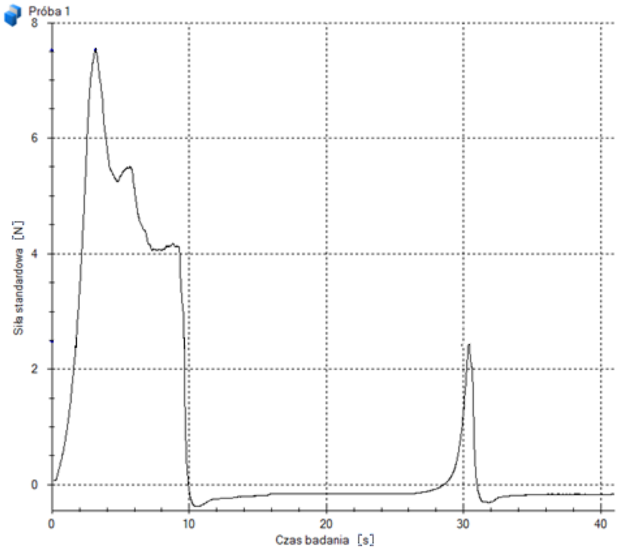


Fig. 2. Example of a TPA test result graph

The following properties were read and calculated:

– hardness [N], i.e. the maximum force during the first compression cycle,
– elasticity [-] characterising the degree of shape recovery (quotient of sample deformation values during the second and the first compression cycle),
– chewiness [N] denoting the force required to chew a bite of the food product before swallowing (product of hardness, cohesiveness, and elasticity),
– cohesiveness [-] characterising internal binding forces ensuring the entity of the product (quotient of the fields under the graph of the second and first compression cycles) [2].

The data were analysed statistically. A significance level α=0.05 was assumed for inference. The analysis was carried out with ANOVA with post-hoc tests for homogeneous groups based on Tukey's test [1]. These groups comprised means between which no statistically significant difference was found at the assumed significance level α.

RESULTS AND DISCUSSION

Figures 3–5 present the mean and standard error values for the analysed properties of the Jerusalem artichoke tubers depending on the steam volume and time of the thermal treatment in the convection-steam oven. For clarity of the figures, the curves of the analysed properties for each volume of steam addition are shifted by ± 2 min relative to the x-axis.

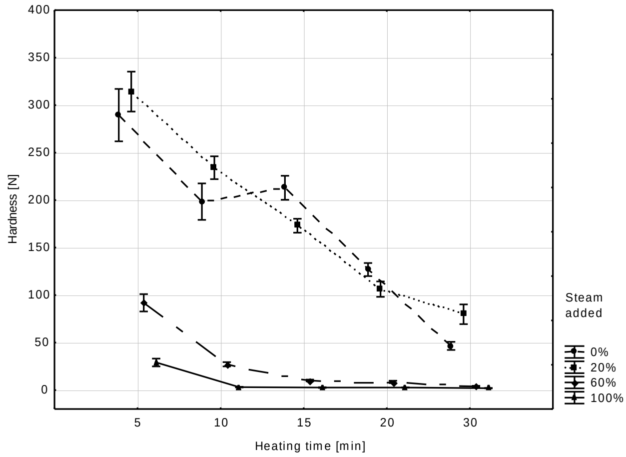


Fig. 3. Changes in the hardness of Jerusalem artichoke tubers depending on the volume of steam added and the time of the thermal treatment in the convection-steam oven

Noteworthy, the mean values of hardness decreased in a majority of cases along the increasing volumes of the steam added and the increasing duration of the process (Fig. 3). The variance analysis revealed significant differences between the analysed mean values. It was found that both the heating time (F=112,553; p<0,001) and the steam addition applied (F=378,444; p<0,001) had a significant effect on the hardness of the material. The same conclusions were drawn for the interactions between these two factors (F=18,336; p<0,001). Detailed analysis performed with post-hoc tests allowed identification of 8 homogeneous groups, which were marked with different superscripts at the mean values of hardness of the Jerusalem artichoke tubers (Table 1). It should be noted that the mean values of hardness of the tubers subjected to the thermal treatment in the convection-steam oven with 60 and 100% steam addition did not change significantly along the increase in the duration of the process. When the tubers were heated in the convection-steam oven without steam addition or at the 20% steam volume, the mean values of the analysed property were significantly different at the 10-min thermal treatment, compared with those obtained at the 5-min heating. The further increase in the process duration still reduced the hardness of the tubers. As presented in Table 1, the addition of the 20% steam volume did not significantly change the mean values of this property, compared with those noted in the process without steam addition. The hardness of the Jerusalem artichoke tubers changed significantly only after the application of 60% of steam.

A comparison of the results of this study with literature data [3, 11] reveals analogical correlations of the duration of the thermal treatment in the convection-steam oven and the volume of steam added with the material hardness reported by other authors. Interestingly, the intensity of changes in hardness accompanying the increase in the heating time is different. The literature [10] shows that changes in the hardness of courgette heated in the convection-steam oven little differed from those observed for the Jerusalem artichoke tubers. Was observed that the values of this property declined to a lesser extent in the initial phase of the process. The most significant changes in courgette hardness were observed after 20–25 minutes of the thermal treatment. Hence, it can be assumed that the course of changes in the hardness of a heat-treated plant material is correlated with its chemical composition and cellular structure.

Table 1. Results of Tukey's test for the mean values of Jerusalem artichoke tuber hardness relative to the volume of steam and heating time (different superscripts at the mean values denote statistically significant differences between the results)

	Hardness [N]			
Heating time [min]	Steam added [%]			
	0	20	60	100
5	289,500^{a}	314,250^{a}	91,875^{gh}	29,038^{gh}
10	198,375^{bc}	234,125^{b}	27,163^{h}	3,094^{h}
15	213,000^{bc}	173,000^{cd}	10,104^{h}	2,629^{h}
20	126,875^{de}	106,250^{e}	8,545^{h}	2,619^{h}
30	46,525^{efg}	79,775^{efg}	3,883^{h}	1,961^{h}

The statistical analysis did not confirm the significance of the changes in the elasticity of Jerusalem artichoke tubers heated in the convection-steam oven at the different process duration and the different steam volumes added. Although the steam addition (F=5,059; p=0,002) and the duration of the thermal treatment (F=13,440; p<0,001) in the convection-steam oven exerted a significant effect on the elasticity of the material, no significant changes in this property were induced by the interaction between these two factors (F=1,077; p=0,384).

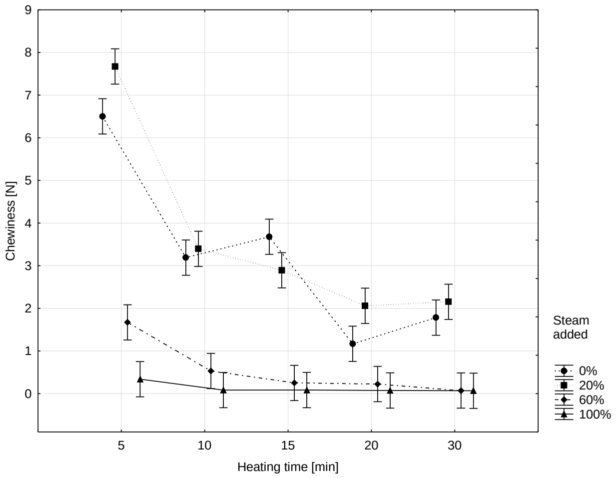


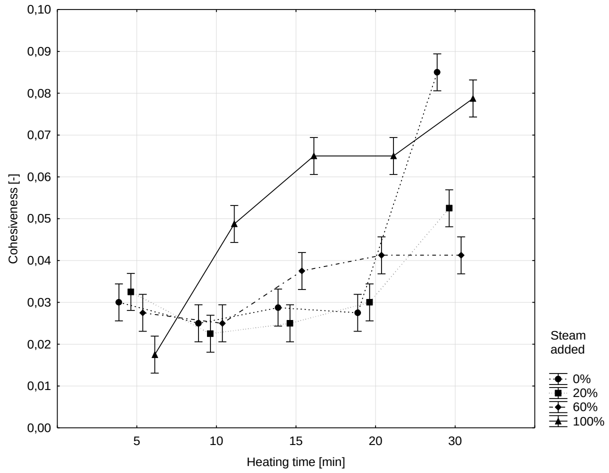
Fig. 4. Changes in the chewiness of Jerusalem artichoke tubers depending on the volume of steam added and the time of the thermal treatment in the convection-steam oven

The changes in the mean values of chewiness of the material exhibited a decreasing tendency along the increasing values of the process parameters applied (Fig. 4). The greatest reduction of the mean value of the analysed property (by 55,74%) was noted when the duration of the thermal treatment increased from 5 to 10 minutes at the addition of 20% of steam.

Table 2. Results of Tukey's test for the mean values of Jerusalem artichoke tuber chewiness relative to the volume of steam and heating time (different superscripts at the mean values denote statistically significant differences between the results)

	Chewiness [N]			
Heating	Steam added [%]			
time [min]	0	20	60	100
5	$6{,}503^{a}$	$7{,}673^{a}$	$1{,}671^{bcde}$	$0{,}339^{de}$
10	$3{,}190^{bc}$	$3{,}396^{b}$	$0{,}531^{de}$	$0{,}083^{de}$
15	$3{,}679^{b}$	$2{,}894^{bc}$	$0{,}250^{de}$	$0{,}084^{de}$
20	$1{,}169^{cde}$	$2{,}060^{bcde}$	$0{,}225^{de}$	$0{,}074^{e}$
30	$1{,}783^{bcde}$	$2{,}154^{bcd}$	$0{,}073^{e}$	$0{,}068^{e}$

The statistical analysis revealed significant changes in the chewiness of the Jerusalem artichoke tubers induced by the thermal treatment in the convection-steam oven at the varied duration of the process (F=37,787; $p<0{,}001$) and the different steam levels (F=95,857; $p<0{,}001$). The same was observed in the case of the interaction between these two factors (F=7,183; $p<0{,}001$). As indicated by the statistical tests (Table 2), only the 60% steam addition induced significant changes in the analysed property. The increase in the parameter level to 100% did not produce further changes in the tuber chewiness. In the case of the thermal treatment without the steam addition and at the 20 and 60% steam levels, significant reduction of the value of the property was noted after the increase in the duration of the process from 5 to 10 minutes. However, the longer thermal treatment had a significant effect only on the chewiness of the heat-treated tuber at the absence of steam. As indicated by the data presented in Table 2, the analysed property did not change significantly along the different process duration values in the case of the material subjected to the thermal treatment in the convection-steam oven with the addition of 100% of steam.



Rys. 5. Changes in the cohesiveness of Jerusalem artichoke tubers depending on the volume of steam added and the time of the thermal treatment in the convection-steam oven

The mean values of cohesiveness of the Jerusalem artichoke tubers increased with the increasing time of the thermal treatment in the convection-steam oven (Fig. 5). A different relationship was observed after the 10-minute thermal treatment of the material in the absence and with 20 and 60% of steam, in this case, the mean value of tuber cohesiveness declined, compared with the value noted for the product heated for 5 minutes.

Table 3. Results of Tukey's test for the mean values of Jerusalem artichoke tuber cohesiveness relative to the volume of steam and heating time (different superscripts at the mean values denote statistically significant differences between the results)

	Cohesiveness [-]			
Heating	Steam added [%]			
time [min]	0	20	60	100
5	$0{,}030^{abc}$	$0{,}033^{abc}$	$0{,}028^{abc}$	$0{,}018^{a}$
10	$0{,}025^{ab}$	$0{,}023^{ab}$	$0{,}025^{ab}$	$0{,}049^{cde}$
15	$0{,}029^{abc}$	$0{,}025^{ab}$	$0{,}038^{abcd}$	$0{,}065^{ef}$
20	$0{,}028^{abc}$	$0{,}030^{abc}$	$0{,}041^{bcd}$	$0{,}065^{ef}$
30	$0{,}085^{f}$	$0{,}053^{de}$	$0{,}041^{bcd}$	$0{,}079^{f}$

The analysis of variance confirmed the significant effect of the heating time (F=44,085; *p*<0,001), steam addition (F=26,581; *p*<0,001), and the interaction between these two factors (F=9,361; *p*<0,001) on changes in the cohesiveness of the material. The highest increase in the mean value of the analysed property, i.e. from 0,028 to 0,085 for the 20- and 30 minute-heating, respectively, was observed when the material was subjected to the thermal treatment without steam addition. Furthermore, as shown in Table 3, the mean values of the cohesiveness of the Jerusalem artichoke tubers subjected to the thermal treatment without and at 20% steam addition changed significantly only after the increase in the duration of the process from 5 to 30 minutes. In contrast, at the 100% steam addition, the values of the analysed property changed significantly already after the increase in the length of the process from 5 to 10 minutes. It should also be noted that the mean values of cohesiveness of the product heated for 5 minutes did not change significantly with the addition of the different steam volumes. The 100% steam addition exerted a significant effect on changes in the values of this property only when the time of the thermal treatment was increased to 10 minutes.

CONCLUSIONS

The following conclusions were formulated based on the results obtained and analysed in the study:

1. Thermal treatment in a convection-steam oven carried out with different process parameters has a significant effect on the textural properties of plant materials.
2. The increase in the heating time is accompanied by a decline in the mean values of material hardness and chewiness. Significant changes in the chewiness of the product induced by the longer process time are noted in the case of the thermal treatment without and with 20% of steam.
3. The values of the cohesiveness of Jerusalem artichoke tubers increase in response to the thermal treatment in the convection-steam oven.
4. The mean values of product hardness and chewiness decline upon increasing the steam volume to 60%.
5. In the initial thermal treatment phase, the increase in the volume of the steam does not induce significant changes in the mean values of material cohesiveness. At the increased duration of the thermal treatment, the mean values of the analysed property of the product increase with the increasing amounts of steam. In turn, in Jerusalem artichoke tubers subjected to the 30-minute thermal treatment, the addition of 20 and 60% of steam resulted in a decline in the cohesiveness of the product.

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