ECONTECHMOD. AN INTERNATIONAL QUARTERLY JOURNAL – 2018, Vol. 07, No. 4, 37 – 44

Influence of brine containing probiotic on the mechanical properties of fruit of selected varieties of field-grown cucumbers during the process of pickling

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Received September 07, 2018: accepted December 12, 2018

*Abstract***.** The study presents an assessment of selected mechanical properties of peel and flesh in raw field-grown cucumbers (*Cucumis sativus* L.), as well as changes occurring in the fruit during the process of pickling, with the use of two types of brine with different composition and with addition of a probiotic. Contents of water in two size fractions of fresh cucumbers were determined using oven-drying method. A puncture test performed with a 5 mm punch probe measured peel and flesh puncture strength and energy as well as apparent modulus of elasticity in raw cucumbers, and following 10, 30, 60 and 90 days of the pickling process. The specified mechanical parameters of cucumber peel and flesh were found to decrease during the pickling process. The reduction in peel and flesh puncture strength is described by a logarithmic function, in energy by linear function and in modulus of elasticity by a power function. The decrease in the puncture strength was slower in the cucumbers subjected to pickling in the brine containing probiotic (B), the decrease in energy was slightly faster in smaller cucumbers (fraction I) subjected to pickling, and during the pickling process in the probiotic containing brine.

*Keywords***:** field-grown cucumber, pickling, brine, probiotic, mechanical properties

INTRODUCTION

Lactic acid fermentation has been known to people for years. It is used in various food industries, e.g. in fruit and vegetable processing, production of rye bread and fermented milk beverages [1, 15].

Pickled vegetables (gherkins, sauerkraut) and fruit, as well as vegetable and fruit juices and other foods produced by bacterial lactic acid fermentation are an important component of diet because of their healthy properties and the characteristic taste and flavour. The probiotics (LAB, lactic acid bacteria) contained in them commonly occur in majority of food products. Lactic acid bacteria present in pickled products are considered to be safe, therefore they have the GRAS (Generally Recognized as Safe) status. Due to the growing number of people with food allergies caused by milk protein intolerance, there is a growing demand for foods obtained from plants, and for non-dairy products containing probiotics [2, 17, 21].

In the process of manufacturing fermented fruit and vegetable juices it is necessary to select appropriate starters to ensure fine quality of the final product with health-promoting properties. Prado et al. [2008] reported high survival rates of bacterial cultures of *Lactobacillus delibereci*, *Lactobacillus acidophillus*, *Lactobacillus casei* and *Lactobacillus pantarum* in tomato juice, as well as extended shelf life of juice with decreased pH.

Targeted lactic fermentation of raw plant materials in the presence of LAB cultures makes it possible to obtain products with desired sensory properties, leading to a decreased use of preservatives, and to reduced risk of abnormal microflora [8, 21].

Probiotics are living organisms which beneficially affect human organism [9]. A bacterial strain, recognised as a probiotic and used in food industry, must meet strict criteria defined by the FAO/WHO. In the case of such strains it is necessary to confirm their stability in acidic environment (gastric juice and bile salts), capability of adhesion and survival in the intestines, anti-bacterial activity and health-related effects, as well as their safety for use and their origin from natural human microflora [7, 9, 13].

Given the fact that field-grown cucumbers (*Cucumis sativus* L.), as biological material, show anisotropic properties resulting from genetic and environmental determinants, it is necessary to monitor mechanical properties of the raw material as they affect the processes of harvesting, storage, cleaning, transport and processing [3, 4, 19, 20].

The laboratory study was designed to assess mechanical parameters of peel and flesh in raw fruit of selected varieties of field-grown cucumbers, as well as changes of the properties during the process of pickling, with the use of two types of brine with different composition.

MATERIALS AND METHODS

The material was collected from experimental plots located in the village of Rogoźnica and brought to the Mechanical Analyses Laboratory at the Department of Food and Agriculture Production, University of Rzeszów; it was subsequently rinsed and divided into size fractions, based on their length (Fraction I - from 3.5 to 5.5 cm; Fraction II - from 6 to 8 cm).

Each size fraction of the raw cucumbers was examined for water contents, using oven-drying method, and for their mechanical properties (peel and flesh puncture strength and energy and apparent modulus of elasticity); the remaining sample was subjected to pickling, in two types of brine with varied composition (Table 1).

Table 1. Composition of the brines (%) used in the process of cucumber pickling

Components	Additive to 100 kg of fruits (% w/w)	
	A	B
Brine (water solution of NaCl)	5	5
Fresh dill. stems and umbels	2.5	2.5
Horseradish root	0.2	0.2
Garlic	0.2	0.2
Mustard seed	-	0.04
Bay leaves (Galeo Firm)	0.1	0.1
Allspice (Galeo Firm)	0.1	0.1
Grainy black pepper	-	0.04
Probiotic	-	0.3

The cucumber fruits were placed into the glass jars with twist-off type lids, which before the souring process were subjected to sterilization. Aside of the cucumber fruit, the jars were filled with brine consisting of water at the temperature of 90 °C including sodium chloride and spices. The cucumbers were subjected to souring procedures in two brines with a different composition. One of the brines was enriched with FD-DVS YC-X16 - Yo-Flex (Chr. Hansen, Denmark), these products include thermophilic yoghurt culture consisting of *Streptococcus thermophilus* and *Lactobacillus delbrueckii*. Before the start of the turbulent fermentation, the jars were kept at a constant temperature of 20 °C and then they were transferred into the room where the temperature was 5°C.

The mechanical properties of cucumber peel and flesh were examined with a puncture test, performed using Zwick/Roell Z010 testing machine [3-6, 12], equipped with a 5 mm cylindrical probe to puncture the mesocarp tissue at a test speed of 0.33 $mm \cdot s^{-1}$. The puncture test was carried out in raw cucumbers and after 10, 30, 60 and 90 days, in the middle and at the top end (near the blossom end) of the fruit. A sample of 10 fruit was used in each variant of the examination.

Statistical analysis of the results was conducted using the Statistica 10 program. To verify the normal distribution and the homogeneity of the variance the data was analyzed using the Shapiro-Wilk test. Confidence level was $\alpha = 0.05$. Then the ANOVA test was used to determine the significance of the differences between the parameter mean values. After the analysis was performed, when the differences between the mean values of the parameters were confirmed, Tukey's post-hoc test was performed to specify and verify them

RESULTS AND DISCUSSION

The lowest contents of water in fresh cucumbers (Table 2) were identified in Polan cultivar, Fraction I (94.3%), and the highest in Partner cucumbers, Fraction I (95.6%). These findings are consistent with those reported by Gorzelany et al. [2014b] for five varieties of cucumbers, including Polan and Śremski.

Table 2. Water contents (%) in raw cucumbers of the field cultivars examined

Fraction	Cultivar			Average C
	Partner	Polan	Śremski	
I	94.35	95.35	94.85	94.85
II	95.10	95.25	94.70	95.02
Average F	94.73	95.30	94.78	94.93

The strength needed to puncture the cucumber peel and flesh varied in the cultivars and depended on the size of the fruit (Table 3) and puncture location.

The lowest puncture strength (28.4 N) in size Fraction I was found in Polan cultivar, at the top end of the cucumber, and in Partner variety in the middle of the fruit. On the other hand the highest puncture strength (30.7 N) was measured in Śremski cucumber, at the top end. In Fraction II the highest puncture strength (30.1 N) was measured at the top end of Partner cucumber, and the lowest (28.8 N) in the middle of cucumbers of Śremski variety. McMurtrie and Johanningsmeier [2018] show that firmness was higher in smaller diameter cucumbers, consistent with previous findings by Sistrunk and Kozup [1982]. Rosenberg [2013] also found that 3.5-3.8 cm diameter cucumbers had significantly firmer mesocarp tissue than 3.8-4.4 cm diameter, but the difference in texture was not detected with a whole cucumber fruit pressure test that is commonly used by the industry for monitoring texture quality during processing.

The larger cucumbers (Fraction II) were characterised by lower puncture energy (Table 4) compared to the smaller fruit (Fraction I) except for Polan variety; they were also found with a greater apparent modulus of elasticity, except for Śremski cultivar. The highest peel and flesh puncture energy was measured in both fractions of Śremski cucumbers, and the lowest energy was needed to puncture Partner cucumbers of both size fractions. The lowest value of apparent modulus of elasticity was identified for Fraction II cucumbers of Śremski cultivar (2.99 MPa), and the highest in Fraction II of Polan cucumbers (3.64 MPa).

The highest decrease in peel and flesh puncture force was observed after the first ten days of the pickling process. In the subsequent periods the decrease in the force was gradually slower. The relationship between the puncture force F of the cucumbers of the relevant varieties and time t of the pickling process is well described by the logarithmic function (Fig. 2) expressed by the equation: $F = a \ln(t) + b$.

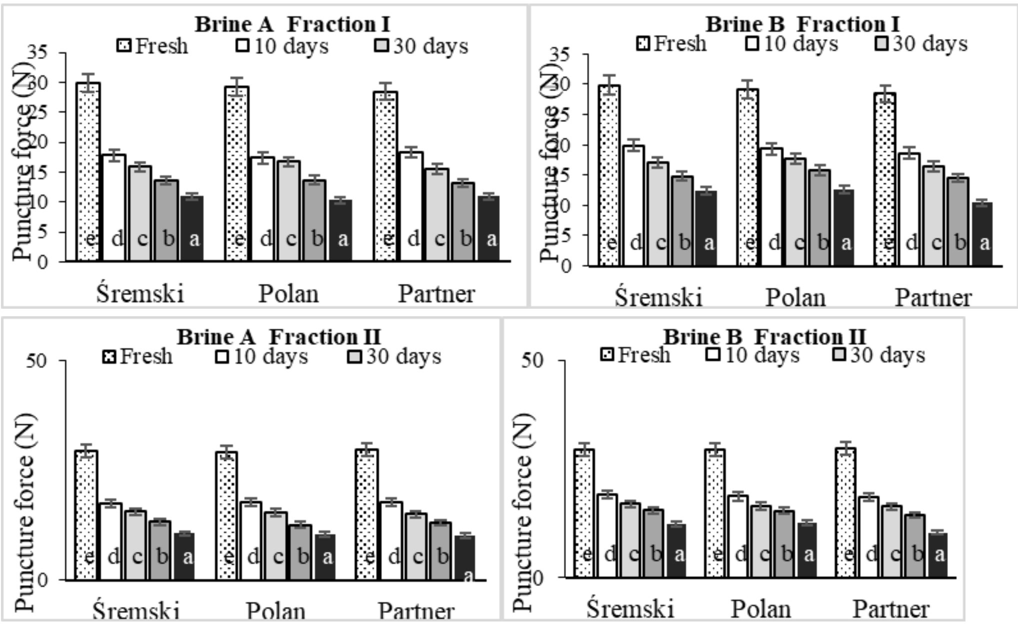
During the pickling process the value of peel and flesh puncture force in the cucumbers of all the cultivars significantly decreased, irrespective of the size fraction or the type of brine (Fig. 1).

Table 3. Peel and flesh puncture force (N) in raw cucumbers of the field cultivars examined

Cultivar	Fruit section	Fraction		Average F
		I	II	
Partner	Middle Top end	28.4±0.4 28.5±0.3	29.2±0.5 30.1±0.2	28.8±0.6 29.3±1.1
	Average Fs	28.5±0.1	29.7±0.6	29.1±0.8
Polan	Middle Top end	30.0±0.1 28.4±0.6	29.1±0.3 29.5±0.5	29.6±0.6 29.0±0.8
	Average Fs	29.2±1.1	29.3±0.3	29.3±0.1
Śremski	Middle Top end	29.0±0.5 30.7±0.4	28.8±0.1 29.9±0.7	28.9±0.1 30.3±0.6
	Average Fs	29.9±1.2	29.4±0.8	29.6±0.4
Average C	Middle Top end	29.1±0.1 29.2±0.2	29.0±0.2 29.8±0.4	29.1±0.1 29.5±0.5
	Average Fs	29.2±0.1	29.4±0.6	29.3±0.3

Table 4. Peel and flesh puncture energy as well as apparent modulus of elasticity in two size fractions of raw cucumbers of the field cultivars examined

Cultivar	Fraction	Energy (mJ)	Apparent modulus of elasticity (MPa)
Partner	I II	89.77 ± 5.81 86.78 ± 0.52	3.56 ± 0.04 3.57 ± 0.45
	Average F	88.28 ± 2.17	3.57 ± 0.15
Polan	I II	86.63 ± 4.59 87.42 ± 7.30	3.16 ± 0.09 3.64 ± 0.15
	Average F	87.03 ± 4.95	3.40 ± 0.10
Śremski	I II	91.10 ± 7.11 88.26 ± 2.12	3.29 ± 0.36 2.99 ± 0.01
	Average F	89.68 ± 4.92	3.14 ± 0.21
Average C	I II	89.16 ± 5.83 88.28 ± 3.51	3.33 ± 0.16 3.32 ± 0.21
	Average F	88.72 ± 3.67	3.33 ± 0.09



*Different letters signify significant differences at α = 0.05

Fig. 1. Fruit puncture force of all the cucumber varieties examined

Analysis of the coefficients of the logarithmic equations describing the relation between the puncture force of the cucumbers and the pickling process duration, as presented in Table 5, shows a few notable regularities. Compared to all the relevant cultivars, puncture force most visibly decreased during the pickling process in Partner cucumbers; this is reflected by the highest absolute value of the coefficient *a* (3.888) and one of the lowest coefficients *b* (28.61). The cucumbers immersed in brine B (with the probiotic) required a higher puncture force, after the same duration of time, as those immersed in brine A (the lowest absolute value of the coefficient a = 3.644 and the highest coefficient b = 28.821). On the other hand the size fraction of the cucumbers was not related to the puncture force during the pickling process. These findings aren't consistent with those reported by McMurtrie [2016]. The average peak force of raw cucumber mesocarp was increased by 1.5-2 N during the first week of brining and was decreased by about 1 N during the next two weeks. McMurtrie and Johanningsmeier [2018] show that time spent in storage was found to negatively correlate with fermented cucumber mesocarp firmness relating to a loss of ~0.7 ± 0.2 N over 100 days.

Mean values of peel and flesh puncture energy in the two size fractions of cucumbers of the field varieties relative to the pickling process duration are shown in Table 6, and the mean values of apparent modulus of elasticity are shown in Table 7.

The data (Tables 6 and 7) show that the mean values of apparent modulus of elasticity, and mean energy needed for puncturing cucumber peel and flesh decreased with the pickling process duration, in each cultivar and size fraction.

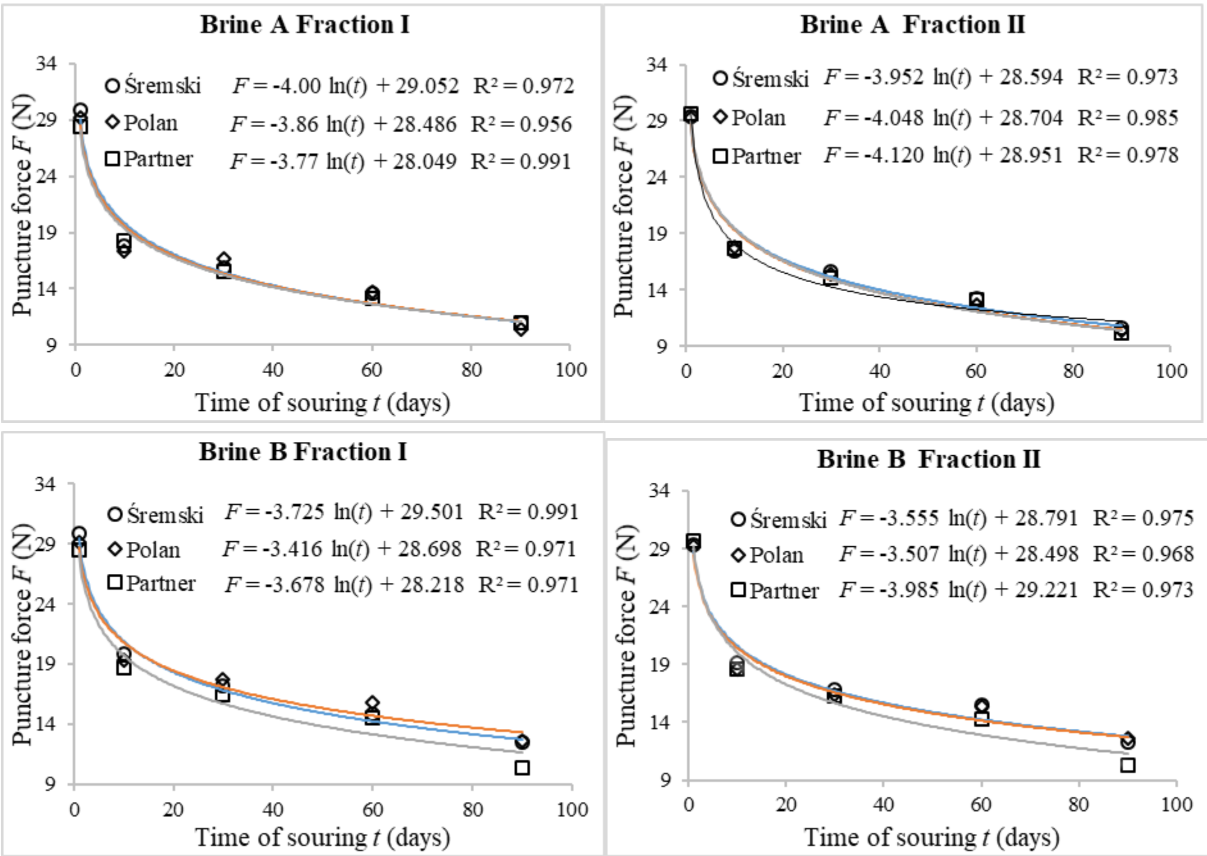


Fig. 2. Relationship between puncture force in cucumbers of the field varieties and the pickling process duration

Table 5. Coefficients of the logarithmic equation describing the relation between the puncture force of the cucumbers of the field varieties and the pickling process duration

Specification		Equation coefficient *a*	Equation coefficient *b*	R^2
Cultivar	Partner	-3.888	28.610	0.981
	Polan	-3.708	28.596	0.973
	Śremski	-3.808	28.984	0.979
Fraction	I	-3.742	28.667	0.979
	II	-3.861	28.793	0.977
Brine	A	-3.959	28.639	0.978
	B	-3.644	28.821	0.977

Table 6. Peel and flesh puncture energy (mJ) for the pickled cucumber of field-grown variety during fermentation

Cultivar	Brine	Fraction	Time of souring (days)			
			10	30	60	90
Śremski	A	I	84.92 ± 3.61	73.57 ± 2.64	61.04 ± 2.78	45.64 ± 1.82
		II	84.46 ± 2.40	75.06 ± 5.53	61.70 ± 4.72	45.43 ± 0.36
		Average F	84.69 ± 3.00	74.32 ± 4.08	61.37 ± 3.75	45.54 ± 1.09
	B	I	92.99 ± 0.71	79.15 ± 2.25	64.57 ±1.08	45.45 ± 2.58
		II	93.86 ± 3.77	78.63 ± 0.21	66.23 ± 2.83	42.52 ± 0.13
		Average F	93.43 ± 2.24	78.89 ± 1.23	65.40 ± 1.95	43.99 ± 1.35
Polan	A	I	87.05 ± 1.50	78.15 ± 0.56	57.55 ± 4.66	43.96 ± 2.02
		II	85.85 ± 5.50	77.60 ± 0.89	60.51 ± 1.51	47.24 ± 0.27
		Average F	86.45 ± 3.50	77.88 ± 0.72	59.03 ± 3.08	45.60 ± 1.14
	B	I	91.66 ± 1.23	75.76 ± 4.03	69.00 ± 0.52	44.62 ± 1.64
		II	92.67 ± 2.36	76.93 ± 1.88	66.21 ± 2.51	48.34 ± 2.04
		Average F	92.17 ± 1.79	76.35 ± 2.95	67.61 ± 1.51	46.48 ± 1.84
Partner	A	I	95.48 ± 3.25	71.38 ± 0.83	63.12 ± 1.77	48.70 ± 1.33
		II	90.86 ± 1.50	79.76 ± 0.19	62.82 ± 2.78	53.86 ± 0.03
		Average F	93.17 ± 2.37	75.57 ± 0.51	62.97 ± 2.27	51.28 ± 0.68
	B	I	82.48 ± 1.21	79.22 ± 1.62	50.68 ± 0.62	45.00 ± 4.63
		II	83.25 ± 1.50	79.48 ± 0.47	55.44 ± 6.05	43.39 ± 2.43
		Average F	82.87 ± 1.35	79.35 ± 1.04	53.06 ± 3.33	44.20 ± 3.53
Average C	I		89.10 ± 2.30	76.21 ± 1.98	60.99 ± 1.90	45.56 ± 2.33
	II		88.49 ± 2.83	77.91 ± 1.53	62.15 ± 3.40	46.80 ± 0.87
	A		88.10 ± 3.41	75.92 ± 1.77	61.12 ± 3.03	47.47 ± 0.97
	B		89.48 ± 1.79	78.20 ± 1.55	62.02 ± 2.26	44.89 ± 2.24

Table 7. Peel and flesh apparent modulus of elasticity (MPa) for the pickled cucumber of field-grown variety during fermentation

Cultivar	Brine	Fraction	Time of souring (days)			
			10	30	60	90
Śremski	A	I	0.97 ± 0.01	0.76 ± 0.04	0.61 ± 0.01	0.44 ± 0.06
		II	0.95 ± 0.02	0.79 ± 0.00	0.66 ± 0.01	0.48 ± 0.01
		Average F	0.97 ± 0.02	0.77 ± 0.04	0.63 ± 0.01	0.46 ± 0.03
	B	I	0.91 ± 0.07	0.77 ± 0.00	0.67 ± 0.00	0.53 ± 0.02
		II	0.96 ± 0.00	0.75 ± 0.00	0.68 ± 0.04	0.56 ± 0.00
		Average F	0.93 ± 0.07	0.76 ± 0.00	0.67 ± 0.04	0.54 ± 0.02
Polan	A	I	0.93 ± 0.07	0.79 ± 0.00	0.68 ± 0.00	0.59 ± 0.00
		II	0.92 ± 0.07	0.79 ± 0.00	0.68 ± 0.00	0.58 ± 0.01
		Average F	0.93 ± 0.07	0.79 ± 0.00	0.68 ± 0.00	0.58 ± 0.01
	B	I	0.88 ± 0.02	0.67 ± 0.02	0.56 ± 0.04	0.48 ± 0.01
		II	0.87 ± 0.03	0.71 ± 0.00	0.59 ± 0.03	0.46 ± 0.01
		Average F	0.86 ± 0.03	0.69 ± 0.02	0.57 ± 0.04	0.47 ± 0.01
Partner	A	I	0.85 ± 0.02	0.79 ± 0.01	0.68 ± 0.00	0.48 ± 0.01
		II	0.98 ± 0.00	0.78 ± 0.03	0.68 ± 0.00	0.57 ± 0.00
		Average F	0.92 ± 0.02	0.78 ± 0.02	0.68 ± 0.00	0.52 ± 0.01
	B	I	0.95 ± 0.01	0.79 ± 0.00	0.70 ± 0.00	0.59 ± 0.00
		II	0.96 ± 0.00	0.80 ± 0.00	0.70 ± 0.00	0.59 ± 0.00
		Average F	0.95 ± 0.01	0.78 ± 0.00	0.70 ± 0.00	0.59 ± 0.00
Average C	I		0.92 ± 0.03	0.76 ± 0.01	0.65 ± 0.01	0.52 ± 0.01
	II		0.94 ± 0.02	0.77 ± 0.00	0.65 ± 0.01	0.54 ± 0.00
	A		0.95 ± 0.04	0.78 ± 0.00	0.66 ± 0.01	0.54 ± 0.01
	B		0.91 ± 0.04	0.75 ± 0.00	0.63 ± 0.01	0.50 ± 0.01

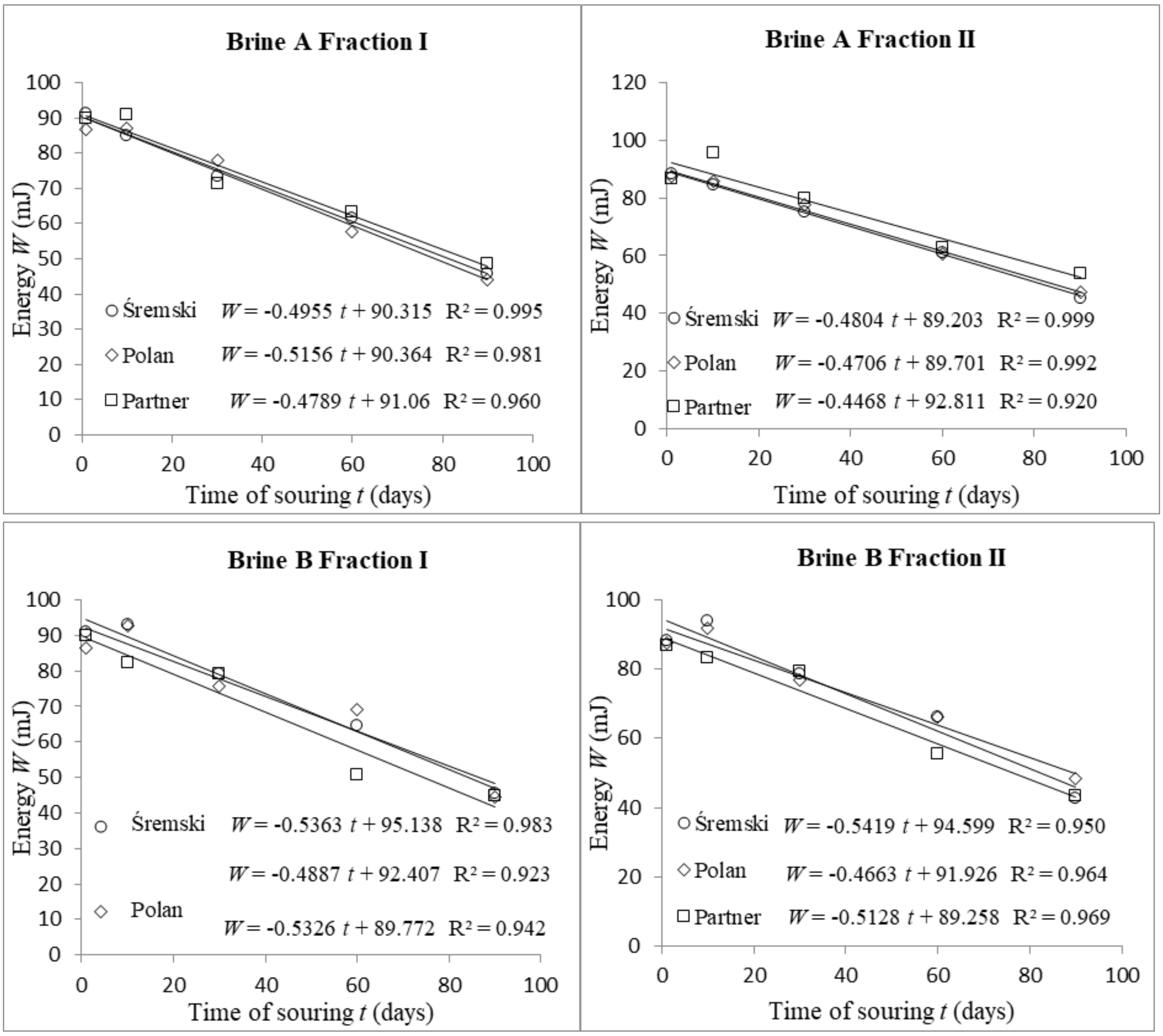


Fig. 3. Relationship of puncture energy in the cucumbers of the field varieties and the pickling process duration

Relationship of puncture energy *W* in selected fruit of field varieties of cucumber and duration *t* of the pickling process is well described by the linear function (Fig. 3, Table 8) expressed by the equation: $W = a \cdot t + b$. On the other hand the relationship of apparent modulus of elasticity *E* in the cucumbers and the duration *t* of the pickling process is well described by the power function (Fig. 4, Table 9).

The values of the coefficients of the linear equations describing the relation between the puncture energy for the cucumbers and the pickling process duration (Table 8) show that the decrease in the energy was most visible in Śremski cultivar, and least visible in Polan cucumbers. The relevant parameter decreased slightly more rapidly in smaller cucumbers (Fraction I) and in the brine B, with the probiotic.

Table 8. Coefficients of the linear equation $W = a \cdot t + b$ describing the relation between the puncture energy *W* of the cucumbers of the field varieties and the pickling process duration *t*

Specification		**Equation coefficient**		**R²**
		a	***b***	
Cultivar	Partner	-0.4928	90.725	0.983
	Polan	-0.4853	91.099	0.980
	Śremski	-0.5135	92.313	0.991
Fraction	I	-0.5079	91.509	0.995
	II	-0.4865	91.249	0.985
Brine	A	-0.4813	90.576	0.993
	B	-0.5131	92.183	0.986

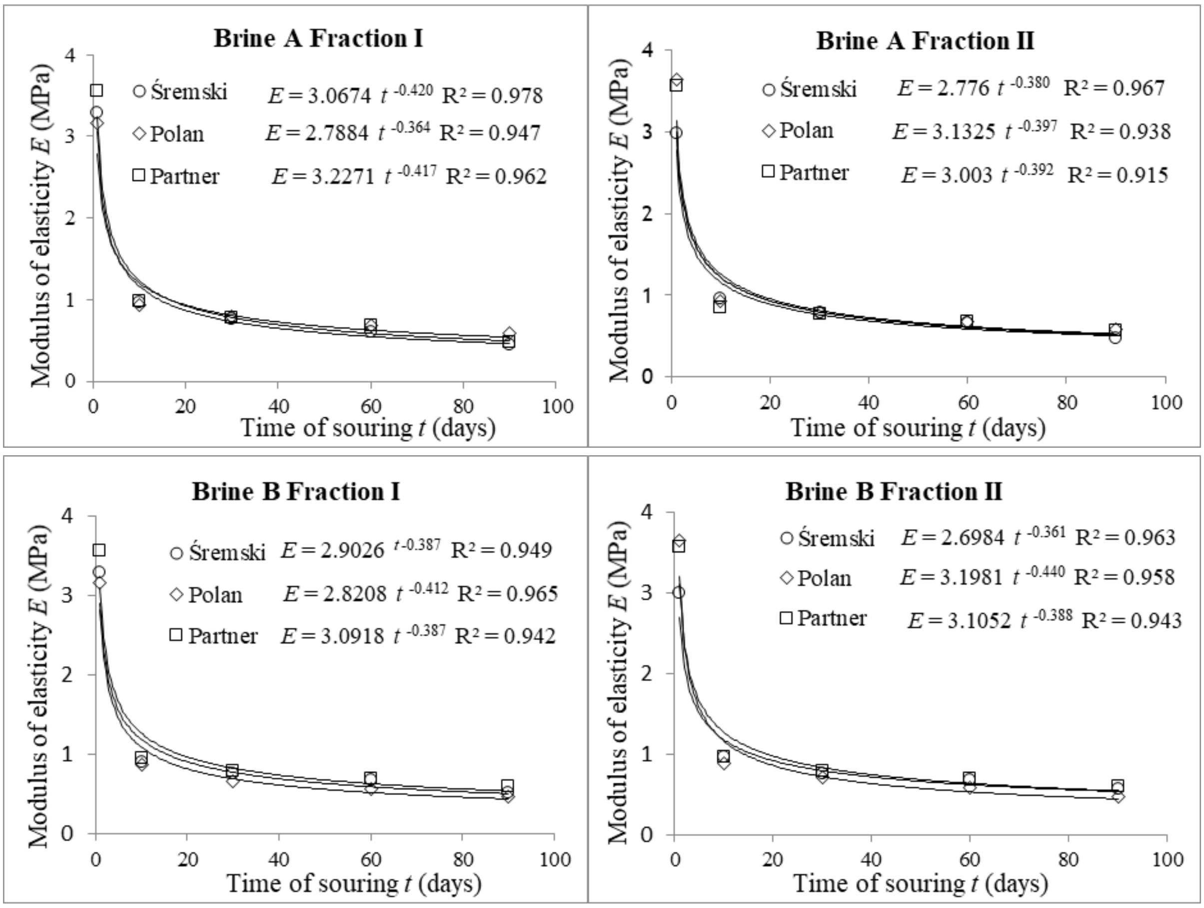


Fig. 4. Relationship of apparent modulus of elasticity in cucumbers of the field varieties and the pickling process duration

The power equations, presented in Fig. 6, describing the relationship of modulus of elasticity in the cucumbers and the pickling process duration, as well as the coefficients shown in Table 9 reflect the fact that a decrease in the module of elasticity in the cucumbers during the process of pickling was not varied in the relevant cultivars, or relative to the size fractions of the fruit, or the brines used.

Table 9. Coefficients of the power equation $E = a \cdot t^b$ describing the relation between the apparent modulus of elasticity E of the cucumbers of the field varieties and the pickling process duration t

Specification		Equation coefficient		R^2
		a	*b*	
Cultivar	Partner	3.1054	-0.395	0.944
	Polan	2.9829	-0.403	0.952
	Śremski	2.8587	-0.387	0.967
Fraction	I	2.9797	-0.397	0.960
	II	2.9878	-0.393	0.950
Brine	A	2.9987	-0.395	0.956
	B	2.9688	-0.395	0.954

CONCLUSIONS

1. The raw cucumbers of Śremski variety were characterised by the highest peel and flesh puncture force (29.6±0.4 N) and energy (89.68±4.92 mJ), as well as the lowest apparent modulus of elasticity (3.14±0.21 MPa). Partner cucumbers were found with the lowest puncture force (29.1±0.8 N) and the highest modulus of elasticity (3.57±0.15MPa), while Polan cucumbers presented the lowest puncture energy (87.03±4.95 mJ).

2. During the pickling process peel and flesh puncture force and apparent modulus of elasticity decreased in the cucumbers of the relevant cultivars, and the change was most visible after the first 10 days. The puncture energy slightly increased during the first 10 days, and then decreased as well.

3. The effects of the pickling process duration in peel and flesh puncture force is described by logarithmic function, in puncture energy by linear function and in the modulus of elasticity by power function.

4. During the pickling process puncture force more rapidly decreased in Partner cucumbers and less quickly in the cucumbers immersed in the brine with the probiotic.

5. During the pickling process puncture energy decreased most visibly in Śremski cucumbers and the change was least visible in Polan cucumbers. Puncture energy decreased slightly more rapidly in smaller cucumbers (Fraction I) and in those immersed in the brine with the probiotic.

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