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CHANGES IN ELECTRIC PROPERTIES OF APPLE JUICE CONCENTRATE AS A FUNCTION OF SELECTED QUALITY FACTORS*

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Key words: apple juice concentrate, extract, density, acidity, impedance, admittance

The research presented aimed at determining the electric properties of apple juice concentrate obtained industrially as well as at identifying the effect of selected quality factors on changes in its electric properties.

A highly significant positive correlation was found between impedance and resistance values and extract content, refractive index value and density of the apple juice concentrate. On the other hand, a highly significant but negative correlation occurred between admittance and conductance and the parameters mentioned. No significant mathematical correlations were reported between reactive and potential acidity of the apple juice concentrate, its viscosity and electric properties measured.

INTRODUCTION

Apple juice concentrate (AJC) is a popular semi-product in the juice industry. It has been applied mainly for the reconstitution of drinking apple juices and for the correction of the taste of products whose acidity needs to be increased, *e.g.* carrot puree-based pulpy juice. A great benefit of AJC is its stability resulting from a high concentration of natural juice components, mainly saccharides and organic acid.

In determining AJC quality, use is made of numerous and different factors which in turn involve various examinations and analyses. The evaluation of the apple juice concentrate quality requires determination of the chemical composition of a product, its sensory attributes as well as the presence of undesired or detrimental substances (preliminary fermentation products, patulin, metals harmful to health). As complicated and often expensive methods are necessary for this purpose, a complete analysis is performed periodically, *e.g.* at the change of technology or at contractor 's request. The evaluation of individual AJC batches is usually reduced, and the conformity of the concentrate composition with the recommendations of trade turnover is confirmed by determinations of extract content, total and volatile acidity, and sensory attributes, namely: colour, clarity, taste and aroma [Nagy, 1993; PN-94/A-75957].

Search for high quality of apple juice concentrate and profitability of its production requires the application of enzymatic methods for obtaining and clarifying of juice.

Enzymatic processing of pulp as well as depectinisation and filtration of juice before concentration performed by means of evaporation, results in almost complete removal of hydrocolloids [Beveridge, 1986; Ibarz, 1990]. The concentrated apple juice may therefore be acknowledged as a non-ideal solution with a high concentration degree of water-soluble components. The content of soluble dry matter, called "extract", results from the concentration degree of the components of natural apple juice and should account for no less than 65% by weight or 65 °Brix. The main components of AJC extract include: fructose, glucose and saccharose. In addition, the apple juice concentrate contains organic acids, mainly organic (hydroxysuccinic) acid (2.5% w/w), mineral salts, vitamins, dyes, and phenolic compounds [Nagy, 1993; Karadenitz, 2002]. Most of water-soluble juice components, except for saccharides, undergo dissociation and form ions which demonstrate the capability of electric conductivity upon the application of voltage [Strebeyko, 1976].

Electric conductance is characterised by such parameters as: impedance, resistance, admittance, effective conductance and capacitance. The characteristics of the electric properties of raw materials and food products usually covers the measurements of impedance or conductance. In practice, it consists in the measurements of the intensity and frequency of electric current flowing through the electrolyte system under study [Budny *et al.*, 2003].

Most of investigations, the results of which have been presented in literature, refer to dielectric properties of food products, non-conventional methods of their preservation with the use of changeable electric field or the application of ohmic heating. Few researches only have reported on the electric conductance of foodstuffs as well as the use of their passive electric properties for the evaluation of quality and the possibility of detecting food adulterations. Therefore undertaking a research into this scientific area has seemed interesting.

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The objective of the presented study was to determine passive electric properties of apple juice concentrate obtained industrially and the effect of selected quality factors on changes in its electric properties as well as to identify the possibilities of applying those measurements for the evaluation of AJC quality and detection of potential adulterations.

MATERIAL AND METHODS

The experimental material comprised the concentrate of domestic apple juice. Samples of apple juice concentrate (AJC) were collected as means of daily production within 12 consecutive days. The AJC samples were collected after cooling to +4°C and stored at that temperature until analysed.

The determinations of the physicochemical properties were performed according to AOAC methods [AOAC, 1998].

The content of total extract and refractive index were assayed with refractometric method, density (d_{20}) – with densimetric method, and reactive acidity (pH) – with a Piccolo pH-meter (*Hanna*). The total acidity was determined with titration method using a conversion factor of apple juice content. The measurement of viscosity was performed at a temperature of 20°C with a *Rheotest 2* apparatus coupled with a measuring cylinder S_2, at nine shear rates.

The determinations of electric properties involved measurements of resistance: impedance (Z) and effective resistance (R), conductance: admittance (Y) and effective conductance (G), as well as equivalent parallel capacitance (Cp) and equivalent series capacitance (Cs), performed with an HP4263B meter (*Hewlett Packard, USA*). A glass container measuring 92 x 55 x 75 mm, was equipped with tabular electrodes, made of acid-proof steel. The electrodes were attached adjacent to two opposite walls of the container. The container was filled with 200 mL of juice concentrate and placed in the air washer to reach the measurement temperature of 20°C. When the required temperature has been reached, measurements of Z, R, Y, G, Cp, and Cs were made using a sinusoidal voltage of 200 mV and a frequency of 100 Hz, 120 Hz, 1 kHz, 10 kHz, and 100 kHz. The frequencies of measuring current used in quality assessment belong to the so-called "low frequencies" and usually range from 100 Hz to 100 kHz.

The sample size was n=12, and analyses and measurements were repeated three times.

RESULTS AND DISCUSSION

The quality assessment of the apple juice concentrate was performed based on selected physicochemical properties, both the obligatory ones including extract content and total acidity, and these providing additional information, namely: reactive acidity (pH), refractive index, density, and viscosity (Table 1). The extract content in the samples of apple juice concentrate examined ranged from 65.5 to 68.0% by weight, and the coefficient of variation reached v=1%. Analogously, little changes have been reported for the refraction index and concentrate density. The intragroup diversification calculated for the refractive index and AJC density accounted for v=0.11 and v=0.36%, respectively.

Higher fluctuations were observed for the content of organic acid (v=6.19%), reactive acidity (v=1.5%), and viscosity of the concentrate (v=21.66%), which may be explained by varietal diversification of the processed material or by the degree of maturity of processed apples. Taking into account the extract content and total acidity, the apple juice concentrate complied with Polish Standard recommendations, and the values of the other product's qualities corresponded to those generally accepted in trade turnover [Niewiarowicz, 1998, PN-94/A-75957].

The passive electric properties of apple juice concentrate were determined by means of electrolytic conductivity. On the basis of an experimental model which have been proved successful in analyses of other food products [Żywica, 2000; Pierzynowska-Korniak *et al.*, 2003], it was assumed that the impedance and effective resistance as well as admittance and effective conductance of AJC will constitute the properties characteristic and specific for AJC and that they will depended on the basic composition and quality factors of the concentrate.

As results from pilot studies [Wójcik *et al.*, 2003], AJC demonstrates qualities described as resistance-capacitance, hence the electric capacitance was the next property to be examined.

The apple juice concentrate was characterised by high resistivity values and relatively low values of electric conductivity (Table 2).

An analysis of the results of AJC resistivity indicated that both impedance (Z_{100Hz}) and resistance (R_{100Hz}) reached almost identical values. Similar values were also reported for standard deviation and coefficient of variation. The average values of Z_{100Hz} and R_{100Hz} calculated for 12 AJC samples approximated 1.1 kΩ. In both cases, the coefficient of variation was slightly higher than 10%. The average values of admittance (Y_{100Hz}) and conductance (G_{100Hz}) of the apple juice concentrate reached *ca.* 0.9 mS, at a variation coefficient of v=10%. Differences between the results of Z, R, Y, and G measurements performed at the measuring current frequencies of: 100 Hz, 120 Hz, 1 kHz, 10 kHz, and 100 kHz, were not statistically signifi-

TABLE 1. Physicochemical parameters of apple juice concentrate.

Parameters	Statistical measures					
	Sample size	Mean	Standard deviation	Coefficient of variation	Extreme values	
	(n)	($\bar{x}$)	(δ)	(v)	minimum	maximum
Extract (°Brix)	12	66.80	0.67	1.00	65.60	68.10
Refractive index	12	1.4573	0.0016	0.11	1.4545	1.4605
Density 20°C (g·cm^{-3})	12	1.3411	0.0048	0.36	1.3429	1.3498
pH	12	3.11	0.05	1.51	3.03	3.19
Organic acid (g/100g)	12	3.19	0.20	6.19	2.81	3.49
Viscosity (mPa·s)	12	365.58	79.19	21.66	252.0	497.9

TABLE 2. The electric propertiess of apple juice concentrate.

Electric properties measured at the frequency of 100 Hz	Statistical measures					
	Sample size (n)	Mean ($\bar{x}$)	Standard deviation (δ)	Coefficient of variation (v)	Extreme values	
					minimum	maximum
Impedance (Ω)	12	1124.06	120.09	10.68	986.30	1412.90
Resistance (Ω)	12	1122.74	119.85	10.67	985.47	1411.10
Admittance (mS)	12	0.8989	0.0879	9.78	0.7083	1.0144
Conductance (mS)	12	0.8998	0.0880	9.78	0.7089	1.0153
Parallel capacitance (nF)	12	6.0927	1.2496	20.51	3.8506	8.3285
Series capacitance (μF)	12	341.69	28.19	8.25	290.75	377.98

TABLE 3. The relationships between the values of electric properties and parameters of apple juice concentrate.

Electric properties measured at the frequency of 100 Hz	AJC parameters					
	Extract (°Brix)	Refractive index	Density (g/m^{-3})	pH	Organic acid (g/100g)	Viscosity (mPa·s)
	Coefficient of determination R^2					
Impedance (Ω)	0.80*	0.80*	0.66*	0.47	0.03	0.05
Resistance (Ω)	0.80*	0.80*	0.60*	0.47	0.03	0.05
Admittance (mS)	0.77*	0.77*	0.64*	0.43	0.02	0.05
Conductance (mS)	0.77*	0.77*	0.64*	0.43	0.02	0.05
Parallel capacitance (nF)	0.61*	0.63*	0.68*	0.21	0.002	0.17
Series capacitance (μF)	0.03	0.03	0.05	0.17	0.12	0.21

* significant correlation at a level of α=0.01

cant (p=0.01). Hence it may be concluded that, at the measuring current frequencies applied, the impedance of the apple juice is almost completely resistance-like, whereas the admittance consists mainly of conductance.

The changes of Z, R, Y, and G in the function of selected physicochemical parameters of apple juice concentrate were exemplified in Figures 1 and 2, and mathematical relationships calculated between the values of those parameters and electric qualities were compiled in Table 3.

With increasing extract content, density and refractive index, the samples of apple juice concentrate were characterised by higher impedance and effective resistance values. A positive highly significant correlation was found between the impedance and resistance values and extract content, refractive index value and density of the AJC samples examined. The coefficients of determination calculated at a level of α=0.01 reached: r^2=0.80, 0.80 and 0.66, respectively.

The results of the measurement of AJC electric conductivity have shown that a tendency of changes in admittance

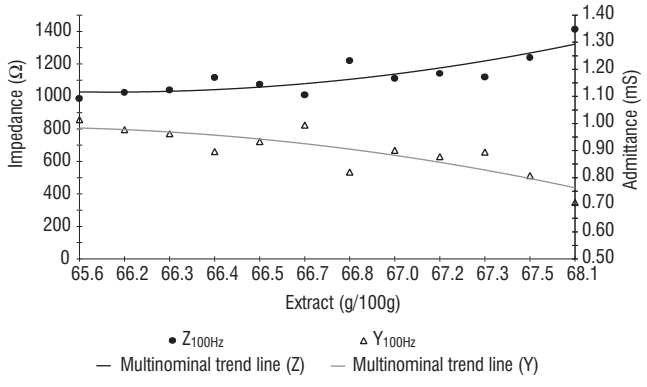

FIGURE 1. Changes in impedance and admittance of apple juice concentrate as a function of changes in extract content.

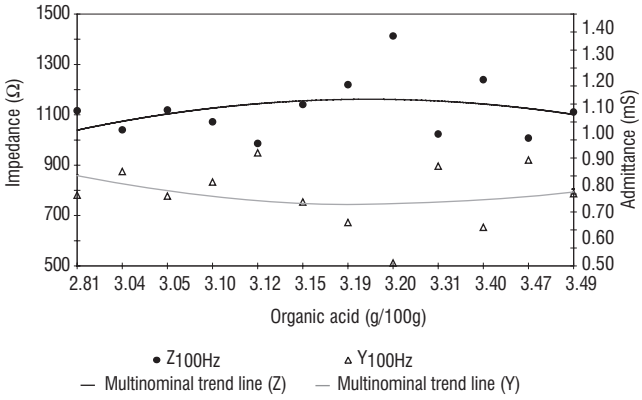

FIGURE 2. Changes in impedance and admittance of apple juice concentrate as a function of changes in organic acid content.

and conductance as a function of the physicochemical parameters examined is opposite to that of impedance and resistance. A highly significant inverse correlation was observed between the Y and G values and such parameters as: extract content, refraction and density of the concentrate. The coefficients of determination calculated at a level of α=0.01 ranged from 0.77 to 0.64.

The pH value, organic acid content, and absolute viscosity of the apple juice concentrate did not demonstrate any significant impact on the changes in its resistivity and electric conductivity, which was proved by low values of coefficients of determination. A lower range of changes in Z and Y in respect to the changes in malic acid content, substantiates its relatively low percentage in the concentrate, compared to the share of saccharides.

The samples of apple juice concentrate were diversified in terms of the electric capacitance values (Table 2). The equivalent parallel capacitance (Cp_{100Hz}) showed intragroup diversification at a level approximating 20%, whereas the changes in equivalent series capacitance (Cs_{100Hz}) barely

exceeded 8%. The Cp and Cs values were significantly different (p=0.01) depending on the measuring current frequency. Only the results obtained at the frequencies of 100 and 120 Hz were found coherent.

The results of the measurements of electric conductivity did not provide an unequivocal answer to the question about the relationship between Cp and Cs electric capacitance and physicochemical parameters of the apple juice concentrate. Although a highly significant correlation (α=0.01) was found between the equivalent parallel capacitance and extract content, refractive index value and density of AJC, it occurred only at the measuring current frequencies of 100 and 120 Hz. The exemplary changes in the Cp_{100Hz} value as a function of extract content were presented in Figure 3.

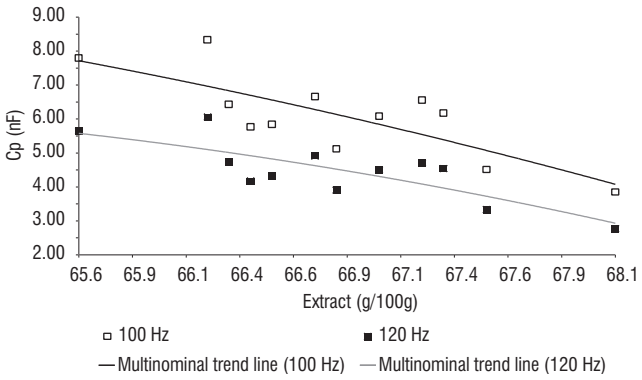

FIGURE 3. Changes in equivalent parallel capacitance of apple juice concentrate as a function of changes in extract content.

No significant correlations were observed between the analysed AJC parameters and equivalent series capacitance at the measuring current frequencies applied.

CONCLUSIONS

At the range of measuring current frequencies applied, the apple juice concentrate was found to demonstrate resistivity-capacitance-like character.

The results of the analyses performed suggest the possibility of applying the measurements of impedance (Z_{100Hz}) and admittance (Y_{100Hz}) for the assessment of apple juice concentrate.

Significant changes in impedance (Z) and admittance (Y) correspond to the relatively low changes in the following concentrate parameters: extract, refraction, density. Those correlations were proved by highly significant coefficient of determination which indicate that over 80% of impedance and admittance variability observed may be explained by the changes in the values of AJC physicochemical parameters examined.

The highly significant correlations shown in the changes of impedance and admittance as a function of not only extract content but also refractive index and density substantiate undertaking of studies aimed at applying those parameters for the estimation of the basic chemical composition of apple juice concentrate and its authenticity.

The possibility of potential application of Cp_{100Hz} measurements for the determination of capacitance properties of AJC, exclusively at low current frequencies, requires further studies.

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ZMIANY WŁAŚCIWOŚCI ELEKTRYCZNYCH KONCENTRATU SOKU JABŁKOWEGO W FUNKCJI WYBRANYCH WYRÓŻNIKÓW JAKOŚCI

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Prezentowane badania miały na celu określenie właściwości elektrycznych koncentratu soku jabłkowego otrzymywanego przemysłowo oraz ustalenie wpływu wybranych wyróżników jakości na zmiany jego właściwości elektrycznych.

Stwierdzono występowanie wysoce istotnej dodatniej zależności między wartościami impedancji i rezystancji a zawartością ekstraktu, wartością współczynnika refrakcji i gęstością koncentratu soku jabłkowego. Również wysoce istotna, ale ujemna zależność miała miejsce między admitancją i konduktancją a wymienionymi wyróżnikami. Nie stwierdzono istotnych matematycznych zależności pomiędzy czynną i potencjalną kwasowością koncentratu soku jabłkowego oraz jego lepkością, a mierzonymi wielkościami elektrycznymi.