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Comparative analysis of selected physicochemical properties of quinoa (*Chenopodium quinoa* Willd.), maize, wheat and potato starch

Analiza porównawcza wybranych właściwości fizykochemicznych skrobi z komosy ryżowej (*Chenopodium quinoa* Willd.), kukurydzy, pszenicy oraz z ziemniaków

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ABSTRACT

A favourable protein amino acid profile and the absence of gluten, being a strong allergen, are just some of the advantages of the quinoa. Besides to protein, other important component of quinoa seeds of is starch. This polysaccharide, due to its origin, can also have interesting properties. The aim of the study was to compare starch isolated from the Faro cultivar of quinoa grown in Poland with commercial starches of various botanical origins (potato, wheat and maize). The analysis included the colour, paste clarity and thermodynamic and rheological pasting properties of the starches. The research has demonstrated that the paste clarity of quinoa starch was 1.26%, which means that the paste was the cloudiest, of all those tasted. Quinoa starch differed from the other starches in terms of thermodynamic and rheological pasting characteristics. It had the lowest temperature at the onset of transition (T_o) and the lowest transition enthalpy ΔH_G. Additionally, quinoa starch demonstrated the lowest pasting temperature and the paste had the highest final viscosity (FV). The highest gelatinization temperature of was noted for maize starch, whose paste had the lowest viscosity.

Keywords: colour, quinoa, rheological properties, starch

STRESZCZENIE

Korzystny profil aminokwasów białka oraz brak glutenu, będącego silnym alergenem to tylko niektóre z zalet komosy ryżowej. Obok białka, ważnym składnikiem jej nasion jest skrobia. Ten polisacharyd ze względu na specyfikę pochodzenia może także mieć interesujące właściwości. Celem pracy była charakterystyka porównawcza skrobi wyodrębnionej z uprawianej w Polsce odmiany Faro, komosy ryżowej z handlowymi preparatami skrobi różnego pochodzenia botanicznego (ziemniaczana, pszenna i kukurydziana). Analizowano barwę skrobi, klarowność kleików skrobiowych oraz termodynamiczną i reologiczną charakterystykę kleikowania. Na podstawie przeprowadzonych badań wykazano, że klarowność kleiku skrobi z komosy ryżowej wynosiła 1,26% co oznacza, że kleik ten spośród badanych był najbardziej mętny. Skrobia z komosy ryżowej różniła się od pozostałych skrobi pod względem termodynamicznej oraz reologicznej charakterystyki kleikowania. Odznaczała się ona najniższą wartością temperatury początku przemiany

T_o oraz najniższą wartością entalpii przemiany ΔH_G. Ponadto skrobia z komosy ryżowej wykazała najniższą wartość temperatury kleikowania, a kleik omawianej skrobi charakteryzował się najwyższą wartością lepkości końcowej (FV). Z kolei, najwyższą temperaturą kleikowania charakteryzowała się skrobia kukurydziana, której kleik miał najniższą lepkość.

Słowa kluczowe: barwa, komosa ryżowa, skrobia, właściwości reologiczne

INTRODUCTION

The decline in the biodiversity of foodstuffs and the risk of deficiencies of essential nutrients call for a search for alternative plant sources. An example is quinoa, whose unique nutritive value would well justify its use. Quinoa (*Chenopodium quinoa* Willd.), is a pseudocereal with properties that may allow it to play an essential role in human nutrition in the future (Sułkowski et al., 2011). The quinoa belongs to the amaranth family. In Poland, the family *Chenopodiaceae*, is generally, associated with common field weeds such as white goosefoot (*Chenopondium album*) and many seed goosefoot (*Lipandra polysperma*) (Abugoch, 2009; Li et al., 2016). White goosefoot was once used in herbal medicine and in baking "hunger-bread". Quinoa was first cultivated 3000 years ago in the Andes of South America and later also in Peru, Brazil, Chile, Bolivia, Ecuador, and Colombia. The considerable range of quinoa cultivation is due to its high tolerance to extreme climatic and agrotechnical conditions. Quinoa can be grown in unfavourable soil conditions with high salinity, high alkalinity and lack of moisture deficits. The plant tolerates both high-mountain and lowland areas (Jakobsen and Stolen, 1993; Sułkowski et al., 2011; Steffolani et al., 2013). Due to the substantial variation in the geographic and agrotechnical conditions of quinoa cultivations individual cultivars of the species differ from one another in many morphological features e.g. growth and inflorescence colour and physicochemical properties (Gęsiński, 2008; Vega-Gálvez et al., 2010; Gęsiński, 2012; Jan et al., 2016; Li et al., 2016).

Quinoa seeds were the basic component of the diet of the Inca and Aztec people. Today quinoa seeds are used in Bolivia and Peru in soups, in refreshing drinks, and mixed with honey in energy bars (Steffolani et al., 2013). Peru is the primary producer and exporter of quinoa. In Poland, quinoa has been considered an exotic plant and was formerly used only as seasoning (Sułkowski et al., 2011). However, the last two decades seen a renaissance of this pseudocereal due to greater knowledge of its nutritive value. Quinoa seeds provide a well-balanced content of all nutrients, with a high protein content (12-22%) and unique amino acid composition. High content of lysine and sulphur-containing amino acids (methionine and cysteine) distinguish it from cereals. Moreover, the quinoa protein amino acid profile is most similar to the one recommended by the FAO and the WHO (Prakash and Pal, 1998; Sułkowski et al., 2011; Li et al., 2016). Due to its lack of gluten, quinoa is recommended in the diet of people suffering from coeliac disease and to supplement amino-acid-poor vegan and vegetarian diets (Steffolani et al., 2013; Elgeti et al., 2014). Today, quinoa seeds are used for the production of baby food, breadstuffs and extruded products.

An important component of quinoa seeds is carbohydrates, primarily represented by starch, whose content ranges from 53.5% to 69.2% in dry weight (Wright et al., 2012; Li et al., 2016). Quinoa starch grains 1-3 µm in size are located in the periderm layer of the seed (Ahamed et al., 1996). The content of amylose in starch ranges from 4% to 25% (Steffolani et al., 2013; Li et al., 2016). Short glucose chains predominate in the amylopectin structure. The low content of amylose and high degree of amylopectin branching affect the properties of this carbohydrate. The applicable literature provides information (Qian and Kuhn, 1999; Wright et al., 2012; Steffolani et al., 2013) on the properties of starch isolated from various quinoa cultivars. However, it is difficult to find information on the properties of starch isolated from the Faro cultivar grown in Poland. Such information is essential as plant growth conditions affect the properties of the polysaccharide.

The aim of this paper was to compare selected physicochemical and rheological properties of starch isolated from the Faro quinoa cultivar with commercial preparations of starch of various botanic origins.

MATERIALS AND METHODS

Materials

The research material included four kinds of starch of various botanical origin: potato starch (PS) (Superior Standard, WPZZ, Luboń), wheat starch (WS), maize (corn) starch (CS) (Cargill, Poland) and quinoa starch (QS). Faro quinoa seeds were derived from a field experiment performed in 2013 at the Experimental Cultivar Testing Station in Chrząstowo (53°11′ N, 17°35′ E), located in Nakło County, Kujawy and Pomorze Province. The research was carried out on Haplic Luvisol (sandy loam). The nutrient content in the soil was as follows: 68.17 mg/kg P, 150.77 K and 36.18 Mg and pH=6.1. Fertilization included 60 kg/ha N, 21 kg/ha P and 60 kg/ha K applied pre-sowing in the form of triple superphosphate and potassium chloride (60%), and nitrogen in the form of ammonium nitrate. Quinoa was sown at a rate of 9 kg of seeds per hectare on 5.05.2013 at 40 cm row spacing and 1-2 cm sowing depth. Harvest was carried out on 26.09.2013. Quinoa starch was isolated by a laboratory method in which the involved quinoa seeds were ground and the starch was washed from flour by a method used for cereal starches (Richter et al., 1968). The starch was dried at ambient temperature (about 25 °C), crushed in a lab grinder, and sieved through a sieve with mesh 0.125 mm in diameter. The content of dry matter was assayed in all the starches by the oven-drying method (Polish Standard PN-EN ISO 1666:2000, Polish Committee for Standardization, 2000).

Methods

Starch colour analysis

The colour of the starches was assayed using an X-Rite Colour i5 colour spectrophotometer from Invert Systems. An illuminant D_{65} was used with the d/8 measurement geometry and a 10° observer angle. The aperture was 10 mm. X-Rite Colour Master software was used to determine the values of the coordinates: L*- describing lightness, a*- expressing red-green balance, b*- expressing blue-yellow balance. The analysis was performed in three replications.

Starch paste clarity analysis

Paste clarity was determined by spectrophotometry method (Pycia et al., 2015). A suspension of the starches (1 g/100 g) was heated at 95 °C and continuously mixed with a mechanical stirrer (IKA Werke, Germany). The transmittance of the starch pastes was measured with a UV-Vis spectrophotometer (V 530, Jasco, Japan) at a wavelength of λ=640 nm. The measurements were taken in three replications.

Thermal properties

The thermal properties of the starches were recorded with an F204 Phoenix differential scanning calorimeter (DSC) (Netzsch, Germany). A mixture of starch (in dry weight) and water (1:3) was hermetically sealed in aluminum pans and left for 24 h to allow the starch to take up the water. The samples were heated in a calorimeter in a temperature range from 25 to 100 °C at a rate of 10 °C/min. An empty calorimetric pan served as the reference. Pasting thermograms were used to determine the onset temperature T_O, peak temperature T_P, end of peak temperature T_E and transition enthalpy ΔH_G (J/g). The analyses were performed in three replications.

Pasting properties

The pasting characteristics of 5% starch (in dry weight) suspensions were determined using the an RVA viscosity analyzer (Rapid Visco Analizer, TecMaster, Perten Instruments, Sweden). The samples (continuously mixed at a rate of 160 rpm) were kept at 50 °C for 1 min., heated to 95 °C at a rate of 12 °C/min, maintained at the temperature of 95 °C for 5 min, cooled down to 50 °C at the rate of 12 °C/min and, finally keep at 50 °C for 2 min. The viscograms provided the following readings: pasting temperature (TP), peak viscosity during heating (PV), viscosity at 95 °C (HPV), final viscosity at 50 °C (FV), drop in viscosity during heating, i.e. PV–HPV (BD), and the increase in viscosity during cooling, value: FV-HPV (SB).

Statistical analysis

The significance of differences between means, was evaluated using one-way analysis of variance and Duncan's test at a significance level of P=0.05. The calculations were made in Microsoft Office Excel (2007) and StatSoft Statistica 9.0. Additionally, Principal Component Analysis (PCA) was used to visualize the differences and similarities between the starches.

A statistical evaluation of the physicochemical properties of the starch from the four species (potato, wheat, maize and quinoa) was also performed by multivariate profile method (Brzeziński, 2002; Jędrzejczak and Nowaczyk, 2006). Prior to the analysis, data transformation was performed for all characteristics separately to the same interval scale (9- point), which was used to develop models (profiles) describing the physicochemical properties of the starches.

The profiles were compared using Cohen's profile similarity coefficient r_c, as calculated from the following formula:

$$r_c = \frac{\sum_{i=1}^{n} A_i B_i + nm^2 - m\left(\sum_{i=1}^{n} A_i + \sum_{i=1}^{n} B_i\right)}{\sqrt{\left(\sum_{i=1}^{n} A_i^2 + nm^2 - 2m\sum_{i=1}^{n} A_i\right)\left(\sum_{i=1}^{n} B_i^2 + nm^2 - 2m\sum_{i=1}^{n} B_i\right)}} \quad (1)$$

where:

A_i, B_i –transformed values of features in profiles A and B,

n – number of features in the profile,

m – midpoint of the rating scale.

The value of the coefficient was measured in the range (0 ± 1). For $r_c<0$, then the similarity of profiles was considered negative and for $r_c>0$ the similarity was positive. An r_c = value of 0 or close to zero indicated, a lack of similarity. The closer the rc values were to the limit values (-1) or (+1), the greater the similarity of the profiles.

RESULTS AND DISCUSSION

Starch colour and paste clarity

The colour of the starches of various botanical origins was analysed in the CIE L*a*b* colour space (L* lightness, a* red-green balance, b* blue-yellow balance). Table 1 presents the starch colour parameters. The results showed the highest value of parameter L* for maize (corn) starch (90.22) and the lowest values of that variable were observed for potato and wheat starch but no significant differences were found (Table 1). In the case of quinoa starch, the L* value was 88.87, which was lower than the value for starch derived from the seeds of white goosefoot (*Chenopodium album*) (Jan et al., 2016). The authors cited reported L* the values ranging from 95.95 to 96.83 in the starches. According to Jan et al. (2016), the value of the lightness parameter affects the whiteness of flour, which is an important parameter of its value for processing. The high L* value for the maize starch may have resulted from a relatively high content of fatty substances, which is a botanical characteristic of the species. Parameter a* had a negative value in all the samples, which indicates that the colour green made the greatest contribution to the overall impression of colour. All the starches demonstrated positive values for parameter b*, but the cereal starches and quinoa had higher values than the potato starch, by about two units (Table 1). The b* value for quinoa starch was 4.31, which was lower than for the cereal starches.

Table 1. Parameters of the colour of the starches

Starch	*L**	*a**	*b**
PS	87.46±0.01[a]	-0.31±0.02[a]	2.73±0.06[b]
CS	90.22±0.1[b]	-0.84±0[b]	4.76±0.07[a]
WS	87.43±0.05[a]	-0.04±0.01[c]	4.64±0.13[a]
QS	88.87±0.06[c]	-0.22±0[d]	4.31±0.05[c]

[a,b,c,d] Means in columns marked with the same letters do not show significant differences at the significance level of P=0.05. PS – potato starch, CS – maize starch, WS – wheat starch, QS – quinoa starch, L* - lightness, a* - red-green balance, b* - blue-yellow balance

Clarity analysis of the starch pastes involved spectrophotometric measurement of transmittance i.e. the amount of light transmitted by a layer of paste, expressed as a percentage. The results are presented in the form of a bar chart (Figure 1). The highest clarity was found for potato starch (88%) (Figure 1). The clarity of the cereal and quinoa starches was much lower, ranging from 1.3% (QS) to 2.8% (WS). The quinoa starch paste was the least clear. The clarity of the quinoa starch was lower than that reported by another author (Ahamed et al., 1996). According to cited researchers (Ahamed et al., 1996) the poor clarity of quinoa starch pastes is due to the small size of the starch granules (1-3 µm). A botanical trait of quinoa is its high content of non-starch components, which may have reduced the clarity of its starch paste. The opaque nature of this starch is a desirable quality characteristic for salad dressing.

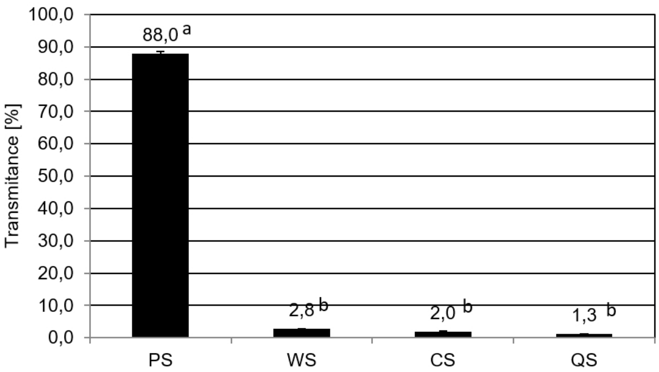

Figure 1. Pastes clarity of starch of various botanical origin (PS – potato starch, CS – maize starch, WS – wheat starch, QS – quinoa starch. [a, b] Means in columns marked with the same letters do not show significant differences at the significance level of P<0.05.)

The clarity of starch pastes is a function of many factors including the ratio of amylose to amylopectin and the content of non-starch substances, primarily fat (Pycia et al., 2012). In addition, as reported by Singh and Singh (2001), factors causing pastes to become cloudy during storage include starch granule imbibition, presence of granule residue in the paste, amylose and amylopectin leakage from starch granules, chain length, intra- and intermolecular interactions, and cross-linking between chains.

Thermodynamic characteristics of starch pasting

Starch pasting and water-binding capacity for water bonding are two properties which depend on the molecular structure of amylopectin (chain length, branching ratio, and molecular weight) as well as on the ratio of amylose to amylopectin and the content of non-starch substances (Steffolani et al., 2013). Figure 2 presents a DSC thermogram demonstrating thermal changes during heating of starch paste. Analysis of the diagram reveals marked variation in starch in terms of thermal transformations during pasting. The thermodynamic pasting characteristics parameters have been broken down in Table 2. The characteristic transition onset temperatures To ranged from 58 °C (QS) to 67.2 °C for corn starch. The T_o value for quinoa was higher than those recorded for various quinoa cultivars by other authors (Wright et al., 2012; Steffolani et al., 2013; Li et al., 2016), which ranged from 50 °C to 55.7 °C. Maize starch demonstrated the highest peak temperature T_p (72.1 °C), and the final transition temperature T_E ranged from 70.1 °C (WP) to 77.9 °C (CS). The occurrence of differences in transition temperature ranges are linked to the varied level of crystallinity of the starches.

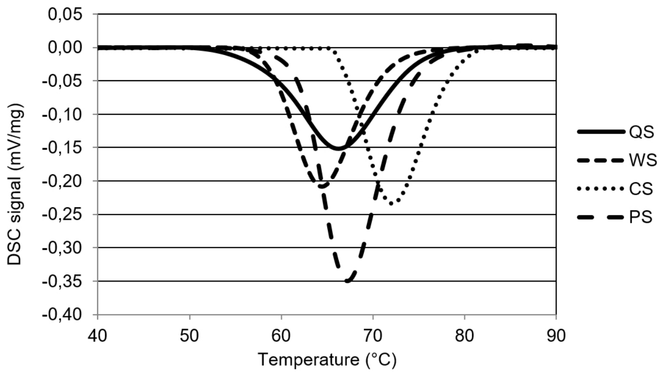

Figure 2. DSC thermogram of the starches of a various botanical origin (PS – potato starch, CS – maize starch, WS – wheat starch, QS – quinoa starch)

According to Singh and Singh (2001), starch granules with a higher level of crystallinity paste at their greater temperature due to a higher stability and resistance to high temperature and the presence of water. Variation in the pasting characteristics of starches stems from differences in amylopectin structure of amylopectin, amylose levels, granule size, and the content of non-starch substances (Srichuwong and Jane, 2007; Li et al., 2016). The transition enthalpy value ΔH_G ranged from 10 J/g for wheat starch to 16.4 J/g for potato starch, but the values for WS and QS did not differ significantly. Furthermore, the cereal and quinoa starches demonstrated a lower value for the parameter, than potato starch. The determined ΔH_G values were consistent with than administered to by other authors (Tang et al., 2002). However, Jan et al. (2016) reported lower value ΔH_G for QS.

Table 2. Parameters of thermodynamic pasting characteristics of starches

Starch	T_O [°C]	T_P [°C]	T_E [°C]	ΔH_G [J/g]
PS	62.5 ± 0.1^{a}	67.1 ± 0.1^{a}	73.5 ± 0.1^{a}	16.4 ± 0.1^{c}
CS	59.4 ± 0.2^{b}	64.3 ± 0.1^{b}	70.1 ± 0.2^{b}	10 ± 0.1^{a}
WS	67.2 ± 0.1^{c}	72.1 ± 0.1^{c}	77.9 ± 0.1^{c}	12.1 ± 0.1^{b}
QS	58 ± 0.1^{d}	66.2 ± 0.1^{d}	74.5 ± 0.2^{d}	10.1 ± 0.3^{a}

[a,b,c,d] Means in columns marked with the same letters do not show significant differences at the significance level of P=0.05. PS – potato starch, CS – maize starch, WS – wheat starch, QS – quinoa starch.

Transition enthalpy reflects the amount of energy needed to disintegrate the ordered structure of the starch granule and depends on the availability of water, and thus the starch to water ratio. A low transition enthalpy value indicates a low molecular weight and a shorter chain length in the amylopectin structure (Steffolani et al., 2013). The transition enthalpy value is affected by many other factors. In the case of potato starch, these include granule shapes and sizes, the degree of crystallinity level, and the content of phosphate groups (Pycia et al., 2012). Numerous authors have reported that, the thermal properties of starch are influenced by many factors, e.g. the size and shape of starch granules, the content of phosphorus and other non-starch substances, amylopectin chain length, and the presence and size of crystalline regions in starch granules (Singh et al., 2003; Singh et al., 2007). According to Yasui et al. (2002) the amylopectin structure and starch granule size (Svihus et al., 2005) are the key factors affecting the transition enthalpy value.

Starch pasting characteristics

Starch pasting characteristics are an essential parameter providing information on the starch behaviour in heating and cooling cycles during food production. During heating of a starch suspension in water, the starch granules swell and break and as a result, amylose escapes and a colloidal solution is formed. Cooling of such a system increases viscosity, being a result of the formation of a three-dimensional network made up of amylose and amylopectin chains connected by hydrogen bonds, which is capable of holding water. Further cooling, with a high concentration of starch in the solution results in the formation of an elastic gel (Hoover, 2001). Starch behaviour during pasting in aqueous systems depends on the physical and chemical properties of the starch granules, e.g. their mean size, size distribution, the ratio of amylose to amylopectin, imbibition capacity, and mineral content (Singh et al., 2003; Pycia et al., 2015). When starch pasting occurs above the characteristic temperature referred to as the pasting temperature, the viscosity of the starch mixture increases sharply to reach the maximum viscosity. Further heating of the starch suspension leads to a decrease in viscosity; however, at the cooling stage the viscosity increases to a specific maximum. Such changes in viscosity are observed pasting curves. The pasting curves for the starches of different botanical origins are given in Figure 3a and b. Of all the starches studied, potato starch (PS) has demonstrated the highest viscosity when heated (Figure 3a), followed by a rapid drop in viscosity during further heating and a slight increase during cooling. In the case of the cereal and quinoa starches, maize starch (CS) and quinoa starch

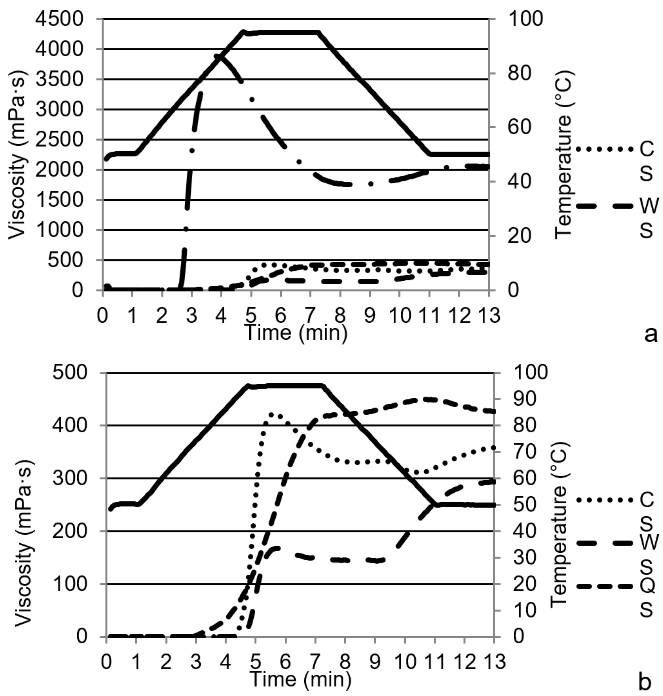

Figure 3. Characteristics of pasting for the starch of various botanical origin (a) as well as corn and wheat and quinoa starches (b) (PS – potato starch, CS – corn starch, WS – wheat starch, QS – quinoa starch)

(QS) demonstrated the highest maximum paste viscosity values with no significant differences between them (Figure 3b). In the maize starch, a slight drop in paste viscosity was noted during cooling The pasting curves indicate, the lowest viscosity for wheat starch (WS), with the paste viscosity decreasing slightly during further heating and increasing significantly during cooling; hence the final viscosity of this paste was higher than its maximum viscosity. The pasting parameters are broken down in Table 3. All the starches analysed demonstrated significantly different pasting temperatures, with the highest values recorded for the corn and wheat starches, and the lowest for quinoa starch (Table 3). The pasting temperature of quinoa starch was similar to that reported by other authors (Wright et al., 2012; Steffolani, 2013; Li et al., 2016). Jan et al. (2016) reported that the pasting temperature for the starch from the seeds of white goosefoot (*Chenopodium album*) was 76 °C. According to Sandhu and Singh (2007) and Pycia et al. (2015) a high pasting temperature reflects granule resistance to imbibition and, thus pasting. A high pasting temperature for maize and wheat starches can result from the formation of phospholipid-amylose complexes limiting the water holding capacity of granules and thus the pasting process (Song and Jane, 2000). The increased pasting temperature for the cereal, (maize and wheat) starches is a result of their higher content of fats and proteins, which bond amylose in a form of complexes and thus make its inhibition difficult (Le-Thanh-Blicharz et al., 2011). The starches demonstrated variation in the maximum viscosity value, with the highest value recorded for potato starch paste (3,886 mPa·s). The maximum viscosity of CS and QS did not differ significantly. The lowest viscosity was recorded for wheat starch paste (162 mPa·s). The viscosity values of the pastes derived from various quinoa cultivars investigated by Wright et al. (2012) and Li et al. (2016) were similar to those noted in this research, ranging from 321 mPa·s to 448 mPa·s, whereas Jan et al. (2016) showed higher viscosity values for pastes from starch isolated from quinoa seeds. The pasting parameter specifying the drop in viscosity during further heating of the starch paste is BD, which was highest for the paste derived from potato starch and the lowest for the wheat starch paste. According to Jan et al. (2016), the BD parameter indicates the rheological stability of paste during heating. Among the cereal and quinoa starches the highest final viscosity values were recorded for the quinoa starch paste, but the highest increase in viscosity after the cooling was observed for wheat starch.

Comparison of physicochemical properties of starches derived from the species studies

Figure 4 shows results of principal component analysis (PCA) of the physicochemical properties of starches of various botanical origins. The first two factors explain 90.23% of the total variance (eigenvalues of 5.45 and 1.76, respectively). Figure 4a shows distribution of the variables on the plot of factors. PV, BD, FV, clarity and ΔH_G were found to play an important role for the first factor, and mainly for parameters T_o, L* and PT for the second factor. Figure 4b distribution of the analysed starches on the plot of factors 1 and 2 are presented. Factor 1 clearly separates potato starch (PS) from the others. Factor 2

Table 3. Parameters of the characteristics of pasting for the starches of a various botanical origin

Starch	PT (°C)	PV (mPa·s)	HPV (mPa·s)	BD (mPa·s)	FV (mPa·s)	SB (mPa·s)
PS	69±0.5a	3,886±8^{b}	1,747±13^{c}	2,139±57^{a}	2,047±43^{a}	300±21^{a}
CS	93.2±0.46^{b}	419±5^{a}	307±2^{a}	110±2^{b}	351±3^{b}	44±1^{b}
WS	94.6±0^{c}	162±2^{c}	137±2^{b}	26±2^{c}	279±10^{c}	144±9^{c}
QS	66±0.3^{d}	398±8^{a}	309±7^{a}	88±6^{d}	413±9^{d}	104±5^{d}

^{a,b,c,d} Means in columns marked with the same letters do not show significant differences at the significance level of P=0.05. PS – potato starch, CS – corn starch, WS – wheat starch, QS – quinoa starch.

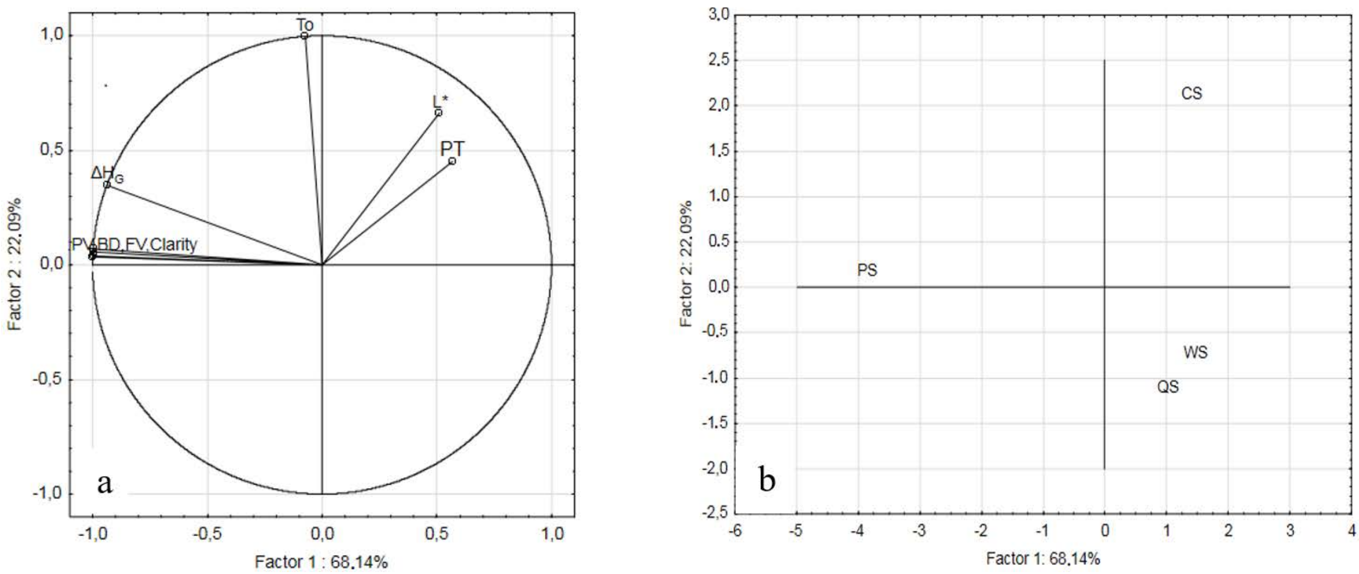

Figure 4. Principal component analysis: (a) distribution of analysed parameters, ΔH_G - transition enthalpy, clarity, PV - peak viscosity, FV - final viscosity, BD - breakdown, T_o - onset temperature, PT - pasting temperature, L* - describing lightness, (b) distribution of starch of various botanical origin (PS – potato starch, CS – maize starch, WS – wheat starch, QS – quinoa starch)

shows that there are similarities for wheat starch (WS) and quinoa starch (QS) in comparison with corn starch (CS) and potato starch (PS).

For a full characterization of the physicochemical properties of the starches derived from the four species a profile analysis was carried out by developing multivariate -models. The systems were compared across the objects. The models of the physicochemical properties of the starches differed from one another (Figures 4 a, b). For a precise comparison, Cohen's coefficients of similarity r_c were calculated, and indicated the highest similarity between the starches derived from quinoa and wheat (r_c=0.63) (Table 4). This similarity also confirms the pattern of the multivariate models (Figures 4 a, b). A lack of similarity was noted between the maize and quinoa starches and low similarity between the maize and wheat.

Table 4. Cohen's similarity coefficient r_c for the models of physicochemical parameters of starch

Species	Potato	Wheat	Corn
Quinoa	-0.61	0.63	0.31
Potato		-0.68	-0.89
Wheat			0.49

PS – potato starch, CS – maize starch, WS – wheat starch, QS – quinoa starch

A high negative similarity was observed between potato and maize (r_c = -0.89), and slightly lower similarity between potato and wheat (r_c = -0.68) and potato and quinoa (r_c= -0.61). The results confirm that potato starch is very much different in terms of physicochemical differences from the starches derived from cereals (wheat and maize) and the pseudocereal (quinoa) (Figure 5). Differences between potato starch and starches of different botanical origins have been confirmed by numerous reports (Hoover, 2001; Leszczyński, 2001; Singh et al., 2003).

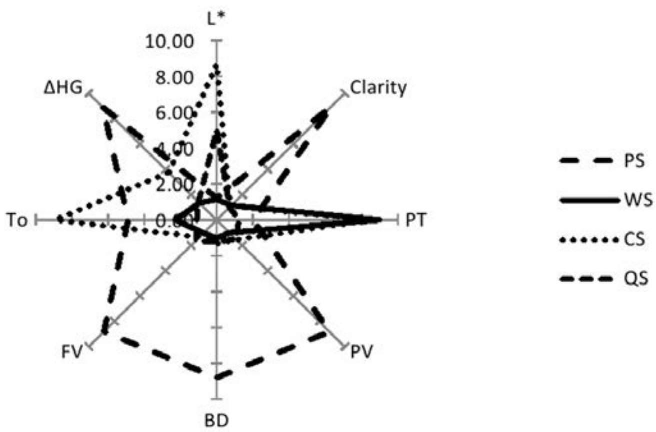

Figure 5. Models of the physicochemical parameters of starches derived from various species (PS – potato starch, CS – maize starch, WS – wheat starch, QS – quinoa starch)

CONCLUSIONS

The results of research results have demonstrated that quinoa starch differed in terms of physicochemical and rheological properties from the other starches of various botanical origins. The paste of the starch isolated from quinoa showed the lowest clarity, but its clarity was similar to that of the pastes from the cereal starches. Quinoa starch differed from the potato, wheat and corn starches in terms of its thermodynamic and rheological pasting parameters. QS had the lowest pasting temperature of all the starches, and the paste derived from this starch, had higher value of final viscosity, than the pastes from cereal starches. Owing to the interesting properties of quinoa starch, it can be used in food technology in place of wheat starch, which it most resembles. Another advantage that supports wider application not only starch but also flour from quinoa is its lack of gluten a strong allergen. This means that quinoa can be a component ingredient of gluten-free diets, especially that wheat flour is added to products as a filler, which unfortunately completely eliminates them from the diet of people suffering from coeliac disease.

REFERENCES

Abugoch, J. L. E. (2009) Quinoa (Chenopodium quinoa Willd.): Composition, chemistry, nutritional, and functional properties. Advances in Food and Nutrition Research, 58, 1-31. DOI: https://doi.org/10.1016/S1043-4526(09)58001-1

Ahamed, N. T., Singhal, R. S, Kulkarni, P. R., Pal, M. (1996) Physicochemical and functional properties of *Chenopondium quinoa* starch. Carbohydrate Polymers, 31, 99-103. DOI: https://doi.org/10.1016/S0144-8617(96)00034-3

Brzeziński, J. (2002) Psychological study methodology. Warszawa: Wydawnictwo Naukowe PWN Warszawa. (in Polish)

Elgeti, D., Nordlohne, S. D., Foste, M., Besl, M., Linden, M. H., Heinz, V., Jekle M., Becker, T. (2014) Volume and texture improvement of gluten-free bread using quinoa white flour. Journal of Cereal Science, 59, 41-47. DOI: https://doi.org/10.1016/j.jcs.2013.10.010

Gęsiński, K. (2008) Evaluation of American and European cultivars of quinoa (*Chenopodium quinoa* Willd.) in the conditions of Poland. Fragmenta Agronomica, 2 (98), 49-60. (in Polish)

Gęsiński, K. (2012) Biological and agrotechnical-functional conditions of growing quinoa (*Chenopodium quinna* Willd.). Bydgoszcz: Rozprawy, Wydawnictwo Uczelni UTP Bydgoszcz.

Hoover, R. (2001) Composition, molecular structure and physicochemical properties of tuber and root starches: a review. Carbohydrate Polymers, 45, 253-267. DOI: https://doi.org/10.1016/S0144-8617(00)00260-5

Jakobsen, S. E., Stolen, O. (1993) Quinoa-morphology, phenology and prospects for its production as a new crop in Europe. European Journal of Agronomy, 2, 19-29. DOI: https://doi.org/10.1016/S1161-0301(14)80148-2

Jan, R., Saxena, D. C., Singh, S. (2016) Pasting, thermal, morphological, rheological and structural characteristics of Chenopodium (*Chenopodium album*) starch. LWT - Food Science and Technology, 66, 267-274. DOI: https://doi.org/10.1016/j.lwt.2015.10.040

Jędrzejczak, E., Nowaczyk, L. (2006) Applying interpolation analysis in *Capsicum annuum* breeding studies. Colloquium Biometryczne, 36, 159-170. (in Polish)

Leszczyński, W. (2001) Variation in starch properties. Food Industry, 55, 38-39. (in Polish)

Le-Thanh-Blicharz, J., Lubiewski, Z., Voelkel, E., Lewandowicz, G. (2011) Evaluation of rheological commercial properties of natural starches. Food. Science. Technology. Quality, 3 (76), 53-65. (in Polish)

Li, G., Wang, S., Zhu, F. (2016) Physicochemical properties of quinoa starch. Carbohydrate Polymers, 137, 328-338. DOI: https://doi.org/10.1016/j.carbpol.2015.10.064

Polish Committee for Standardization (2000) Polish Standard PN-EN ISO 1666:2000 Starch. Moisture determination. Drying method. Warszawa: Polish Committee for Standardization.

Prakash, D., Pal, M. (1998) Chenopodium: seed protein, fractionation, and amino acid composition. International Journal of Food Science and Nutrition, 49, 271-275. DOI: https://doi.org/10.3109/09637489809089398

Pycia, K., Juszczak, L., Gałkowska, D., Witczak, M. (2012) Physicochemical properties of starches obtained from polish potato cultivars. Starch/Stärke, 64 (2), 105-114. DOI: https://dx.doi.org/10.1002/star.201100072

Pycia, K., Gałkowska, D., Juszczak, L., Fortuna, T., Witczak, T. (2015) Physicochemical, thermal and rheological properties of starches isolated from malting barley varieties. Journal of Food Science and Technology Mysore, 52 (8), 4797-4807. DOI: https://doi.org/10.1007/s13197-014-1531-3

Qian, J. Y., Kuhn, M. (1999) Characterization of Amaranthus cruentus and Chenopodium quinoa starch. Starch/Stärke, 51, 116-120. DOI: https://doi.org/10.1002/(SICI)1521-379X(199904)51:4<116::AID-STAR116>3.0.CO;2-R

Richter, M., Augustat S., Schierbaum, F. (1968) Ausgewähle Metoden der Stärkechemie. Leipzing: VEB Fachbuchverlag.

Sandhu, S. K., Singh, N. (2007) Some properties of corn starches II: Physicochemical, gelatinization, retrogradation, pasting and gel textural properties. Food Chemistry, 101, 1499-1507. DOI: https://doi.org/10.1016/j.foodchem.2006.01.060

Singh, J., Singh, N. (2001) Studies on the morphological, thermal and rheological properties of starch separated from some Indiana potato cultivars. Food Chemistry, 75, 67-77. DOI: https://doi.org/10.1016/S0308-8146(01)00189-3

Singh, N., Singh, J., Kaur, L., Singh Sodhi, N., Singh Gill, B. (2003) Morphological, thermal and rheological properties of starches from different botanical sources. Food Chemistry, 81, 219-231. DOI: https://doi.org/10.1016/S0308-8146(02)00416-8

Singh, J., Kaur, L., McCarthy, O. J. (2007) Factors influencing the physico-chemical, morphological, thermal and rheological properties of some chemically modified starches for food applications-a review. Food Hydrocolloids, 21, 1-22. DOI: https://doi.org/10.1016/j.foodhyd.2006.02.006

Song, Y., Jane, J. (2000) Characterization of barley starches of waxy, normal, and high amylase varieties. Carbohydrate Polymers, 41, 365-377.
DOI: https://doi.org/10.1016/S0144-8617(99)00098-3

Srichuwong, S., Jane, J. L. (2007) Physicochemical properties of starch affected by molecular composition and structures. Food Science Biotechnology Journal, 16, 663-674.

Steffolani, M. E., Leon, A. E., Perez, G. T. (2013) Study of the physicochemical and functional characterization of quinoa and kaniwa starches. Starch/Stärke, 65, 976-983.
DOI: https://doi.org/10.1002/star.201200286

Sułkowski, M., Gawlik-Dziki, U., Czyż, J. (2011) Quinoa; a hardly known pseudocereal with rocket-science properties. Cosmos - the problems of biological sciences, 60, 3-4, 475-481. (in Polish)

Svihus, B., Uhlen, A. K., Harstad, O. M. (2005) Effect of starch granule structure, associated components and processing on nutritive value of cereal starch: a review. Animal Feed Science and Technology, 122, 303-320.
DOI: https://doi.org/10.1016/j.anifeedsci.2005.02.025

Tang, H., Watanabe, K., Mitsunaga, T. (2002) Characterization of storage starches from quinoa, barley and adzuki seeds. Carbohydrate Polymers, 49, 13-22.
DOI: https://doi.org/10.1016/S0144-8617(01)00292-2

Vega-Gálvez, A., Miranda, M., Vergara, J., Urbine, E., Puente, L., Martinez, E. A. (2010) Nutrition facts and functional potential of quinoa (*Chenopodium quinoa* Willd.), an ancient Andean grain: A review. Journal of the Science of Food and Agriculture, 90, 2541-2547.
DOI: https://doi.org/10.1002/jsfa.4158

Wright, K. H., Huber, K. C., Fairbanks, D. J., Huber, C. S. (2012) Isolation and characterization of *Atriplex hortensis* and sweet *Chenopodium quinoa* starches. Cereal Chemistry, 79, 715-719.
DOI: http://dx.doi.org/10.1094/CCHEM.2002.79.5.715

Yasui, T., Seguchi, M. N., Ishikawa, Fujita, M. (2002) Starch properties of a waxy mutant line of hull-less barley (*Hordeum vulgare* L.). Starch/Staerke, 54, 179-184.
DOI: https://doi.org/10.1002/1521-379X(200205)54:5<179::AID-STAR179>3.0.CO;2-3