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PHYSICOCHEMICAL PROPERTIES OF POTATO DRY MATTER ISOLATED FROM VARIOUS CULTIVARS AT DIFFERENT TIMES DURING GROWTH

Summary

Potato dry matter was isolated from three cultivars of potato tubers at different times during growth. The physicochemical properties of these potato dry matters were characterized for starch and protein content, thermal properties by differential scanning calorimtery (DSC) and paste properties by rapid viscosity analysis (RVA). Dry matter content of potato tubers increased to the highest level and then decreased as growth processed. Superior cultivar potato had a lowest dry matter content and the highest protein content as compared to Snowden and Shepody potatoes. Gelatinization enthalpy and temperature of dry matter varied with growth times and potato cultivars. Immature potato tubers (the earliest harvest) resulted in the highest temperatures for gelatinization, pasting and retrogradation of dry matter, indicating the molecular structure of starch plays an important role in the functional properties of potato dry matter. The quality of table and processing potato could be affected by growth times and cultivars.

Introduction

Fresh potato tubers contain 13 to 37% dry matter which includes starch, cellulose, hemicellulose and ash, and 63 to 87% of water and water-soluble components such as carbohydrates, proteins, phenolic substances, mineral components and organic acids [10]. Chemical composition and structure of components such as starch, non-starch polysaccharide, sugars, organic and inorganic compounds, and proteins influence the properties of potatoes and potato products [6, 7, 8]. The yield of potato chips and French fries, and the texture of French fries and canned and reconstituted dehydrated potatoes are directly related to the dry matter content of the potatoes [3].

However, no information is available on the physicochemical properties of dry matter due to the complexity of the potato. In this paper, we report the physicochemi-

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cal properties of dry matter isolated from various cultivars at different times during growth. The objective of this study was to provide the physicochemical analysis tools for characterizing the functional properties of potato dry matter and for predicting the quality of potato tubers. The effect of major components of potato dry matter on the functional properties is also discussed.

Materials and methods

Materials

Three potato varieties (Superior, Shepody and Snowden) grown at the Cambridge Research Station, University of Guelph, Cambridge, Ontario (Canada) were harvested at different growth times in the year 2000 season and were stored at room temperature for one day before isolation of dry matter and starch.

Potato dry matter was isolated according to the method of Liu et al [5].

Methods

Dry matter content

Dry matter content was determined from the difference in the weight of potato samples before and after freeze-drying in a Freeze Dryer 8 (Labconco®, Kansas City, MO, USA). Moisture content of dry matter was measured by weighing samples (triplicate) before and after drying at 85°C and 710–740 mm Hg vacuum for 7 hr.

Starch content

Starch content of dry matter isolated from various cultivars at different times during growth was determined based on AACC method 76.13 [1] with modification [5]. To 100 mg potato dry matter, 100 μL (300U) α-amylase (Sigma A-6380, St. Louis, MO) solution, and 2.9 mL 45 mM MOPS buffer (pH 7.0) were added. The sample was heated in a boiling water bath for 6 min with constant stirring, was then cooled to below 50°C. 100 μL (20U) amyloglucosidase (Sigma A-7255, St. Louis, MO) and 3.9 mL 200 mM sodium acetate buffer (pH 4.5) were added to the sample. The sample was mixed well and incubated at 50°C for 30 min with constant stirring. The glucose content of supernatants was measured by YSI 2700 Select Biochemistry Analyzer (Yellow Springs, Ohio, USA). Pure starch from different potatoes was employed as a standard in every batch experiment to verify enzyme activity. Starch content of potato dry matter was expressed as a ratio of glucose content in the dry matter to glucose content in pure starch following starch hydrolysis. Blank samples (without enzymes) were also measured using the same protocol. Finally, starch content in potato tubers was expressed by multiplying dry matter content by starch content in dry matter. The reported values are the means of triplicate measurements.

Protein content

Protein content of dry matter was determined by using a ThermoQuest CE Instruments NA 2100 Protein Analyzer (ThermoQuest Italia S.P.A., MI) according to AACC method 46-30 (AACC). The nitrogen content was determined using software (Eager 200 for Windows™, Version 1.02, ThermoQuest Italia S.P.A., MI). Atropine, DL-methionine, acetanilide and nicotinamide were used as standards. Protein content was calculated by multiplying nitrogen content by the factor 6.25. The reported values are means of triplicate measurements.

Differential Scanning Calorimetry (DSC)

Thermal analyses were performed using a differential scanning calorimeter (2920 modulated DSC; TA Instruments, New Castle, DE, USA) for dry matter gelatinization and retrogradation. Samples of dry matter were weighed into high-volume pans (Part number: 900825-902; TA Instruments, New Castle, DE, USA). Distilled water was added to make suspensions with 70% moisture content. Pans were sealed and equilibrated for 2–4 h at room temperature before heating in the DSC. The measurements were carried out at a heating rate of 10°C/min from 5 to 180°C. Sample weights were about 20 mg. The instrument was calibrated using indium and an empty pan as reference. The enthalpy (ΔH) of phase transitions was measured from the endotherm of DSC thermograms using software (Universal Analysis, Version 2.6D, TA Instruments) based on the mass of dry solid. Peak temperature (Tp) of endotherms was also measured from DSC thermograms.

After heating to 180°C, samples were air-cooled to 5°C. Once the temperature reached 5°C, the sample was immediately removed from the DSC and stored in a refrigerator (5°C). After 14 days, the sample pan was removed from the refrigerator and placed into the sample holder of the DSC. Stored samples were heated from 5°C to 180°C at 10°C/min. The enthalpy (ΔH) and peak temperature (Tp) of the endotherm was measured from DSC thermograms based on dry solid mass. The reported values are means of duplicate measurements.

Rapid Viscosity Analysis (RVA)

A Rapid Visco™ Analyser RVA-4 (Newport Scientific Pty. Ltd, Warriewood, NSW, Australia) was employed to measure the pasting properties of potato dry matters (8% dsb, 28 g total weight). Experiment was performed using STD 2 profile (AACC method 76–21), in which the sample was equilibrated at 50°C for 1 min, heated at

6°C/min to 95°C, held at 95°C for 5 min, cooled at 6°C/min to 50°C, and held at 50°C for 2 min. The speed was 960 rpm for the first 10 s, then 160 rpm for the remainder of the experiment. Peak viscosity, final viscosity and pasting temperature of starches were compared from pasting curve.

Results and discussions

Dry matter, starch and protein contents of potato dry matter isolated from various cultivars at different times during growth

Due to the differences among cultivars in tuber growth rates and the harvest dates were different for the selected cultivars. Superior was planted earlier than Shepody and Snowden seed potatoes. Dry matter, starch, protein and moisture contents were measured for samples isolated from various cultivars at different times during growth. The results are presented in Table 1. Dry matter content was 16.6, 21.0 and 18.6% (w/w) in the fresh potato tubers for Superior, Shepody and Snowden cultivars, respectively, at the earliest harvest time. As growth time increased, dry matter content in the tubers increased to its highest level between 64 and 71 days, then decreased. The highest dry matter content for Superior potato was 19.2% at 64 days, 24.2% for Shepody potato at 71 days, and 24.0% for Snowden potato at 71 days. Superior tubers had a lower dry matter content than Shepody and Snowden tubers at all harvest days. These results were consistent with previous studies [2, 9] on dry matter content as a function of tuber growth time. Potato tubers high in dry matter may be suitable for the manufacture of dehydrated food products and they may also be suitable for storage [3].

Starch content of dry matter varied with potato cultivar and growth time and ranged from 66 to 80%. Starch content was 66.0, 67.2 and 71.1% at the earliest time and was 79.7, 74.3 and 75.6% in the dry matter of potato harvested at the longest growth time for Superior, Shepody and Snowden cultivars, respectively. The highest starch content in potato dry matter was 80.4% for Superior potato at 84 days, 78.1% for Shepody potato at 91 days and 78.4% for Snowden at 91 days. Based on this study, potatoes with higher dry matter and starch content could be obtained by selecting specific potato cultivars and harvesting at specific times.

The protein content in the dry matter ranged from 9.9 to 15.2%. It was 11.6, 13.9 and 15.2% harvested at the shortest growth time and was 11.3, 11.8 and 13.8% in the dry matter of potato harvested at the longest growth time for Shepody, Snowden and Superior cultivars, respectively. The change of protein content in the dry matter was small when the growth time increased. However, protein content was dependent on the potato cultivar with Superior having higher protein content than either Shepody or Snowden.

Table 1

Dry matter, starch and protein content of tubers at different growth times.

Cultivar	Growth time (day)	Dry matter content of tuber (%, w/w)*	Moisture content of dry matter (%, w/w)*	Starch content of dry matter (%, w/w)*	Protein content of dry matter (%, w/w)*
	55	21.0 ± 0.6	6.0 ± 0.1	67.2 ± 1.4	11.6 ± 0.0
	71	24.2 ± 0.9	6.4 ± 0.1	77.6 ± 1.3	11.2 ± 0.1
Shepody	91	20.1 ± 0.9	5.1 ± 0.1	78.1 ± 1.4	11.8 ± 0.1
	112	18.8 ± 1.0	6.3 ± 0.0	74.8 ± 1.7	13.9 ± 0.1
	124	19.8 ± 0.4	4.0 ± 0.0	74.3 ± 5.2	11.3 ± 0.2
	55	18.6 ± 1.6	6.7 ± 0.2	71.1 ± 1.2	13.9 ± 0.2
	71	24.0 ± 1.3	6.1 ± 0.3	77.2 ± 3.0	9.9 ± 0.2
Snowden	91	20.9 ± 0.6	5.1 ± 0.1	78.4 ± 2.4	10.0 ± 0.1
	112	17.8 ± 1.5	7.5 ± 0.2	75.8 ± 2.8	12.8 ± 0.2
	124	19.8 ± 1.0	3.9 ± 0.0	75.6 ± 1.4	11.8 ± 0.3
	48	16.6 ± 0.2	6.1 ± 0.0	66.0 ± 1.2	15.2 ± 0.1
	56	16.2 ± 0.4	6.0 ± 0.1	72.7 ± 0.7	13.1 ± 0.0
Superior	64	19.2 ± 1.0	5.8 ± 0.0	77.5 ± 1.0	13.8 ± 0.3
	84	17.3 ± 1.0	5.8 ± 0.0	80.4 ± 0.4	13.1 ± 0.2
	117	16.9 ± 1.1	3.8 ∀ 0.1	79.7 ± 0.9	13.8 ∀ 0.2

*Value denotes mean ± standard deviation

Thermal properties of dry matter from potato with different growth times and cultivars

When potato dry matters were heated in the presence of excess water (70%), a single symmetrical endothermic transition was observed between 70.9 and 79.1°C as shown in Figure 1. A similar behavior was observed for the dry matters' corresponding starch [5]. In that study, an endothermic transition was observed between 70.0 and 74.8°C. Table 2 lists the gelatinization and retrogradation properties of potato dry matters. The thermal properties of potato dry matter were influenced by growth times and cultivar of tubers. At the earliest harvest time, the gelatinization temperature (both Tp and To) of potato dry matter was the highest for all three potato cultivars. Similar results were found for their pure starch [5]. As the harvest time increased, gelatinization temperature of dry matter decreased and then remained at the same range. Due to the other components in the sample, gelatinization temperature of dry matter was about 4°C higher than corresponding starch.

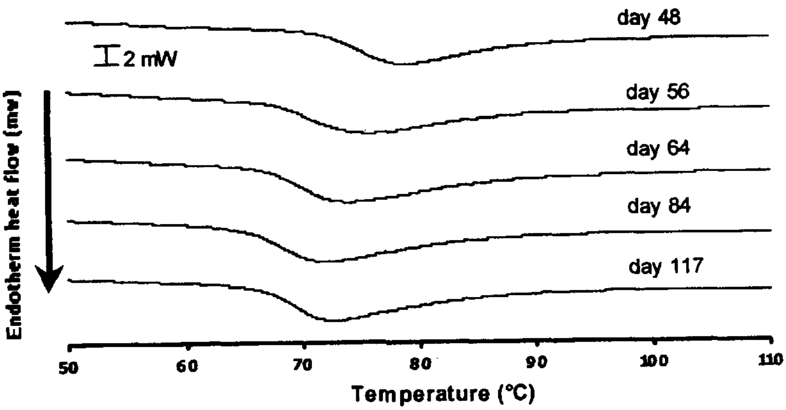

Fig. 1. DSC thermograms of potato dry matter with 70% moisture content during heating (gelatinization). Labeling refers to growth time of Superior potato tuber.

Table 2

Thermal properties of potato dry matter as determined by DSC.

Cultivar	Growth time (days)	Gelatinization			Retrogradation		
		ΔH (J/g)	T_o (°C)	T_p (°C)	ΔH (J/g)	T_o(°C)*	T_p (°C)
Shepody	55	10.0 ± 0.8	71.8 ± 0.1	79.1 ± 0.1	4.0 ± 0.1	-	71.3 ± 0.1
	71	13.5 ± 0.4	65.4 ± 0.3	73.9 ± 1.0	3.4 ± 0.0	-	68.2 ± 0.1
	91	13.7 ± 0.0	66.7 ± 0.1	74.2 ± 0.5	3.6 ± 0.0	-	68.6 ± 0.1
	112	14.2 ± 0.3	66.8 ± 0.2	73.9 ± 0.3	3.7 ± 0.4	-	68.4 ± 0.8
	124	14.3 ± 0.3	66.6 ± 0.1	73.7 ± 0.0	4.5 ± 1.2	-	68.9 ± 1.1
Snowden	55	12.6 ± 0.1	70.0 ± 0.2	77.1 ± 0.0	3.5 ± 0.3	-	70.6 ± 0.8
	71	12.3 ± 0.0	63.7 ± 0.0	70.9 ± 0.1	4.3 ± 0.0	-	67.1 ± 0.0
	91	12.0 ± 0.2	65.0 ± 0.1	72.3 ± 0.0	3.7 ± 0.2	-	68.7 ± 0.2
	112	11.0 ± 0.1	64.9 ± 0.1	73.0 ± 0.1	3.6 ± 0.7	-	69.3 ± 0.3
	124	12.9 ± 0.0	64.8 ± 0.5	72.5 ± 0.5	3.6 ± 0.2	-	68.8 ± 0.9
Superior	48	9.1 ± 0.2	71.3 ± 0.3	78.7 ± 0.2	4.5 ± 0.2	-	70.9 ± 0.3
	56	12.4 ± 0.3	66.8 ± 0.1	75.2 ± 0.3	2.8 ± 1.2	-	71.0 ± 1.8
	64	13.0 ± 0.1	66.2 ± 0.1	73.6 ± 0.2	4.1 ± 0.1	-	68.8 ± 1.1
	84	13.2 ± 0.1	64.9 ± 0.2	72.2 ± 0.1	3.9 ± 0.4	-	68.7 ± 0.4
	117	11.3 ± 1.0	66.4 ± 0.4	72.6 ± 0.0	4.7 ± 0.0	-	69.2 ± 0.2

*not enough slope for software to calculate onset temperature (T_o) for retrograded samples

The gelatinization enthalpy of dry matter was the lowest at the earliest time, i.e. 10, 12.6 and 9.1 J/g for Shepody, Snowden and Superior dry matter, respectively. The enthalpy increased slightly when tuber growth time increased for Shepody and Superior potato. In our previous study [5], the gelatinization enthalpy ranged from 15.6 to 18.1 J/g for starch isolated from various cultivars at different times during growth. The lower gelatinization enthalpy and higher gelatinization temperature of potato dry matter might be due to the following: lower starch content in the sample compared to pure starch, and/or the interference in starch gelatinization by the non-starch components.

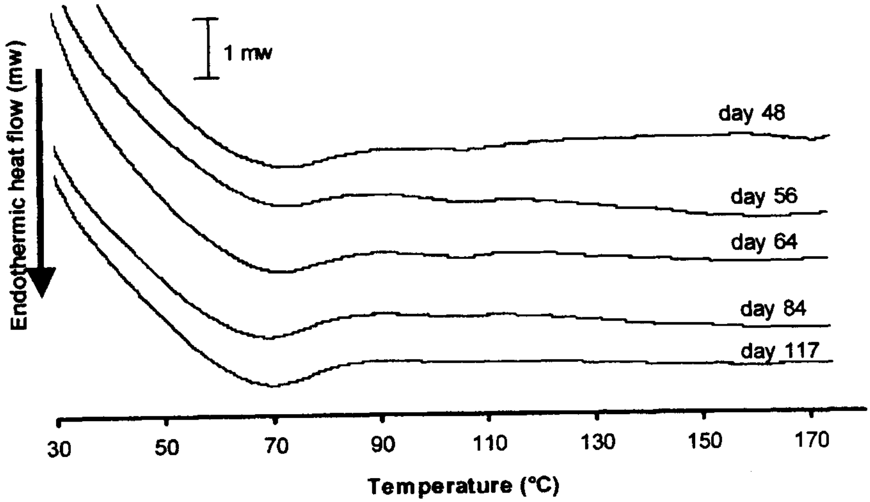

Fig. 2. DSC thermograms of cooked potato dry matter with 70% moisture content after 2-week storage at 5°C. Labeling refers to growth time of Superior potato tuber.

When gelatinized dry matter was heated after it was stored at 5°C for two weeks, an endothermic transition was observed between 68.2 and 71.3°C as shown in Figure 2, indicating starch retrogradation had taken place during storage. Retrogradation endothermic peak temperature was higher for dry matter with the shortest growth time, i.e. 71.3, 70.6 and 70.9°C for Shepody, Snowden and Superior dry matter, respectively. Under the same storage temperature and times, the retrogradation endothermic peak temperature was 69.2, 68.2 and 66.2°C for Shepody, Snowden and Superior starch, respectively, at the earliest harvest. However, the retrogradation enthalpy of gelatinized dry matter was much lower as compared to the corresponding starch. The retrogradation enthalpy was between 2.8 and 4.7 J/g for potato dry matter isolated from various cultivars at different times during growth. It was between 8.4 and 10.2 J/g for starch from potato with different growth times and cultivars. The non-starch components might have inhibited starch retrogradation in the dry matter, resulting in the lower retrogradation enthalpy and higher endothermic peak temperature of gelatinized dry matter compared to the corresponding starch.

Pasting properties of potato dry matter

Table 3 shows the pasting properties of potato dry matter isolated from various cultivars at different times during growth. The pasting curves of Superior potato dry matter during potato growth are presented in Figure 3. The peak viscosity increased slightly, peaked and then decreased slightly as growth time increased. The final viscosity increased slightly as growth time increased for most dry matters. The pasting temperature of dry matter decreased as growth time increased for Superior potato.

Table 3

Pasting properties of potato dry matter by RVA.

Cultivar	Growth time (days)	Peak Viscosity (cP)	Final Viscosity (cP)	Pasting Temperature (°C)
Shepody	55	N/a		
	71	1224	838	72.0
	91	1242	983	70.3
	112	1104	917	70.3
	124	1184	971	69.1
Snowden	55	N/a		
	71	1364	1019	66.7
	91	1499	1076	66.3
	112	1346	1148	67.6
	124	1187	1156	66.8
Superior	48	541	605	92.6
	56	1198	972	72.3
	64	1369	1027	68.7
	84	1338	1040	67.9
	117	1275	1081	67.9

N/a = not analyzed due to insufficient sample

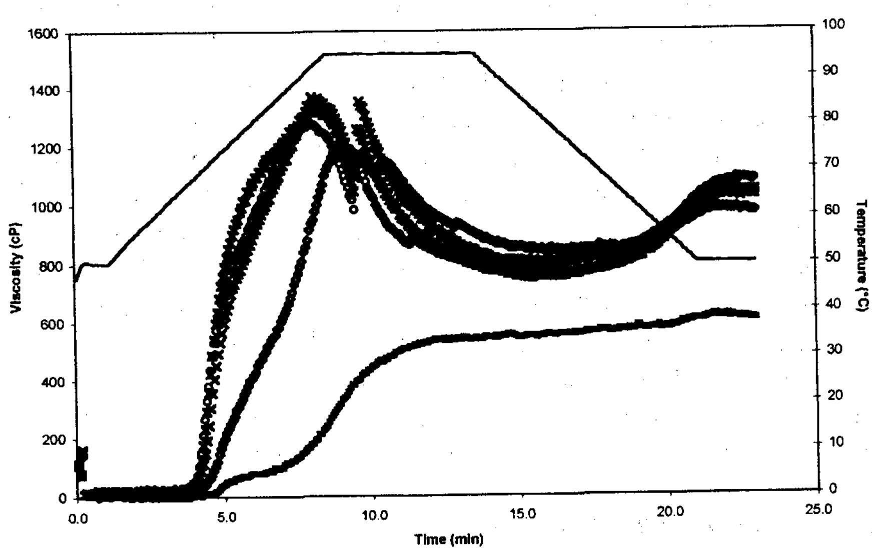

Fig. 3. The RVA pasting curves of Superior potato dry matter during potato growth at 48 (□), 56 (◊), 64 (×), 84 (□) and 117 (○) days as a function of temperature (—).

Among the three cultivars, Shepody potato dry matter had the lowest peak viscosity and final viscosity, and the highest pasting temperatures compared to the dry matter from Snowden and Superior potatoes. For starch isolated from potatoes with the longest growth time, the peak viscosity was 6858, 7217 and 7567 cP for Superior, Shepody and Snowden, respectively. The final viscosity of pasting was 2047, 2738 and 1959 cP from starch isolated from the longest growth time for Superior, Shepody and Snowden potatoes, respectively [5]. However, the peak viscosity was 1275, 1184 and 1187 cP from dry matter isolated from the longest growth time for Superior, Shepody and Snowden potato, respectively. The final viscosity was 1081, 971 and 1156 cP from dry matter isolated from the longest growth time for Superior, Shepody and Snowden potato, respectively.

The lower value of both peak and final viscosity for potato dry matter paste as compared to potato starch paste indicates a weak gel network was formed during the heating of potato dry matter with excess water. Other components such as non-starch polysaccharides, protein, organic and inorganic compounds in the potato dry matter greatly influenced the strength of dry matter gel. The lower starch concentration (about < 6%) [4] might be another factor that produced a lower paste viscosity. The pasting properties of dry matter were almost independent of growth time. However, the peak and final viscosity of dry matter isolated from Superior potatoes with the shortest growth time was much lower (about 50% lower) than that of dry matters isolated from potatoes with longer growth time. From the previous study [5], the lowest molecular weight of starch isolated from the potatoes with the shortest growth time was observed. The peak and final viscosity of its corresponding starch was dependent of growth times and cultivars of potato tubers. Thus, the molecular characteristics of starch and interference of other components might play very important role in the pasting properties of potato dry matter.

Conclusions

Potato dry matter content varied with cultivars and tuber growth times. Starch content in the potato dry matter was the lowest from tubers with the shortest growth time, peaked and then decreased slightly as a function of growth time. Protein content in the potato dry matter was the highest from the tubers with the shortest growth time (< 2 months) for Snowden and Superior potatoes. However, protein content was independent of growth time for Superior potato after 2 months growth. Superior potato dry matter had the highest protein content compared to the other potatoes. The thermal properties of potato dry matter were influenced by the starch as well as non starch components. The shorter growth time of potato tuber resulted in higher gelatinization and retrogradation temperatures and lower gelatinization enthalpies for potato dry matters. The paste made from potato dry matter had much lower viscosity than that from the corresponding starch, indicating starch concentration, interference of non-starch components in the gel formation, and starch molecular characteristics play important roles in the functional properties of potato dry matter. The pasting properties of potato dry matter were independent of growth time after two months.

Acknowledgements

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FIZYKOCHEMICZNE WŁAŚCIWOŚCI SUCHEJ MASY ZIEMNIAKÓW Z RÓŻNYCH ODMIAN I RÓŻNYCH OKRESÓW ICH WZROSTU

S t r e s z c z e n i e

Sucha masa ziemniaków pochodziła z bulw trzech odmian zebranych w różnych okresach ich wzrostu. Fizykochemiczne właściwości suchej masy obejmowały oznaczenie zawartości skrobi i białek, właściwości termiczne (DSC) i reologiczne właściwości kleików (RVA). Zawartość suchej masy w bulwach ziemniaków wzrastała do pewnego poziomu, a potem w miarę opóźniania zbioru obniżała się. Odmiana Superior cechowała się najniższą zawartością suchej masy i najwyższą zawartością białek w porównaniu z ziemniakami odmian Snowder i Shepody. Entalpia kleikowania i temperatura suchej masy zmieniały się w miarę wzrostu, w różny sposób specyficzny w poszczególnych odmianach. Niedojrzałe bulwy (wczesny zbiór) dawały materiał o najwyższej temperaturze kleikowania i najłatwiejszej retrogradacji co wskazywało, że struktura molekularna skrobi ma istotny wpływ na funkcjonalne właściwości suchej masy. Odmiana ziemniaków i czas ich zbioru mogą mieć wpływ na jakość ziemniaków spożywczych i przemysłowych.