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Effects of Extrusion Conditions on Pasting Properties of Potato

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Abstract An advantage to the extrusion of raw potatoes is a reduction in the energy input required to process potato products; however, the effects of extrusion on the properties of raw potato have not been studied. The purposes of this study were to develop a workable extrusion process for raw potato and to study the effects of extrusion conditions on the pasting properties of extruded potato products. The peak viscosity, final viscosity, pasting temperature, water solubility index, and water absorption index of pressed and pressed-dried potato extrudates decreased as die exit temperature increased, whereas they did not change as screw speed increased. The peak viscosity, final viscosity, and water solubility of steam-cooked potato products decreased with extrusion processing; however, they did not change with increasing die exit temperature and screw speed. Potato products with different degrees of depolymerization of extruded potato starch, depending on die exit temperature, were produced from raw potatoes.

Keywords: pasting, property, potato, extrusion, steam-cooking

Introduction

Many food manufacturers have adopted extrusion processes for the continuous production of snack foods, breakfast cereals, and crisp breads. The introduction of the twin-screw extruder has widened the scope of food extrusion in the manufacture of cereals and starches, ready-to-eat cereals, infant formulas, snack foods, soft moist pet foods, breadings, and coatings. Extrusion-processed potato snacks have captured large segments of the market once dominated by potato chips. Dehydrated potato granules or flakes and other ingredients are mixed with water and then fed through an extruder to produce potato snacks. Extrusion has the added advantage of being able to utilize potatoes that have good internal quality but might be culled from conventional processing because they are too large, too small, or misshapen. The effects of extrusion have been studied on potato starch (1, 2), potato flakes (3), and blends of potato and wheat flours (4).

The thermal and mechanical energies used during extrusion change the physical and rheological properties of the raw food materials as well as the functional properties of the extruded food products (5). The rheological properties of extruded food products include the paste consistency and viscosity-related parameters that are used to characterize quality attributes. Pasting properties of extrudates are important when the pregelatinized extrudate powders are used as food thickeners. Changes in viscosity of extrudate powders produced under various operating conditions have been studied to determine the factors affecting pasting properties (1, 4, 6-10). Walker *et al.* (11) first reported the use of a modified rapid visco analyser (RVA) to study the pasting characteristics of starch gelatinization, disintegration, swelling, and gelling ability. The advantages of the RVA technique over the commonly used viscograph system are its requirement for only a small sample, easy operation, and high sensitivity in distinguishing among samples.

The use of dehydrated potato granules for the manufacture of snacks invariably involves the addition of water that was removed during the dehydration process. In the studies referring to potato starch extrusion, processing difficulties have been reported that were solved by running the process at higher moisture content and shorter screw length (1, 2). Ferdinand *et al.* (12) studied the extrusion cooking of fresh potatoes as an alternative to the use of the dehydrated granules. The energy consumption was reduced during extrusion when fresh potato was used instead of dehydrated potato. However, the effect of extrusion conditions on the properties of fresh potato products has not been reported. The utilization of fresh potatoes for extrusion may reduce the detrimental effects that occur when tubers unsuitable for stock reach the fresh market.

In the present study, 3 differently pre-processed potatoes were extruded at various die exit temperatures and screw speeds. The specific objectives of this study were to develop the processes for extrusion dehydration and carbohydrate modification of raw potato, to study the effects of die exit temperature and screw speed on the pasting properties (RVA profile, water solubility index, water absorption index, and water activity), and to develop an empirical model to predict peak viscosity and final viscosity of extruded potato products.

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Material and Methods

Materials The tuber cultivar used in this study was Atlantic with specific gravity in the range of 1.080 to 1.090. The tubers were grown at the Michigan State University Montcalm Research Farm and transported after harvest to the Food Science and Human Nutrition

Department. Raw potatoes were pre-processed prior to extrusion to provide feed material with a shape appropriate for introduction into an extruder as well as the desired moisture content. Each of the pre-processes included peeling and cutting into cubes (1 cm^3). Some of the cubes were then ground using a food processor. The ground potatoes were pressed to reduce their moisture content from 85 to 7% (w.b.) (pressed potatoes). Some of the pressed potatoes were processed further by partially drying at 75°C for 30 min using a forced-air oven to further lower the moisture content from 73 to 57% (pressed-partially-dried potatoes). Some potato cubes were steam-cooked for 10 min (steam-cooked potatoes).

Proximate composition Samples of each of the pressed, pressed and partially dried, and steam-cooked potatoes were dried at 40°C overnight using a forced-air oven, then ground into powder using a cyclone sample mill (Udy Corporation, Fort Collins, CO, USA) equipped with a 0.5 mm mesh screen, as controls. Moisture, nitrogen, starch, and ash contents of the ground samples were determined by AACC methods 44-19, 46-13, 76-13, and 08-03, respectively (13). Fiber content was determined by AOAC method 991.43 (14). Protein content was estimated using the N conversion factor of 6.25. Fat content was obtained by subtraction of the other contents mentioned from 100%. All samples were run in duplicate.

Experimental design A blocked split-plot design was used to evaluate the effects of extrusion temperature and screw speed on the physical properties of extruded potato products. The block variable was 3 differently preprocessed potatoes (pressed, pressed-partially-dried, and steam-cooked potatoes). Whole plot was die exit temperatures (110, 135, and 160°C), and sub plot was screw speeds (50, 100, and 150 rpm). Response variables were viscosity properties, water solubility index, water absorption index, and water activity. All tests for pasting properties, water solubility index, water absorption index, and water activity were replicated 3 times. The Statistical Analysis System (SAS Institute, Cary, NC, USA) was used for all statistical analyses. Means were compared by the least significant difference (LSD) test at the α=0.05 level.

Extrusion process The 3 differently preprocessed potato samples (pressed, pressed-partially-dried, and steam-cooked potatoes) were extruded at different screw speeds and barrel temperatures using a co-rotating and intermeshing twin-screw extruder (model MPF-19; APV Baker, Grand Rapids, MI, USA), with a 19-mm barrel diameter and 25:1 length to diameter ratio. The die used in this study had a single circular orifice with a 3-mm diameter opening. Screw speed was varied from 50 to 150 rpm. The barrel temperature of each zone, from feed end (zone 1) to melt end (zone 4) of the extruder and the temperature at the die exit are listed in Table 1. From the feed end, 39.9 cm long twin-lead screws were used, and 7.6 cm long single-lead screws were used from the melt end (a low shear screw configuration and no paddles). The 3 differently preprocessed potato samples were each extruded in duplicate for each die exit temperature and screw speed studied. After extrusion, extrudates were dried

Table 1. Extruder barrel temperatures of each zone from feed end to melt end (zone 1-4) and die exit temperatures

	Extruder Barrel Temperature (°C)				Die exit temperature (°C)
Trial	Zone 1	Zone 2	Zone 3	Zone 4	
A	80	90	100	105	110
B	80	90	110	125	135
C	80	100	125	145	160

at 40°C overnight using a forced-air oven. Control samples of each of the feed materials were also dried at 40°C overnight in a forced-air oven. All dried samples were ground into small particles using a micro-mill (Bel-Art Products, Pequannock, NJ, USA), and then ground into powder using the cyclone sample mill equipped with 0.5-mm mesh screens.

Measurement of pasting properties The viscosity properties [peak viscosity (PV), peak time (PT), final viscosity (FV), and pasting temperature (TP)] of ground samples were measured using a Rapid Visco Analyser (RVA-4; Newport Scientific Co., Waeeiewood, Australia). Three g of ground sample, adjusted to 14% moisture basis, were added to 25 mL distilled water already placed in the RVA canister. A plastic paddle was inserted into the canister and it was manually rotated to break up any lumps and disperse the powdered material. The canister, along with the paddle, was placed in the RVA, and the test was initiated. The sample temperature was equilibrated to 25°C for 1 min; the sample was then subjected to the heating cycle, increasing at the rate of 7.0°C/min to a maximum temperature of 95°C and holding for 5 min at 95°C, followed by the cooling cycle at the rate of 7.5°C/min to a minimum temperature of 25°C. All viscosity values are reported in rapid visco units (RVU).

Water solubility index (WSI) and water absorption index (WAI) of ground samples were determined as described by Mason and Hoseney (9). Water activity (A_w) of each ground sample was measured using an AwQuick water activity meter (model A2101; Rotronic Instrument Co., Huntington, NY, USA).

Results and Discussion

Extrusion of pre-processed potatoes In preliminary studies, extrusion of raw potatoes using a high shear screw configuration [8D twin lead screws (TLS), 7×30° forward kneading paddles (FKP), 4D TLS, 4×60° FKP, 4×30° Reverse KP (RKP), 2D TLS, 6×60° FKP, 4×30° RKP, 1D single LS (SLS), 7×90° KP, 2D SLS; 1D = 19 mm, 1 KP = 0.25D] was unstable with output fluctuations. This appeared to be due to a combination of both the high moisture content of raw potatoes, about 85%, and the high shear extrusion condition used. Extrudates from the cubes of raw potatoes were only partially cooked, very sticky, and had high moisture content. With the use of a high shear screw configuration, a large number of cell walls might be damaged, allowing starch particles to escape from the potato matrix due to both shearing and heating during the extrusion process. Ferdinand *et al.* (12) reported this same difficulty for raw potato extrusion, and then suggested the reduction of its moisture content and use of a low shear screw configuration. Della Valle *et al.* (2) reported the difficulty of extruding potato starch; in their study, this was characterized by high-energy requirements due to high melt viscosity and early melting in the extruder, when compared to other starches. Therefore, in the present study, screws were configured without paddles (21D TLS, 4D SLS) to decrease shearing and increase die pressure during extrusion. Although this screw configuration decreased residence time, it improved flow behavior, presumably due to reduction in cell wall damage by shearing during extrusion.

In the present study, some raw potato cubes were ground and pressed to reduce their moisture content from 85 to 73%. The proximate analyses for pressed and steam-cooked potatoes dried at 40°C are listed in Table 3. Protein and fat contents of pressed potato samples were lower than those of steam-cooked potato samples, indicating that protein and fat were partly removed during the pressing of ground potatoes. The extrudates from pressed potatoes did expand and attain shape upon exiting the die, however, the shape of these extrudates changed during their accumulation time on a collecting tray, due to extrudate stickiness and moisture content. Some samples of pressed potato were dried at 75°C for 30 min in an air oven to decrease the moisture content and partially gelatinize starch within cells. After oven drying, the moisture content of the preprocessed potato cubes was 57% (w.b.). The extrudates made from these pressed and partially dried potatoes expanded, maintained their strand shape and dried quickly.

Some cubes of raw potatoes were steam-cooked prior to extrusion to reduce cell wall damage due to shearing in the extruder and to facilitate the separation of potato cells from each other during extrusion. The steam-cooking might hydrolyze the pectic substances, which are polymers of galacturonic acid with the carboxyl groups largely methylated, and thereby facilitate cell separation and minimize cell wall breakdown. Additionally, gelatinization of starch within cells by steam-cooking might eliminate starch particles escaping in the presence of any cell wall damage during subsequent extrusion (15). Although steam-cooking prior to extrusion reduced the moisture content and viscosity of extrudates, the extrudates made from steam-cooked potatoes were soft with high moisture content (about 68%), and had relatively brittle strands after drying as compared to extrudates made from pressed and pressed-partially-dried potato cubes. However, the stickiness of the extrudates was reduced dramatically relative to pressed potato extrudates.

Table 2. Dimensions of twin-lead screws, single-lead screws, and kneading paddles[1]

Variable	Twin-lead screws	Single-lead screws	Kneading paddles
Major diameter (mm)	18.2	18.2	
Root diameter (mm)	10.8	10.5	
Channel depth (mm)	3.9	4.1	
Tip width (mm)	0.4	0.9	
Helix angle (°)	17.8	4.6	
Length of tip along helix (mm)	120.0	246.0	
Length of root along helix (mm)		143.0	
Volume (mm^3)	2,515.7	2,965.7	691.4
Disc tip area (mm^2)			72.2
Disc flange area (mm^2)			110.0
Disc side area (mm^2)			798.0

[1]All measurements were based on 19-mm axial length.

Table 3. Proximate analysis of pressed potatoes[1] and stem-cooked potato extruder feed materials

Component (%)	Pressed potato	Steam-cooked potato
Moisture (w.b.)	13.39	9.94
Starch (d.b.)	86.56	75.33
Protein (d.b.)	1.60	6.03
Fiber (d.b.)	7.45	7.54
Fat (d.b.)	0.36	7.15
Ash (d.b.)	1.03	3.95

[1]Similar data were obtained for pressed and pressed-dried potato samples.

RVA parameters Viscosity curves of potato products rose to peak value during starch swelling, and then decreased due to rupture and alignment of starch structure by heating. Upon cooling, the viscosity increased again due to re-association between starch molecules (16). Viscosity properties (PV, PT, FV, and TP) of non-extruded and extruded potato products are listed in Table 4, 5, and 6. The PV and FV values of all 3 kinds of pre-processed potatoes decreased after extrusion processing ($p<0.05$). This result indicated that the water-binding capacity of starch decreased but water solubility increased due to

Table 4. Viscosity properties[1] of pressed potato feed material (control)[2] and pressed potato extruded products

Die exit temperature (°C)	Screw speed (rpm)	PV (RVU)	PT (min)	FV (RVU)	TP (°C)
Control		653.34a	10.97a	795.71a	66.18a
110	50	434.88b	7.77b	315.88b	43.58b
110	100	427.05b	7.77b	312.96b	42.35b
110	150	425.63b	7.70b	309.25b	41.28b
135	50	322.84c	7.60b	219.79c	30.43c
135	100	318.71c	7.50b	215.58c	27.70cd
135	150	316.13c	7.43b	215.63c	27.55cd
160	50	231.25d	7.27c	174.88d	26.38d
160	100	229.03d	7.25c	169.21d	25.45d
160	150	226.00d	7.10c	163.29d	25.38d

[1]PV, peak viscosity; PT, peak time; FV, final viscosity; TP, pasting temperature; values followed by the same letter in the same column are not significantly different ($p<0.05$).
[2]Dried at 40°C overnight in an oven.

modification of starch molecular structure during extrusion processing. Davidson *et al.* (17) observed that extrusion processing contributed to a decrease in intrinsic viscosity (as PV) of wheat starch.

The PV value of dried products (40°C) from pressed potato was 653.34 RVU at 10.97 min, and the FV and TP values were 795.71 RVU and 66°C, respectively (Table 4). The PV, FV, and TP values of pressed potato extrudates decreased significantly as die exit temperature increased from 110 to 160°C, whereas they did not change significantly as screw speed was increased from 50 to 150 rpm (p<0.05, Table 4). Although the specific mechanical energy increased as screw speed increased (2, 4, 18), PV and FV values of extrudates did not decrease along with the decrease in residence time. At higher temperatures, mechanical degradation was less pronounced as the viscosity decreased, whereas the kinetics of thermal degradation became more favorable. Mason and Hoseney (9) found that hot paste viscosity of extruded wheat starch was negatively influenced by die exit temperature and an interaction between screw speed and barrel temperature. This result agreed with the decrease in PV values of pressed potato extrudates with increasing die exit temperature in the current study.

Table 5. Viscosity properties[1)] of pressed-partially-dried potato feed material (control)[2)] and pressed-partially-dried potato extruded products

Die exit temperature (°C)	Screw speed (rpm)	PV (RVU)	PT (min)	FV (RVU)	TP (°C)
Control		637.64a	10.82a	781.78a	64.58a
110	50	393.04b	7.90b	285.67b	40.83b
110	100	388.96b	7.64bc	279.84b	38.98bc
110	150	386.63b	7.64bc	281.46b	35.65c
135	50	311.63c	7.44c	215.33c	29.25d
135	100	310.71c	7.37c	212.84c	26.85d
135	150	305.84c	7.35c	211.71c	25.30d
160	50	203.92d	7.19cd	143.17d	25.75d
160	100	193.88d	6.94d	140.46d	26.73d
160	150	194.75d	6.87d	140.29d	26.10d

1)PV, peak viscosity; PT, peak time; FV, final viscosity; TP, pasting temperature; values followed by the same letter in the same column are not significantly different (p<0.05).
2)Dried at 40°C overnight in an oven.

Table 6. Viscosity properties[1)] of steam-cooked potato feed material (control)[2)] and steam- cooked potato extruded products

Die exit temperature (°C)	Screw speed (rpm)	PV (RVU)	PT (min)	FV (RVU)	TP (°C)
Control		251.96a	8.83a	240.13a	59.00a
110	50	124.29b	9.30b	106.04b	62.85b
110	100	151.50c	9.17b	132.42c	62.63b
110	150	157.63c	9.24b	135.67c	63.28b
135	50	139.79d	9.00ab	129.42c	62.75b
135	100	140.73d	9.00ab	133.25c	62.68b
135	150	141.11d	9.00ab	134.16c	62.95b
160	50	149.79c	8.97a	126.25c	62.08b
160	100	152.96c	8.94a	123.04c	62.28b
160	150	153.54c	8.90a	130.17c	61.10b

1)PV, peak viscosity; PT, peak time; FV, final viscosity; TP, pasting temperature; values followed by thesame letter in the same column are not significantly different (p<0.05).
2)Dried at 40°C overnight in an oven.

The PV, FV, and PT values of pressed-partially-dried potato extruded products decreased significantly as die exit temperature increased from 110 to 160°C, whereas they did not change significantly as screw speed increased from 50 to 150 rpm within each die exit temperature range (p< 0.05, Table 5). The PV and FV values of pressed-partially-dried potato extrudates were lower than those of pressed potato extrudates for each given extrusion condition. Published reports have indicated that initial peak viscosity (i.e., PV) and cold paste viscosity (i.e., FV) of extruded wheat and potato flour blends (4) and cold (i.e., FV) and cooked viscosities (i.e., PV) of extruded corn starch (8) all increased with increases in moisture content of the feed. In the current study, partial gelatinization of starch within cells by oven-drying potato cubes at 75°C for 30 min prior to extrusion might contribute to decreases in the PV and FV values of pressed-partially-dried potato extrudates relative to these of pressed potato extrudates.

An empirical model was applied to develop the equations for predicting the PV and FV values of extruded potato products. The Arrhenius equation was used to incorporate the effect of die exit temperature on the PV and FV values.

$$\mathrm{PV(or\ FV)} = \mathrm{A}\exp\left(\frac{\mathrm{B}}{\mathrm{T}}\right)$$

where, PV is the peak viscosity (RVU), FV is the final viscosity (RVU), T is the absolute temperature (K), and A and B are constants. The resulting equations and regression correlation coefficients (R^2) are given below.

For pressed potato extruded products:

$$\mathrm{PV} = 1.888\exp\left(\frac{2083.639}{\mathrm{T}}\right), \quad R^2 = 0.992$$

$$\mathrm{FV} = 1.477\exp\left(\frac{2047.065}{\mathrm{T}}\right), \quad R^2 = 0.987$$

For pressed-partially-dried potato extruded products:

$$\mathrm{PV} = 1.179\exp\left(\frac{2237.908}{\mathrm{T}}\right), \quad R^2 = 0.947$$

$$\mathrm{FV} = 0.742\exp\left(\frac{2287.019}{\mathrm{T}}\right), \quad R^2 = 0.973$$

The calculated values generally were within 10% of the measured values of peak viscosity and final viscosity.

The PV value of steam-cooked potato cubes dried at

40°C, was 251.96 RVU at 8.83 min, and the FV and TP values were 240.13 RVU and 59°C, respectively (Table 6). The PV and FV values of steam-cooked potato extrudates both decreased after extrusion processing; however, extrusion temperature, screw speed, and their interaction did not have statistically significant effects on the RVA parameters ($p<0.05$, Table 6). The PV and FV values of steam-cooked potato extrudates were lower than those of pressed potato extrudates, whereas their TP values were higher. These results indicate that steam-cooked potato extrudates had a lower water binding capacity and a lower ability to form a viscous paste after cooking and cooling than did pressed potato extrudates. This might be caused by starch gelatinization within cells during pre-processing by steam-cooking, leading to a decrease in or elimination of starch escaping in the presence of cell wall damage during extrusion.

Water solubility, absorption, and activity The WSI, WAI, and water activity (A_w) of extruded and non-extruded potato products are listed in Table 7. The WSI and WAI values of the non-extruded pressed potato cubes dried at 40°C, were 2.30 and 3.35%, respectively, and both increased significantly after extrusion ($p<0.05$). Pressed potato cubes dried at 40°C did not absorb water at room temperature, whereas extruded pressed potato products absorbed water rapidly to form a paste at room temperature during the RVA test. This paste is formed by solubilized macromolecules but also includes particles swollen by water (19). Chiang and Johnson (20) reported that some hydrolysis of starches might occur during extrusion of cereal starches and grits. However, the WAI value of steam-cooked potato cubes dried at 40°C, was 4.57, and did not change after extrusion. The A_w value of all types of potato products was about 40% and not significantly different among trials regardless of pre-processing treatment and extrusion condition used ($p<0.05$).

Mechanical and thermal energy inputs during extrusion induce change in the physical properties of an extruded substance, which affect properties such as water solubility. WSI is frequently used by industry since it can be determined quickly and has been linked to important product characteristics (6, 21). Colonna *et al.* (19) reported that WSI might be related to the quantity of water soluble molecules, which can be separated quite easily from each other because of limited entanglements. The WSI value for pressed and pressed and partially dried potato products increased significantly from 11.57 to 14.86% and from 13.47 to 15.59%, respectively, as die exit temperature increased from 110 to 160°C, whereas they did not statistically change as screw speed increased from 50 to 150 rpm ($p<0.05$). The increase in WSI with increasing die exit temperature is in agreement with other researchers who have noted that the WSI value of various starches (21), corn starch (8), corn grits (6), and potato starch (1) increased as extrusion temperature increased up to 250°C. However, die exit temperature, screw speed, and their interaction did not show statistically significant effects on the WSI of steam-cooked potato products ($p<0.05$).

The WAI values of pressed and pressed-partially-dried potato products increased significantly from 6.23 to 9.64 and from 6.41 to 9.59, respectively, as die exit temperature increased from 110 to 160°C, whereas they did not significantly change as screw speed increased from 50 to 150 rpm ($p<0.05$). However, no significant differences were observed among the WAI values of steam-cooked potato products ($p<0.05$). The WAI values of corn grits (6, 22), rice (23-25), various starches (21), wheat, rye, barley, and oat flours (26), and wheat semolina (27) reached maxima at extrusion temperatures of 180-200°C. A reduction in WAI was observed at higher temperatures due to intense starch degradation in corn grits (6). Water absorption index was originally developed as a measurement for the swelling power of starch. In the current study, as die exit temperature increased, the WAI values of pressed and pressed-partially-dried potato products increased, whereas their TP values decreased (Table 4 and 5). Colonna *et al.*

Table 7. Water solubility index[1)] (WSI), water absorption index[1)] (WAI), and water activity[1)] (Aw) of feed materials (control)[2)] and potato extrudates[2)] produced under different extrusion conditions

Temperature	Screw speed	Pressed potato product			Press-dried potato product			Steam-cooked potato product		
(°C)	(rpm)	WSI (%)	WAI	Aw	WSI (%)	WAI	Aw	WSI (%)	WAI	Aw
Control		2.30a	3.35a	0.40a	4.56a	3.61a	0.40a	11.78a	4.57a	0.41a
110	50	11.57b	6.23b	0.42a	13.53b	6.41b	0.41a	12.88b	4.36a	0.38a
110	100	11.89b	6.26b	0.40a	13.47b	6.56b	0.39a	13.28b	4.56a	0.39a
110	150	11.84b	6.34b	0.40a	13.56b	6.50b	0.41a	13.38b	4.35a	0.41a
135	50	13.42c	7.38c	0.42a	14.83c	7.57b	0.42a	13.52b	4.30a	0.38a
135	100	13.72c	7.58c	0.41a	14.77c	7.69b	0.41a	13.42b	4.53a	0.41a
135	150	13.62c	7.68c	0.41a	14.91c	7.81b	0.39a	13.26b	4.11a	0.40a
160	50	14.46d	9.25d	0.42a	15.55d	9.19b	0.42a	13.30b	4.16a	0.42a
160	100	14.86d	9.64d	0.40a	15.59d	9.53b	0.39a	13.52b	4.38a	0.41a
160	150	14.44d	9.21d	0.40a	15.49d	9.59b	0.38a	12.86b	4.44a	0.41a

[1)]Values followed by the same letter in the same column are not significantly different ($p<0.05$).
[2)]Pre-processed potatoes (controls) and extrudates were dried at 40°C overnight in an oven.

(19) reported that WAI correlated well with cold-paste viscosity (i.e., FV) because only depolymerized starch granules absorbed water at room temperature and swelled, creating increased viscosity. Thus, it should be possible to use extrusion temperature to manipulate the properties of extruded potato starch for specific usage, such as filler in pharmaceutical, pudding, fish feed, or other products. The extrusion process yielded dehydrated potato products from all 3 preprocessed potato feed materials with low energy input (low shear extrusion was used). The extrusion process appears to allow development of customized starches that will be suitable as ingredients in a variety of value-added products.

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