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Comparison of the Physicochemical Properties and Pasting Characteristics of Flour and Starch from Red and White Sweet Potato Cultivars

OLUWATOOYIN F. OSUNDAHUNSI,[†,§] TAYO N. FAGBEMI,[§] ELLINA KESSELMAN,[†] AND EYAL SHIMONI*,[†]

Department of Food Engineering and Biotechnology, Technion−Israel Institute of Technology, Haifa 32000, Israel, and Deparment of Food Science and Technology, Federal University of Technology, Akure, Nigeria

This research characterized flour and raw starches isolated from red and white sweet potato cultivars. Their composition, determined by proximate analysis, is typical of sweet potato cultivars. These cultivars have high amylose content (32−34%) and exhibit a Ca-type X-ray diffraction pattern. Similar gelatinization characteristics were detected for both starches with onset temperature of 67 °C and enthalpy of 10.5−11.0 J/g. Starches of both red and white cultivars had well-correlated ($r^2 = 0.982$) and high solubilization and swelling temperatures, starting at 80 °C. Pasting properties of the white cultivar exhibit lower tendency for retrogradation. Water and oil absorption capacities were low for both red and white flours. When parboiled, both cultivars showed improved water absorption capacity and decreased least gelation concentration. It is concluded that the white cultivar should be preferred when low retrogradation tendency is required.

KEYWORDS: ***Ipomea batatas*; sweet potato; pasting; physical properties**

INTRODUCTION

Sweet potato (SP) and cassava are the two major starchy crops used in many tropical countries. Sweet potato, *Ipomoea batatas* (L.) Lam., is one of the world's most important starch-producing crops, with >95% of all sweet potatoes produced in Africa and Asia (*1*). Like most root crops, sweet potatoes have traditionally been grown as subsistence crops because they are able to tolerate marginal soil conditions (*2*). This important crop is used in a variety of ways; it can be boiled, steamed, baked, fried, chipped, candied, canned, frozen, made into flour or starch, and processed into a number of products (*3*). Various studies examined these flours and starches by proximate analysis, granular characteristics, pasting properties, and functional properties. An extensive review by Tian et al. (*3*) showed that SP varieties show different crystalline patterns (A and C or mixtures), amylose contents ranging from 8.5 to 38%, gelatinization temperatures of 63−74 °C, pasting temperatures from 66−86.2 °C, and water-binding capacities of 66.3−211.6%. Part of this variability can be attributed to genetic variation. A study of starches from 44 SP genotypes in The Philippines showed variability not only in amylose content (12.9−29.7%) but also in swelling volume (24.5−32.7) and solubility (12.1−24.1) (*4*). Growth conditions may also affect the physical properties of SP starches. Increased amylose content, gelatinization temperature, and average granule size were observed with increased soil temperature (*5*). Interestingly, high amylose content had no significant effect on SP swelling volume; however, it did increase the hardness of the starch gel (*4*). The work of Walter et al. (*6*) showed that the sensory properties of moist and dry sweet potatoes are not correlated with amylose content, granule size, gelatinization temperatures, and pasting properties. They concluded that these sensory attributes are very likely due to α- and β-amylase activities, causing starch degradation and loss of water-binding capacity (*7*, *8*).

Extending the use of SP starch is primarily determined by its physicochemical and functional properties. So far, sweet potatoes have been processed or incorporated into different products and the effect of some processing methods on functional properties determined (*9*, *10*). To date, there is no information on physical properties of SP cultivars in Western Africa. Insight into their physical and molecular structures is of importance for recommendation as to which variety will consistently produce starch of a given quality for specific use. This study was undertaken to determine the physical and pasting characteristics of flours and starches from white- and red-type SP cultivars.

MATERIALS AND METHODS

Preparation of Sweet Potato Flour and Starch. White- and red-skinned varieties of sweet potato used in this study were TIS-1499 (white) and TIB-2 (red) (International Institute of Tropical Agriculture, Ibadan, Nigeria). Raw sweet potatoes were manually peeled into a

* Corresponding author (telephone +972-4-8292484; fax +972-4-8320742; e-mail eshimoni@tx.technion.ac.il).
[†] Technion.
[§] Federal University of Technology.

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Table 1. Proximate Composition of Sweet Potato Flours and Starches[a]

	potato flour				potato starch	
	red		white		red	white
	none	parboiled	none	parboiled	none	none
CHO (%)	83.31 ± 0.06b	85.86 ± 0.45c	77.87 ± 1.21a	81.96 ± 0.57b	87.04 ± 0.54c	87.75 ± 0.57c
amylose (%)	nd[b]	nd	nd	nd	34.16 ± 2.75	32.15 ± 1.06
moisture (%)	3.98 ± 0.08c	2.82 ± 0.11a	3.58 ± 0.05b	4.28 ± 0.04d	4.82 ± 0.07e	5.46 ± 0.06f
ash (%)	1.70 ± 0.06b	1.40 ± 0.03b	3.10 ± 0.11c	3.00 ± 0.02c	0.30 ± 0.06a	0.20 ± 0.03a
protein (%)	6.56 ± 0.06d	5.88 ± 0.06c	8.75 ± 0.06e	6.56 ± 0.14d	5.56 ± 0.06b	4.38 ± 0.06a
fat (%)	4.25 ± 0.14c	3.95 ± 0.03b	6.55 ± 0.06d	4.10 ± 0.13bc	2.28 ± 0.02a	2.21 ± 0.02a
crude fiber (%)	0.20 ± 0.14d	0.09 ± 0.01b	0.15 ± 0.03d	0.10 ± 0.01bc	0.00 ± 0.00a	0.00 ± 0.00a

[a] Significant difference is indicated by different letters within the same row ($p \leq 0.05$). [b] Not determined.

solution of 0.2% sodium metabisulfite. SP flour was produced by drying (Gallenkamp OV-160) and milling (laboratory blender) of the diced potatoes. Parboiled flour was obtained by boiling part of the diced chips for 2 min, cooling, drying, and milling. Starch was obtained by extraction of the un-parboiled samples by a filtration and sedimentation technique (*11*). The starch slurry was washed repeatedly with distilled water and air-dried at room temperature and then at 60 °C for 12 h. The powder was then milled into fine starch flour. The moisture content of the starches was determined by oven-drying on weighed samples and used for weight correction.

Starch and Flour Analyses. *Proximate Analysis.* The proximate composition of SP flours and starches was determined as previously described (*12*). Crude protein (grams of N × 6.25) was determined using the mico-Kjeldahl technique; crude fat was determined using a Soxhlet extractor (Tecato) with petroleum ether. Ash content was determined by dry ashing in a muffle furnace at 550 °C; moisture and crude fiber were determined as described by Kirk and Sawyer (*13*). The carbohydrate was obtained by difference. All determinations were performed in triplicate.

Amylose Content Determination. Amylose content of the starches was determined by differential scanning calorimetry (DSC) based on measurement of the enthalpy of melting of the complex between L-α-lysophosphatidylcholine (LPC) and amylose (*14*). For the preparation of a calibration curve, mixtures of amylose (Sigma) and amylopectin (Amioca, National Starch and Chemical Ltd.) were prepared in the ratios of 0:100, 5:95, 10:90, 20:80, 30:70, 40:60, and 70:30 (w/w %). The mixture (∼10−20 mg dm) was weighed accurately into the DSC (Perkin-Elmer DSC-7) pan, 50−70 μL of a 3% LPC solution added, and the pan sealed. Samples were scanned at a rate of 5 °C/min from 20 to 180 °C (heating rate of 5 °C/min), cooled to 4 °C (cooling rate of 10 °C/min), and reheated to 140 °C (heating rate of 5 °C/min). T_i (initial transition temperature) and T_c (completion transition temperature) of the peak in the DSC thermogram were determined as the points where deviations were noted from the linear portions of the scan before and after the peak, respectively. Transition enthalpies (ΔH) were calculated from the area under the curve described by the recording trace and the baseline joining T_i and T_c. The percent amylose of the starch sample was calculated from the calibration curve.

Scanning Electron Microscopy (SEM). Examination by SEM was carried out. Starch samples were gold coated in a Polaron SC515 (Fisons Instruments) device and scanned by a JSM-5400 scanning microscope (JEOL). Digital images were obtained using an EDS unit with the program Voyager II (Moran).

X-ray Diffraction (XRD) Pattern Analysis. XRD measurements were carried out by using a Siemens D5005 diffractometer. Samples were scanned over the range of 5−35 °2θ in steps of 0.03 °2θ per 2 s. The crystalline nature of the granule was determined by the position of the XRD peaks.

Starch and Flour Paste Properties. Starch thermal properties were measured using a Perkin-Elmer DSC (model DSC-7). A starch sample (10 mg) with 50 μL of double-distilled water was scanned in the DSC pan at a rate of 5 °C/min from 20 to 180 °C (heating rate of 5 °C/min), cooled to 4 °C (cooling rate of 10 °C/min), and reheated to 140 °C (heating rate of 5 °C/min). Onset, peak, and final temperatures and gelatinization enthalpy were measured and calculated.

Starch swelling power and solubility were determined by heating starch−water slurries in a water bath at temperatures ranging from 60 to 90 °C at 5 °C intervals (*15*, *16*). Briefly, weighed starch samples were suspended in double-distilled water and heated with constant agitation for 30 min. The slurries were then centrifuged, the supernatant was removed, and the soluble material was isolated by evaporation of the liquid. The amount of this material was used to calculate the starch solubility. The swelling power was obtained by measuring the amount of residue from the centrifugation and calculating the amount of water absorbed by the starch (percent weight increase) after correction for the amount of solubilized starch (*15*).

Paste viscosities were measured for both flour−water and starch−water mixtures (10% w/v) with a Brabender amylograph (BA; C. W. Brabender, South Hackensack, NJ). The heating, cooking, and cooling schedules were as follows: amylograph (constant stirring at 75 rpm), heated from 25 to 95 °C at 1.5 °C/min, held at 95 °C for 15 min, and cooled to 50 °C at 1.5 °C/min.

Functional Properties Determination. The functional properties, water absorption capacity (WAC), oil absorption capacity (OAC), and least gelation concentration of both the flour and starches were determined. Oil absorption and water absorption capacities were determined according to the method of Beuchat (*17*). Values were expressed as percentages of oil and water absorbed by the flour on a percent basis. Least gelation concentration was determined by using the modified method of Coffman and Garcia (*18*). Increasing flour concentrations were suspended in 10 mL of water in test tubes and heated in a boiling water bath (Gallenkamp) for 1 h. The tubes were rapidly cooled to 4 °C. The least gelation concentration (percent) was taken as the minimum concentration when the sample in an inverted tube did not slip or fall down.

Statistical Analysis. Data were analyzed using the JMPin (SAS Institute Inc.). Difference between treatments was evaluated by least-squares means. Significance is considered when $p \leq 0.05$ unless stated otherwise.

RESULTS AND DISCUSSION

Composition and Characteristics of Flour and Starch. The purpose of this study was to characterize the physicochemical and functional properties of red and white SP cultivars. The results of the proximate composition of both flours and starches are presented in **Table 1**. The red variety showed higher carbohydrate content (83.31%) than the white (77.87%) variety. Parboiling seemed to reduce the amount of crude fiber, ash, protein, and fat of the flour of both the red and white varieties. The protein content of the white SP variety (the flour and starch) was higher than in the red variety. This decrease in fiber, ash, protein, and fat after parboiling may be due to leaching, as was shown for fluted pumpkin by Bekebain and Giami (*19*). Analysis of the starch samples revealed undetectable levels of crude fiber compared with the flour samples, very likely due to the screening operation. The values reported here for ash, fiber, protein, lipid, and CHO content are in agreement with the range of these components reported by Tian et al. (*3*).

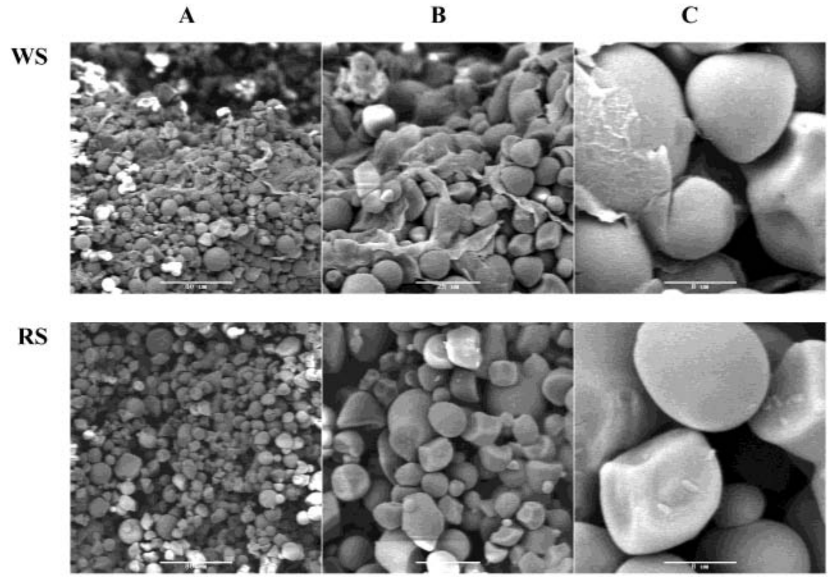

Figure 1. SEM of starch granules of white (WS) and red (RS) sweet potato cultivars. Bars represent 80, 25, and 8 μm, respectively.

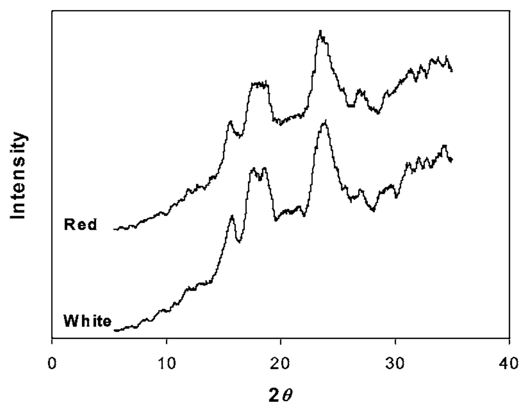

Figure 2. XRD of sweet potato starches from white and red cultivars.

Amylose content determined by DSC exceeded 32% in both varieties. This amylose content is higher than most of the values reported for other SP varieties in previous studies. Walter et al. (*6*) reported amylose contents ranging from 21.7 to 23.5%, and others reported a range of 8.5−32.4% (*3*). Orange and purple cultivars had amylose contents in the range of 12.8−20.6% (*5*). The high amylose content may also be a result of the very sensitive DSC measurement.

Granules of both red and white varieties exhibit a wide range of size as shown in **Figure 1**. The shape and size of the granules appear to be very similar to those of sweet potatoes examined by Noda et al. (*20*). In both varieties, granule size ranged from a few micrometers to >40 μm. This observation agrees with the Tian et al. (*3*) review of various studies showing a wide distribution of granule size. Granule size varies from 2 to >60 μm, with an average size of 10−80 μm. Similar values (3−60 μm) were also reported by Walter et al. (*6*).

X-ray diffraction patterns of both red and white SP starches showed peaks at 15.4, 17.2, 18.3, and 23.4 (**Figure 2**). The appearance of the 15.4 line indicates a C pattern (*21*). This type of crystallinity was reported in a number of studies (*3*, *20*, *22*), and it appears to be a Ca-type (type C near A-type). Because the C type has been suggested as a mixture of A- and B-types, the C pattern is classified as closer to A-type (Ca) or closer to B-type (Cb). The diffraction pattern is specific to the starch botanical origin; our observation clearly indicates that these varieties differ from potatoes, which normally have a B-type diffraction pattern (*23*).

Table 2. DSC Gelatinization Characteristics of Sweet Potato Starches

cultivar	onset temp (°C)	peak temp (°C)	end temp (°C)	enthalpy (J/g)
white starch	66.7 ± 0.2	70.7 ± 0.2	74.8 ± 0.0	10.5 ± 1.3
red starch	67.2 ± 0.9	71.5 ± 1.0	75.7 ± 1.3	11.0 ± 1.7

Paste Properties. To detect differences in pasting properties between flours and starches from red and white varieties, DSC and Brabender amylograph analyses were performed; swelling power and solubility were determined. DSC analysis shows that red and white starches did not differ in their gelatinization temperature (**Table 2**). In addition, no significant difference was detected in the enthalpy of gelatinization, with similar total gelatinization energy for both starches. It should be, however, noted that the characteristic gelatinization temperatures (onset, peak, and end temperatures) are lower than the values reported for SP varieties examined by Chiang and Chen (*24*) and Kitada et al. (*25*), as well as 44 genotypes examined by Collado et al. (*4*), and at various harvesting dates (*22*). The study of Kitada et al. (*25*) also recorded higher enthalpy of gelatinization, ranging from 15.1 to 16.3 J/g. A recent study, however, reports similar and lower peak temperatures (62.8−71.9 °C), butthe calculated enthalpy was much higher (22.6−25.6 J/g) (*6*). The combination of high amylose content detected in the SP starches with the relatively low gelatinization temperatures is surprising, because high amylose content is usually associated with high gelatinization temperatures. Other studies, however, demonstrated that starch gelatinization properties reflect the molecular architecture of amylopectin but not the amylose-to-amylopectin ratio (*26*, *27*). Further studies characterizing the amylose and amylopectin fractions of the starches may shed light on this question.

The swelling and solubility of both starches showed similar changing patterns as the temperature increased (**Figures 3** and **4**). There was no increase in either property up to 75 °C. Beyond 75 °C, starting at 80 °C, a sharp increase in swelling power and solubility was observed. Minor differences in swelling power were found at 80 °C, showing a higher value for the white SP starch. The solubility, however, showed a somewhat higher difference, and starting at 75 °C, it was lower for the

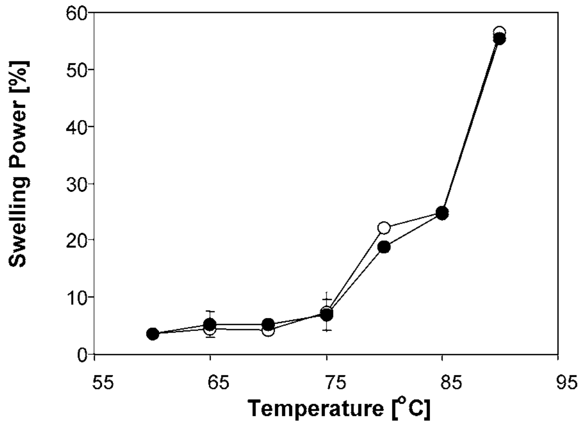

Figure 3. Swelling power of starches from white (○) and red (●) sweet potato cultivars.

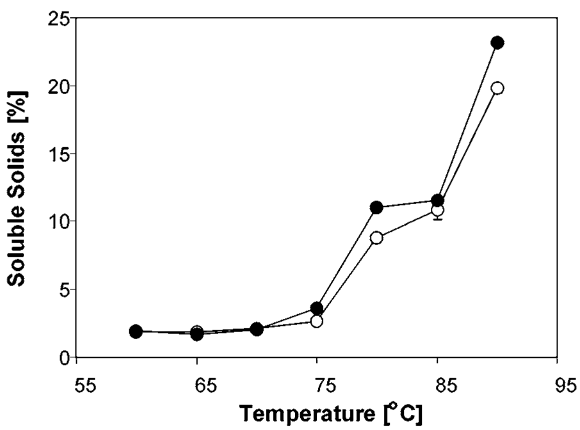

Figure 4. Solubility of starches from white (○) and red (●) sweet potato cultivars.

white SP starch. The high temperature at which swelling and solubilization occur is very likely due to the high amylose content. Because amylose is the solubilized fraction, this can explain the difference between the red and white SP varieties and the cultivars examined by Walter et al. (*6*). Although reaching similar swelling power values as the cultivars tested by Walter et al. (*6*), the varieties studied here exhibit lower solubility values. This was also the case for most of the studies reviewed by Tian et al. (*3*) showing an increase in both parameters already at 70 and 75 °C. In the present study, too, good correlation was found between the swelling power and the solubility ($r^2 = 0.982$), indicating solubilization of starch along with the swelling of its granules.

The Brabender amylograph was used to determine the pasting properties of both native flours and starches, as well as the pasting properties of parboiled flours. Important points (pasting temperatures, peak viscosity, viscosity at 95 °C, viscosity at cooling onset, viscosity at end of cooling, and setback viscosity) were recorded and are given in **Table 3**. Peak viscosity ranged from 160 to 450 BU, with un-parboiled red flour having the highest peak viscosity value (450 BU). The low viscosity indicates flour with high enzymatic activity resulting in low water holding capacity. Parboiling increased the setback of red SP flour; however, it had only moderate effect on white SP flour, which had a high initial setback. Because a high setback value indicates a lower tendency for retrogradation during cooling, the white variety may be preferred. Pasting temperature varied from 50 to 82.5 °C. In this case as for the setback, parboiling significantly increased the pasting temperature of red SP flour. A high gelatinization index is desired in flour, because it is a measure of its good pasting characteristics (*28*); the white variety is likely to be of greater industrial use.

Functional Properties. The functionality of white and red varieties was examined by measuring their water and oil absorption capacities as well as their least gelation concentration (**Table 4**). Water absorption capacity is the ability of the starch or flour to absorb water and swell for improved consistency in food. It is desirable in food systems to improve yield and consistency and give body to the food. The least gelation concentration significantly decreased when SP flour was parboiled. Decreases of about 166 and 133% for red and white variety flours, respectively, were measured. Parboiling improved the water absorption of the potatoes by 175 and 173% for the red and white varieties, respectively. Because parboiling helps to stabilize potato color and stop enzymatic and antinutritional activity in the flour, when potato flour is desired as a thickener, for example, kununzaki beverage, parboiled potato flour should

Table 3. Rheological Properties (Amylograph Pasting Viscosity) of Sweet Potato Starches and Flours

	pasting temp (°C)	peak viscosity (V_p) (BU)[a]	viscosity at 95 °C (BU)	viscosity at cooling onset (V_r) (BU)	viscosity at end of cooling (V_e) (BU)	setback viscosity (BU)	stability ($V_p - V_r$) (BU)	gelatinization index ($V_e - V_r$) (BU)
white flour	82.5	250	150	250	700	450	0	450
red flour	50	450	450	380	715	265	50	335
parboiled white flour	82	160	110	150	580	480	10	490
parboiled red flour	80	280	180	265	760	480	15	495
red starch	75	240	200	235	620	380	5	385
white starch	79.5	275	220	260	680	405	15	420

[a] Brabender units.

Table 4. Functional Properties of Sweet Potato Flours and Starches[a]

	sweet potato flour				sweet potato starch	
	red		white		red	white
property	native	parboiled	native	parboiled	native	native
least gelation concentration	6 ± 1.2a	16 ± 0.6b	6 ± 0.6a	14 ± 1.2b	6 ± 0.6a	6 ± 0.3a
water absorption capacity (%)	24 ± 1.2b	42 ± 0.6c	26 ± 0.6b	45 ± 1.7c	15 ± 1.2a	15 ± 0.6a
oil absorption capacity (%)	12 ± 0.6a	9 ± 0.6a	10 ± 0.6	10 ± 1.2a	10 ± 0.3a	12 ± 1.7a

[a] Significant difference is indicated by different letters within the same row ($p \leq 0.05$).

be used. Both the red and white varieties of the potato starch have the same water absorption capacity. Thus, SP flour as a binding agent in food systems may be more effective in unparboiled form. The starches, however, did not show any difference in their WAC, indicating similar gelation properties. Overall, the results indicate that the red and white varieties of potatoes are quite close in their water absorption capacities, although the white variety is slightly higher. It should be noted that previous studies reported higher capacities (*3*), suggesting that the varieties tested here have unusually low WAC.

Analysis of the oil absorption capacity of flours and starches shows nonsignificant differences between native and parboiled flours, between flours and starches, and between red and white varieties. Only the native red SP flour had a higher OAC compared with the parboiled red SP flour. Parboiling reduced the OAC of red SP flour by 25%. Overall, the OAC of red and white SP products was lower than that reported for native and toasted African breadfruit kernel (91 and 96%, respectively) and toasted wheat flour (148%) (*9*). This could be a result of the lower protein content of SP preparations (4.38−8.75%) as compared to African breadfruit kernel (17%) and toasted wheat flour (10%).

Conclusions. The purpose of this research was to characterize flour and raw starches isolated from red and white sweet potato cultivars. Their composition, determined by proximate analysis, is typical of SP cultivars. These cultivars have high amylose contents and exhibit a Ca-type X-ray diffraction pattern. Similar gelatinization characteristics were detected for both starches, and these were lower than values previously reported for other cultivars. Pasting characteristics suggest that the white variety has a lower tendency for retrogradation, and when a high gelatinization index is required, it should be preferred for industrial uses. Both cultivars exhibit low water absorption capacity as well as oil absorption capacity.

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