Comparison of Oat and Wheat Carbohydrates. II. Starch[1]

L. A. MacARTHUR and B. L. D'APPOLONIA,[2] Department of Cereal Chemistry and Technology, North Dakota State University, Fargo 58105

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ABSTRACT

Starches isolated from three oat cultivars of different protein concentrations were fractionated into amylose and amylopectin, and chemical and physicochemical properties were compared with each other and to a hard red spring wheat starch and its fractions. Values for peak height, 15-min hold height, and height after cooling were highest in oat starches extracted from the lower protein oat flours. During heating at 95°C, the oat starch gels showed greater reduction in viscosity than did the wheat starch gels. Starch content of the oats was similar to that of the wheat, except for the high protein cultivar (Dal), which was lower. Total lipids in the oat flours and brans and corresponding starches were higher in all cases than the wheat flour, bran, and starch.

Oat groats (dehulled oats) have higher protein and fat content and lower carbohydrate content than other cereals, but in oats as in other cereals, the starch, which constitutes 50–55% of the grain's weight, is the major constituent. According to MacMasters et al (1947), between 33 and 43% starch (dry basis [db]) can be extracted from whole oats, but the actual starch content is undoubtedly higher. Kent-Jones and Amos (1967) reported starch content of oat groats to be approximately 61.0% (db). Oat starch appears to be confined to the endosperm where individual granules of 3–10 μm develop in bundles or clusters about 60 μm in diameter (Caldwell 1973). Birefringence of the granules is relatively weak, with the polarization crosses being centrally located. Banks and Greenwood (1967), MacMasters et al (1947), and Matz (1969) found oat starch to contain from 23 to 26% amylose, compared with wheat starch, which has an amylose content of 17–27% (Whistler 1950). Clendenning and Wright (1945), used an acid digestion method of extraction and reported that oat starch has the highest lipid concentrations (1.2%) of several carefully prepared pure starch samples from various cereals. Youngs (1974) also reported oat starch to contain 1.3 and 1.6% total lipid in two different oat cultivars. In general, wheat starch has been reported to contain from 0.5 to 0.8% lipid (Pomeranz 1971). According to Matz (1969), oat starch exhibits relatively high water absorption in baking tests and rather low gelatinization temperature (55°C). Paton (1977) studied the pasting properties of a wide range of oat cultivars and reported that the gelatinization curves were similar to those of other cereal starches, but cooked granules appeared more sheer sensitive than those of corn, wheat, or rice starch. Paton (1977) also noted a difference in the behavior of oat starch on cooling. High viscosity rapidly developed and the cooled gels were clearer, less firm, more elastic, more adhesive, and less susceptible to retrogradation than those of other cereal starches.

This study was a continuation of an investigation to examine the carbohydrates in oats (MacArthur and D'Appolonia 1979). Although studies have been conducted on oat starch (one of the most recent was Paton's study [1977], which was published while our investigation was underway), the most important factor in the quality evaluation of oats has been protein. Our primary intent was to ascertain if differences existed in the starch from three oat cultivars containing low, intermediate, and high protein levels. We also compared the oat starches and a wheat starch because the information could be of value in the use of oats as a partial replacement for wheat for specific end products.

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[2]Chemist and professor, respectively.

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MATERIALS AND METHODS

Flour Samples

A description of the three oat flour and one wheat flour samples and milling methods used in this study have been reported (MacArthur and D'Appolonia 1979).

Starch Isolation

Starch was isolated from the three oat flours and the hard red spring (HRS) wheat flour (800 g). A ratio of one part flour to four parts distilled water was mixed for 2 min in a commercial Waring Blendor on low speed (15,500 rpm). The supernatant and sludge were removed by centrifugation (2,000 × g for 20 min). The prime starch that formed a layer at the bottom of the centrifuge cup was reslurried and centrifuged a second time, removed, air dried (3 days), and passed through a 70-mesh sieve.

Starch Pasting Properties

Pasting properties of the starches were investigated by means of the Brabender Visco/Amylo Graph with and without the incorporation of carboxymethyl cellulose (CMC). We used the technique we described in 1977 for starches without CMC and Sandstedt and Abbott's procedure (1964) for starches with CMC incorporated.

Water-Binding Capacity

The procedure for water-binding capacities initially described by Yamazaki (1953) and later modified by Medcalf and Gilles (1965) was used.

Granule Density

Absolute densities of the different starch samples were determined by the xylene displacement method as described by Schoch and Leach (1964). All determinations were done on defatted samples, in duplicate, and an average of the results was recorded.

Total Lipid Concentration

Total lipid in the different flours, brans, and starches was determined by AACC Method 30-10, incorporating modifications for starch (MacArthur and D'Appolonia 1977).

Starch Fractionation

The amylose and amylopectin were obtained from the starch by using the aqueous leaching procedure described by Montgomery and Senti (1958).

Intrinsic Viscosity

Starches and starch fractions were dissolved in 1N sodium hydroxide as described by Lansky et al (1949). Intrinsic viscosity was determined at 25°C as described by Leach (1963) using an Ubbelohde (Cannon Fenske) viscometer, capillary size 75, equipped with a Wescan automatic viscosity timer (Wescan Instruments Inc., Santa Clara, CA).

Amylose Determination

Amylose in the oat and wheat starches was determined by the blue-value method (Gilbert and Spragg 1964), based on McCready and Hassid's procedure (1943).

Starch Determination

Starch content in the oat and wheat flours and brans was determined using the AACC glucoamylase procedure (Method 76-11).

RESULTS AND DISCUSSION

Chemical Data on Flours and Brans

Table I shows the protein concentrations, summarized previously (MacArthur and D'Appolonia 1979), lipid concentrations, and the starch content for the oat and wheat samples. Total lipid concentrations of the oat flours and brans ranged from 6.3 to 9.6% and 7.6 to 11.8%, respectively, which were higher than the 2.0 and 4.7% in wheat flour and bran.

The starch contents of the oat flours (Table I) were higher than values reported by Kent-Jones and Amos (1967); but the values they reported were for oat groats and not the oat flour itself. Excluding Dal, the other two oat cultivars were similar in starch content to the HRS wheat flour sample.

TABLE I
Pertinent Data of Oat and Wheat Flours and Brans[a]

Sample Source	Protein		Lipid		Starch
	Flour (%)	Bran (%)	Flour (%)	Bran (%)	Flour (%)
Dal	19.3	26.1	9.6	11.8	67.0
Froker	16.9	27.9	6.3	7.6	73.5
Cayuse	14.7	21.7	8.1	9.8	73.3
Waldron[b]	15.8	16.4	2.0	4.7	73.9

[a] Values reported are an average of two or more determinations expressed on a dry basis.
[b] Sample obtained from Brabender Quadrumat Jr. flour mill.

TABLE II
Starch Pasting Properties of Isolated Starches from Oat and Wheat Flour without Incorporation of Carboxymethyl Cellulose[a]

Starch Source	Pasting Temperature (°C)	Peak Height (BU)[b]	Peak Temperature (°C)	15 min Height (BU)	50°C Height (BU)
Dal	82.0	760	95 (0.00 min)	460	870
Froker	83.5	800	95 (0.00 min)	520	1,000
Cayuse	81.0	855	95 (1.00 min)	610	1,130
Waldron[c]	82.5	370	95 (4.75 min)	380	670
Waldron[d]	84.0	390	95 (5.00 min)	400	730

[a] Results expressed on a dry basis.
[b] BU = Brabender Units.
[c] Sample obtained from Brabender Quadrumat Jr. flour mill.
[d] Sample obtained from Miag Pilot flour mill.

TABLE III
Starch Pasting Properties of Isolated Starches from Oat and Wheat Flour with Incorporation of Carboxymethyl Cellulose[a]

Starch Source	Temperature of Initial Pasting (°C)	Peak Height (BU)[b]	Peak Temperature (°C)	15 min Height (BU)	50°C Height (BU)
Dal	58.0	275	95 (14.0 min)	275	380
Froker	55.0	395	95 (11.5 min)	380	480
Cayuse	55.0	415	95 (11.5 min)	410	490
Waldron[c]	55.0	185	95 (2.5 min)	160	240
Waldron[d]	56.5	220	95 (2.5 min)	205	315

[a] Results expressed on a dry basis.
[b] BU = Brabender Units.
[c] Sample obtained from Brabender Quadrumat Jr. flour mill.
[d] Sample obtained from Miag Pilot flour mill.

Starch Isolation

The amount of prime starch recovered from flours of the three oat cultivars Dal, Froker, and Cayuse (42.7, 50.8, and 55.6%, respectively) was low, based on the total starch concentration in these samples as given in Table I. Higher yield of starch from the cultivar Cayuse, which had the lowest protein content, was also found by Paton (1977). Dal, which had higher protein and lipid concentrations, had the least starch. The recoveries were probably low because of incomplete separation of the starch from the high protein layer on top of the starch. Paton (1977) reported starch yields of 48.5–61.0% for several oat groat flours by extraction of the flour under mild alkaline conditions initially to remove protein and nonstarch carbohydrates.

Starch Pasting Properties

The starch pasting properties of the isolated starches from the oat and wheat flours with and without incorporation of CMC are shown in Tables II and III, respectively. Only small differences were noted in the initial pasting temperature of the oat starches compared with wheat starch.

Using the Ottawa starch viscometer, Paton (1977) reported initial swelling for a number of isolated oat starches. Values ranged from 62 to 72°C; the value for wheat starch was 68.5°C.

Peak viscosities for the oat starches were higher than for the wheat starch, with and without incorporation of CMC. Waldron wheat starch has, however, been reported to have a lower peak viscosity than other HRS wheat starches (D'Appolonia and MacArthur 1975). Paton (1977) reported that oat starches exhibit peak viscosities of 122–166 cm-g, and that wheat, corn, and rice starches fell within this range. He also indicated that cooked oat granules appear more shear sensitive than corn, wheat, or rice starch, which agree with our results showing (Fig. 1) that the oat

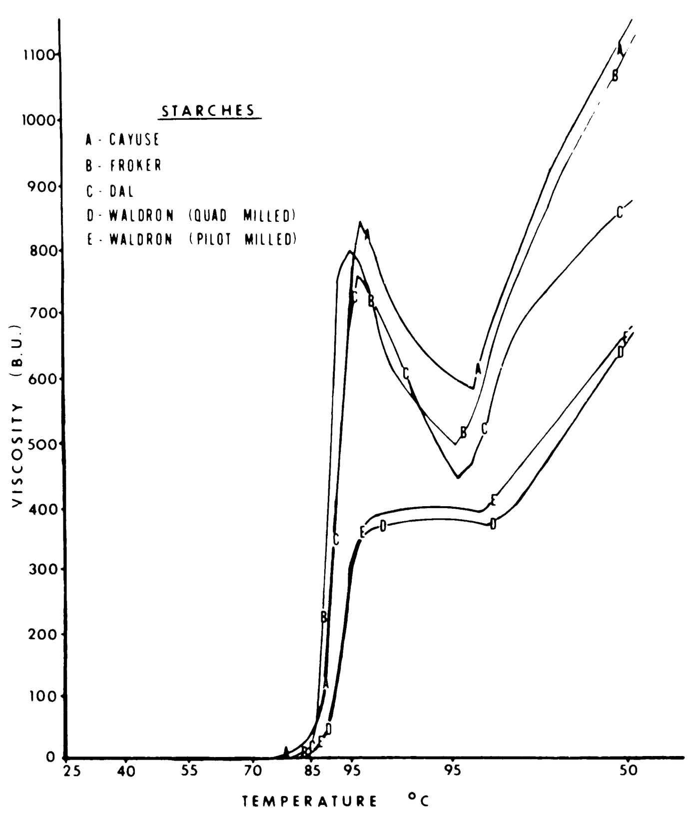

Fig. 1. Amylograph curves of oat and wheat starch without incorporation of carboxymethyl cellulose.

TABLE IV
Physicochemical Properties of Oat and Wheat Starches

Starch Source	Absolute Density at 30°C (g/ml)	Water-Binding Capacity[a] (%)	Intrinsic Viscosity [η]	Amylose (%)	Protein[a] (%)	Total Lipid[a] (%)
Dal	1.46814	85.0	1.59	27.9	0.60	1.11
Froker	1.45569	87.0	1.42	25.5	0.59	0.67
Cayuse	1.45890	86.0	1.45	25.9	0.44	0.81
Waldron[b]	1.46806	86.0	1.80	25.6	0.22	0.48

[a]Results expressed on a dry basis.
[b]Sample obtained from Brabender Quadrumat Jr. flour mill.

TABLE V
Intrinsic Viscosity of Oat and Wheat Starch Fractions[a]

Starch Source	Amylose [η]	Amylopectin [η]
Dal	2.46	2.07
Froker	2.55	1.73
Cayuse	2.99	1.70
Waldron[b]	2.33	1.80

[a]Average of two determinations.
[b]Sample obtained from Brabender Quadrumat Jr. flour mill.

starches were considerably less stable than the Waldron starch during the 15-min holding period at 95°C. Without the use of CMC, the peak viscosity for the oat starches occurred at or nearly at 95°C, whereas with the wheat starch the peak viscosity was not reached until 5 min after heating at 95°C. Also, the oat starches tended to exhibit a faster rate of retrogradation, as indicated by the slope of the curve during the cooling portion of the curve (Fig. 1). The latter results also agree with Paton's (1977).

The difference in response to CMC with oat starch compared with wheat starch was of particular interest. CMC has been used in starch studies to show the two-step gelatinization pattern characteristic of wheat starch. CMC, by competing with the starch for water, results in the first step of gelatinization. With the incorporation of CMC (Fig. 2), the starch gels showed greater stability, and the sharp decrease in viscosity noted without the use of CMC was not as evident. Apparently, CMC somehow contributed to greater gel stability.

With incorporation of CMC (Table III), the oat starches did not reach their peak viscostiy until after more than 10 min of heating at 95°C, but the wheat starch reached peak viscosity 2.5 min after heating at 95°C. As already noted, the reverse occurred without the use of CMC. Also, with the use of CMC, the slope of the curve of the oat starches during the cooling period was more similar to the slope of the curve of the wheat starch.

Generally, high set-back values are associated with greater starch paste retrogradation. Paton (1977) found that oat starch pastes have high set-back characteristics but show little evidence of high turbidity, surface skin formation, or shrinkage normally associated with retrogradation upon storage.

Physicochemical Properties

Table IV shows some physicochemical properties of the oat and wheat starches. For all determinations, small differences were shown among the three oat starches and between the oat and wheat starch. Of the three oat cultivars, Dal showed the greatest difference This oat cultivar showed differences not only in the starch fraction but also in the sugars, compared with the other two cultivars (MacArthur and D'Appolonia 1979). The carbohydrate differences in the Dal oat cultivar could be related to its higher protein content. We observed that in wheat (1977) higher protein-containing flour fractions obtained after pin milling and air classification contained somewhat higher concentrations of particular carbohydrates.

Dal had the highest granule density (Table IV), and densities were slightly lower in Froker and Cayuse than in the HRS wheat starch. These results indicate that Dal may have a more compact granule structure than the other two oat cultivars and may in part also explain differences in the pasting properties of Dal (Table III). The slightly lower water-binding capacity of Dal starch tends to support a more compact granule structure. The intrinsic viscosities of the oat starches (Table IV) had values ranging from 1.42 to 1.59, which were slightly lower than that of the wheat starch (1.80). Dal had the highest value of the three oat starches. Percent amylose in the various starches (Table IV) ranged from 15.5 to 27.9%. Amylose content was similar for Froker, Cayuse, and Waldron starch with values agreeing with reported data (Banks and Greenwood 1967, Whistler 1950). The value for Dal was slightly higher than has been reported for oat starch but may very well be a trait of this particular cultivar.

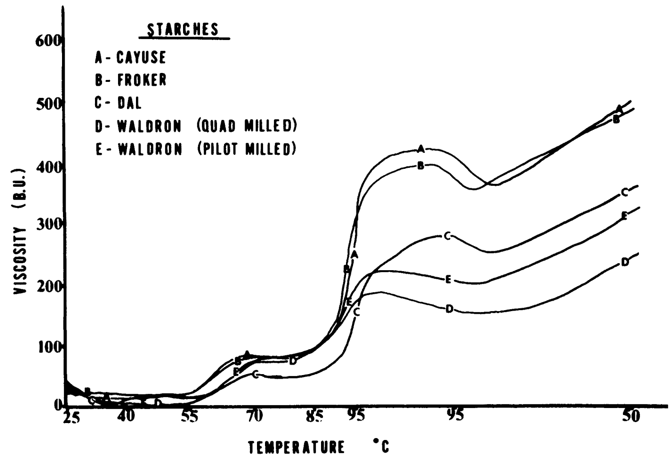

Fig. 2. Amylograph curves of oat and wheat starch with incorporation of carboxymethyl cellulose showing the two-step gelatinization pattern of cereal starches.

Protein content was higher in the oat starches than in the wheat starch (Table IV). The oat starches and the corresponding oat flours showed the same trend in protein levels. Dal, the high protein-containing cultivar, had the highest value, followed by Froker and Cayuse (0.60, 0.59, and 0.44%, respectively).

The total lipid concentration of the various starches showed the same differences as the total lipid in the corresponding flours, with Froker having the lowest value (0.67%) and Dal the highest (1.11%). The higher lipid concentration of the Dal starch may have an influence on the differences in this cultivar's pasting properties. The 0.48% value for the HRS wheat starch is in agreement with reported values (MacArthur and D'Appolonia 1977).

Intrinsic Viscosity of Starch Fractions

Table V shows the intrinsic viscosities of the oat and wheat starch fractions. The intrinsic viscosity of the oat starch amyloses ranged from 2.46 to 2.99 and increased as the protein content of the parent flour decreased. In all cases, the intrinsic viscosities of the oat starch amyloses were higher than of the wheat starch amylose. On the other hand, the intrinsic viscosity of the oat starch amylopectins, which ranged from 1.70 to 2.07, decreased as the flour protein decreased. Dal starch amylopectin showed considerably higher intrinsic viscosity than did the other two oat cultivars or the wheat starch. The differences in the intrinsic viscosity of Dal, as mentioned previously with reference to the higher lipid concentration in its starch, also may account for differences in the pasting properties of this cultivar.

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