

Preparation and Properties of Wheat and Corn Starch Maltodextrins with a Low Dextrose Equivalent¹

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ABSTRACT

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Wheat and corn maltodextrins (W-MD 8 and C-MD 8) with dextrose equivalent (DE) 2–3 were prepared by heterogeneous bacterial α -amylase digestion of a 15% starch paste at 95°C for 8 min followed by cooling and spray-drying. Gels of the two maltodextrins appeared opaque with a glossy surface and melted reversibly at \approx 65°C. Scanning electron micrographs showed that the products were divided finely and had few large remnants of starch granules. The fine granulation of W-MD 8 and C-MD 8 caused some clumping in cold water; homogeneous solutions were achieved with vigorous stirring at 90°C. Size-exclusion chromatograms showed that the two products contained similar broad, molecular-weight distributions of saccharides. A commercial potato maltodextrin marketed

as a fat-replacer contained fewer short-length molecules when compared to W-MD 8 and C-MD 8, whereas a commercial corn maltodextrin fat-replacer contained more. High-performance anion-exchange chromatography with pulsed-amperometric detection showed that all four maltodextrins contained only linear maltosaccharides between DP 2 and 25, with elevated levels of maltotriose and maltohexaose. The new wheat and corn maltodextrins contained 0.6–1.0% lipids and became rancid when stored at $>$ 30°C. The rancidity development in W-MD 8 was eliminated either by alkali treatment of starting starch or by charcoal treatment of the warm hydrolyzate.

Fat-mimetics produced from starches include maltodextrins of dextrose equivalent (DE) 2–6, lintnerized (thin-boiling) starches sheared in water, and hydroxypropylated high-amylose corn starch (Alexander 1992, Setser and Racette 1992, Harris and Day 1993). Most are prepared from potato, maize, and tapioca starches (Alexander 1991). Fat-mimetics made from starch are thought to form a weak network of polymer chains surrounding and connecting microcrystallites within an aqueous system (Reuther et al 1984, Biliaderis 1992).

One type of fat-mimetic, maltodextrin, is produced by the heterogeneous hydrolysis of potato starch by α -amylase (Richter et al 1976a,b; Bulpin et al 1984). Maltodextrin is water-soluble at 20–40% solids and \approx 90°C, and upon cooling forms an opaque gel that melts reversibly at 60–75°C. The gel gives rheological properties resembling a plastic fat.

The objectives here were to produce wheat and corn starch maltodextrins that give thermally reversible gels and to compare their properties to those of two commercial fat-mimetic maltodextrins.

MATERIALS AND METHODS

Materials

Commercial maltodextrins Paselli SA-2 and Maltrin M040 were from Avebe America, Princeton, NJ, and Grain Processing Corporation, Muscatine, IA, respectively. Wheat starch (Midsol 50) was from Midwest Grain Products, Atchison, KS, and dent corn starch was from A. E. Staley Manufacturing Co., Decatur, IL. The α -amylase Termamyl 120L, from Novo Nordisk, Danbury, CT, was \approx 2% solution of a heat-stable enzyme from *Bacillus licheniformis* with an activity of 9.78×10^3 units/mL at pH 6.5 and 25°C. One unit of activity was the amount of enzyme that catalyzes the release of 1 μ mole of reducing groups/min in a 20 mg/mL soluble-starch solution at 25°C and optimum pH (Robyt and Whelan

1968). Sigma Type II-A α -amylase (Sigma Chemical Co., St. Louis, MO) was in powder form from *B. subtilis* with an activity of 1.22×10^3 units/mg at pH 6.9 and 25°C. α -Amylase activity was followed in a reaction mixture or was determined in a laboratory-prepared maltodextrin, using the Ceralpha kit (Megazyme Pty. Ltd., Sydney, Australia) as described by McCleary and Sheehan (1987). Maltose monohydrate (Grade HHH) was from Hayashibara Biochemical Lab., Inc. (Okayama, Japan) and maltooligosaccharides of DP 3–15 from Nakano Vinegar Co., Ltd. (Tokyo, Japan). Pullulan standards with average molecular weights (M_n) of 0.58, 2.37, 10.0, and 38.0×10^4 with M_w/M_n 1.09–1.12 were from Polymer Laboratories (Amherst, MA). All chemicals were reagent-grade unless otherwise noted.

General Methods

Moisture and free lipids were measured using Methods 44-15A and 30-20, respectively (AACC 1995). Total carbohydrate was assayed by the phenol-sulfuric acid method using maltose as a reference standard (Dubois et al 1956), and DE was determined using the modified Park-Johnson method according to Hizukuri et al (1981). The maximum wavelength (λ_{max}) of absorbance by a polysaccharide iodine-iodide complex was determined as described by Ma and Robyt (1987). Total lipids in a wheat maltodextrin were estimated by phosphorous level (Morrison 1964), where total lipid (%) = $16.4 \times \%P$ (Morrison 1988). Scanning electron micrographs were taken of maltodextrins sprinkled onto double-sided adhesive tape attached to a specimen stub, followed by coating with gold-palladium. Samples were viewed with a scanning electron microscope (Etec-autoscan, Perkin Elmer, Norwalk, CT). Accelerated rancidity testing was done by the Schaal oven test at 63°C (Pool 1931) and in a similar manner at 25 and 30°C. Samples (5.0 g) were weighed into screw-capped vials (18.4 mL), and after a given time interval (12 hr for 30 and 63°C and 24 hr for 25°C), vials were removed from storage and equilibrated to room temperature, and the odor was compared to that of a fresh control sample after removal from cold storage. Differential scanning calorimetry (DSC) studies were performed in a Perkin-Elmer DSC-2 equipped with an FTS Systems Flexi-cooler and temperature controller (FTS Systems, Inc., Stone Ridge, NY). The instrument was calibrated with indium. Before DSC testing, some maltodextrins were extracted with hot 75% propanol to remove

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total lipids (Morrison and Coventry 1985). Samples (≈ 3 mg) and water (≈ 9 mg) were weighed into a DSC pan, and after 1 hr, a mixture was heated at 10 K/min from 280–400 K using an empty pan as reference. Size-exclusion chromatography was performed on a column (25×600 mm) of Sepharose CL-2B (Pharmacia Biotech, Piscataway, NJ) at 27°C. An aliquot (5 mL) of a solution of malto-dextrin (2 mg/mL) in 1% sodium hydroxide was introduced, and the components were eluted in ascending fashion with 1% sodium hydroxide at a flow rate of 0.3 mL/min. Fractions (6 mL each) were collected, and carbohydrate was determined in each fraction. Elution times of the three pullulan reference standards and of DP 15 malto-saccharide were established by injecting an aliquot (5 mL) of a 1% sodium hydroxide solution containing 0.13 mg/mL of each of the four reference compounds. All experiments were duplicated. High-performance anion-exchange chromatography (HPAEC) with pulsed amperometric detection was conducted at 25°C on a Dionex Carbopac PA1 column (4×250 mm) fitted with a Carbopac Guard column (3×25 mm) (Dionex Corporation, Sunnyvale, CA) according to Shi and Seib (1992). Comparisons of chromatograms were done by calculating the ratio of the response area of an oligomer to the sum of all the oligomers of DP 1–20. All HPAEC were replicated three times.

Laboratory-Scale Preparation of Corn and Wheat Maltodextrins

Termamyl α -amylase (1.0 mL) was added to water (100 mL) containing 200 ppm of calcium ion as calcium chloride. Water (160 mL) was added to a 500 mL of three-necked round-bottom

flask fitted with a paddle stirrer, and the flask was heated to 95°C in an oil bath. α -Amylase solution (3.3 mL) was added with rapid stirring followed by a slurry of prime starch (30 g [db] in 40 mL of water), which decreased the temperature of the mixture to $\approx 80^\circ\text{C}$. After thinning of the starch paste, which occurred in <30 sec, the hydrolysis reaction on 15% starch solids was allowed to proceed at 95°C with mild stirring for 5–25 min. The mixture was transferred to a beaker, and the reaction stopped by adding 1M hydrochloric acid to give pH 3.0 at $>90^\circ\text{C}$. After cooling to 60°C, the mixture was adjusted to pH 6 by adding 1M sodium hydroxide, and the hydrolyzate was spray-dried (model 100 fluid bed granulator/coater, Applied Chemical Technologies, Florence, AL). The atomizing nozzle was operated at 2.0 mL/min, and the temperature in the drying chamber was 100°C. The dried product was a white, free-flowing powder with moisture content $\approx 5\%$ that contained no residual α -amylase activity.

Bacterial α -amylase (0.64 mg) from Sigma also was used at digestion temperatures of 60–80°C. In a separate experiment before enzymolysis with Termamyl, wheat starch was extracted with alkali (pH 12) for 24 hr at 25°C. The alkali treatment saponified the lipids to give phosphorus-free wheat starch. However, acid-catalyzed methanolysis of the starch followed by esterification and gas-liquid chromatography of the fatty acid methyl esters showed the treated starch contained almost the same level of fatty acids as untreated starch (Matsunaga 1996).

Large-Scale Preparation of Corn and Wheat Maltodextrins

Thermostable α -amylase (Termamyl, 5.0 mL) was diluted in water (500 mL) containing 200 ppm of calcium as calcium chloride. Water (6.97 L) was heated to 95°C, in a 10-L double-jacketed, steam kettle (DC/2-20 Groen Division of the Dover Corporation, Elk Village, IL). Thermostable α -amylase solution (153.4 mL) was added to the kettle under vigorous stirring, followed immediately by a starch slurry (1.59 kg in 2.32 L of water). The hydrolysis reaction (15% solids, db) was allowed to proceed at 95°C under mild agitation for 8–12 min, after which the pH was adjusted to 3 using 3M hydrochloric acid. The reaction mixture was cooled to $\approx 60^\circ\text{C}$, adjusted to pH 6.5 using 3M sodium hydroxide, and spray-dried.

Rheology of Maltodextrin Gels

Viscoelastic measurements were performed at 25°C using a rheometer (VOR, Bohlin Rheologi, Edison, NJ) equipped with a cone and plate (CP 5/30 at 5.44°) sample cell and a 1.43 g•cm torque bar. Measurements were made at an amplitude of 1.0% over a frequency range of 0.1–10 Hz and strain of 0.2%. All samples displayed a linear response for the storage modulus (G') over a strain sweep between 0.02 and 2%. Maltodextrin solutions (25–40%, w/w) were prepared by placing maltodextrin (3.75–7.5g) in water (15 mL) in screw-cap glass vials (18.5 mL) and heating the vials in a water bath at 95°C until clear solutions were obtained. The vials then were stored at 4°C for 8 hr, during which gelation occurred. A gel was transferred from the vial to the cone and plate

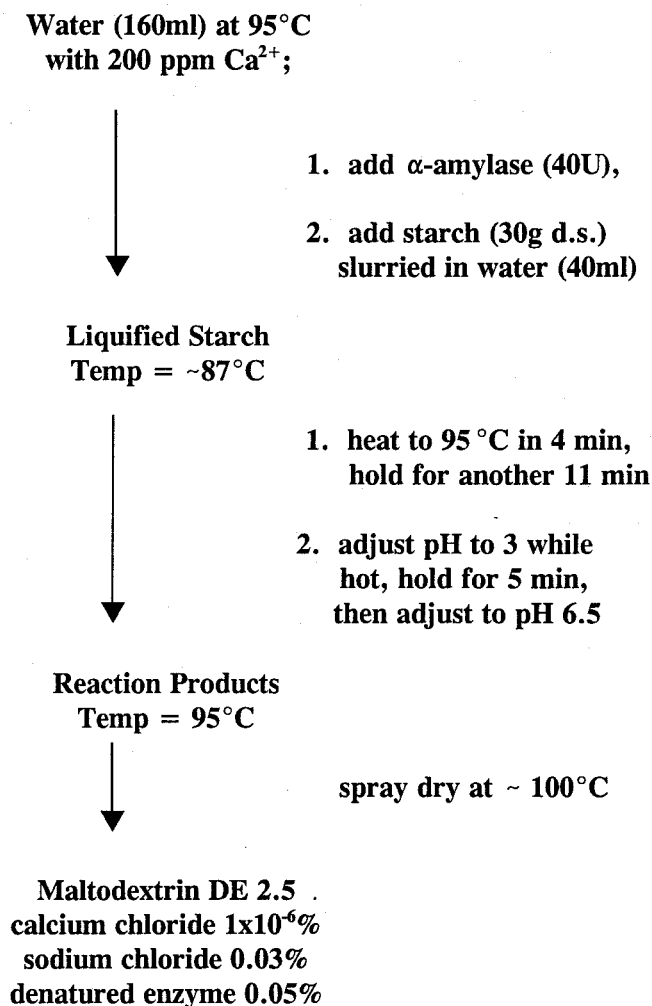


Fig. 1. Preparation of maltodextrin at high temperatures from nonwaxy starch using a glass reactor.

TABLE I
Properties of Maltodextrins Produced in the Large-Scale Stainless Steel Reactor

Product ^a	Time of Digestion (min)	Dextrose Equivalent (DE \pm SD) ^b	Average DP (DP _n)	Absorbance ^c (nm)
Wheat	08	2.53 \pm 1.03	40	555
Wheat	10	3.13 \pm 1.32	32	...
Wheat	12	3.78 \pm 1.95	27	...
Corn	08	2.59 \pm 0.75	39	550
Paselli SA-2	...	2.89 \pm 1.46	35	565
Maltrin M040	...	4.02 \pm 0.77	25	540

^a W-MD 8 and C-MD are wheat and corn maltodextrins.

^b Triplicate determinations.

^c Max. of I₂/I⁻ complex.

sample cell, the cone was lowered to a preset gap setting of 0.15 mm, and excess gel was trimmed from the edges of the cell. The edge of a gel was coated lightly with mineral oil, and measurements were taken at 25°C at 10-sec intervals. All samples were examined in triplicate.

Sensory Analysis of a Pourable Salad Dressing

Caesar salad dressing was prepared using the following recipe (Product information, Avebe America Inc., Princeton, NJ.): water (60.9%), vegetable oil (15.0%), vinegar (6.0%), maltodextrin fat-replacer (5.0%), instant modified starch (4.5%), egg-yolk powder (4.0%), salt (1.5%), dextrose (1.5%), onion powder (0.9%), garlic powder (0.5%), black pepper (0.1%), and mustard (0.1%). The instant modified starch was a 1:1 mixture of Freezist M and Miragel 463, both from A.E. Staley. A total of five salad dressings were prepared using wheat maltodextrin, corn maltodextrin, Maltrin M040, Paselli SA-2, and a blind control (Paselli SA-2). The

dry ingredients were added slowly to the vinegar and water in a blender (Waring Products Division of Dynamics Corporation of America, New Hartford, CT) at low speed. The vegetable oil was added, and the mixture was blended for 3 min at high speed. Each dressing was held at 4°C for 1 hr until served. Sensory analysis was done by the difference-from-control method according to Meilgaard et al (1988), and the tests were replicated three times in a random order of presentation. For each replicate, 12 trained panelists received a tray containing a marked control sample from Paselli SA-2; four randomly coded samples made from Paselli SA-2, Maltrin M040, W-MD 8, and C-MD-8; four ballots; and an instruction sheet. The dressings were evaluated on a score of 1–9, where 9 indicated a very different taste. Panelists recorded each sample number on a ballot, tasted a cracker and sipped water, tasted the control and a sample, and finally recorded the perceived difference. The process was repeated until all samples on a tray had been tasted.

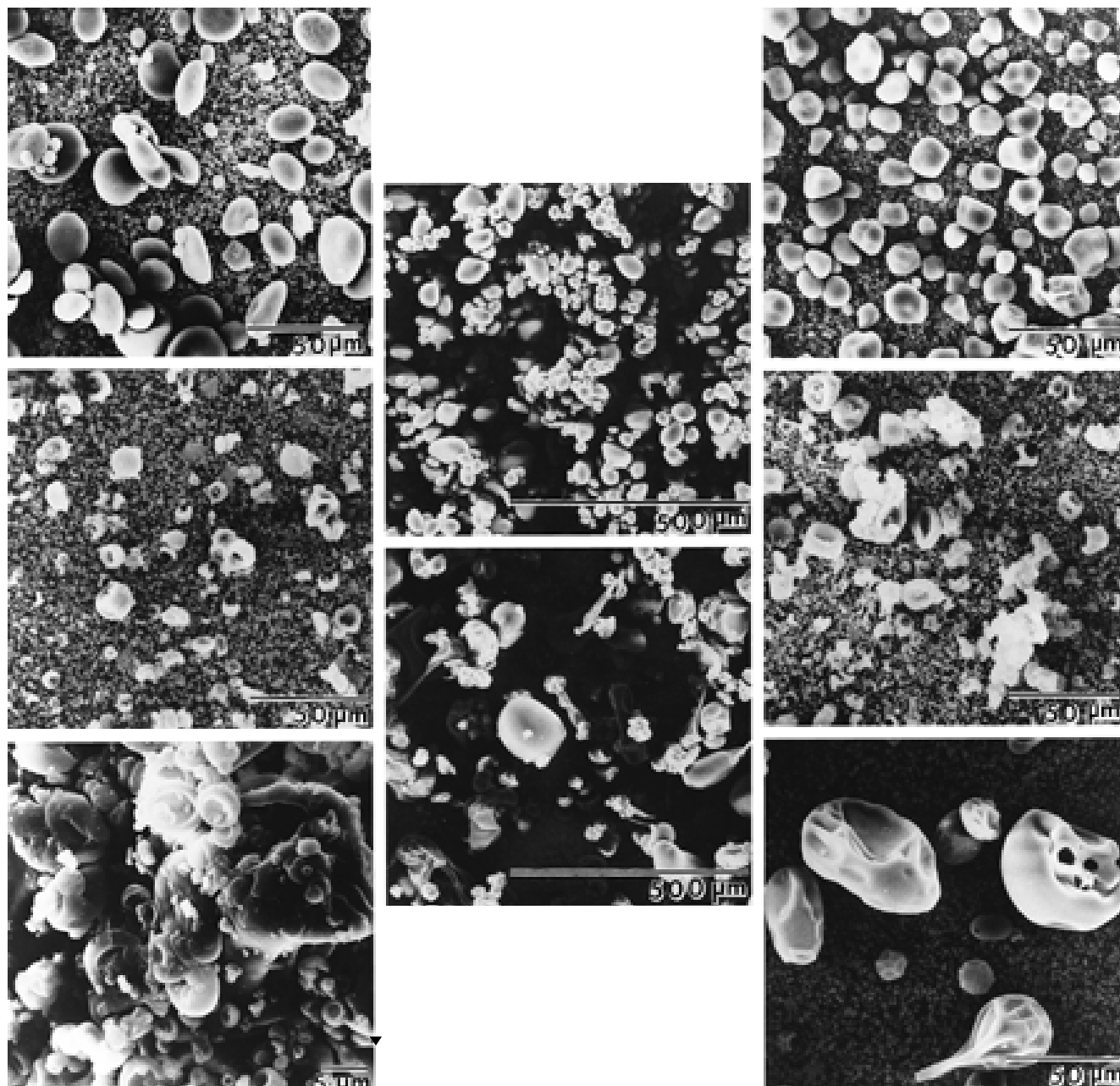


Fig. 2. Scanning electron micrographs of starches and dextrins. Left, top: prime wheat starch ($\times 500$). Left, middle: wheat starch maltodextrin (W-MD-8) ($\times 500$). Left, bottom: W-MD-8 ($\times 1,500$). Center, top: prime potato starch ($\times 100$). Center, bottom: Paselli SA-2 ($\times 100$). Right, top: prime corn starch ($\times 500$). Right, middle: corn starch maltodextrin (C-MD-8) ($\times 500$). Right, bottom: Maltrin M040 ($\times 500$).

RESULTS AND DISCUSSION

Preparation of Low-DE Maltodextrins

A gel made with 20% Paselli SA-2 served as a reference in searching for conditions to produce a fat-mimetic maltodextrin from wheat and corn starch. The properties of 20% maltodextrins monitored in water were: solution clarity at 80°C; gel formation at 4°C; and the opacity, surface gloss, and manual "cutting" properties of a gel.

Initially, wheat starch was digested with Termamyl under the conditions used on potato starch by Richter et al (1976a,b). Typical digestion conditions were used. A wheat starch slurry (15%) was heated in a stepwise fashion with 5.3 U/g (0.0045%) of Termamyl α -amylase (based on starch) starting with a digestion temperature just above gelatinization (\approx 59–64°C), followed by one or more additional digestion temperatures up to 90°C. However, wheat maltodextrin prepared by that method gave gels that appeared less opaque and had stronger textures than the reference gel. HPAE-chromatograms showed that the maltodextrins contained higher levels of maltose and glucose when compared to the reference, but reduced levels of higher oligosaccharides (data not given). Similar results were observed when wheat starch was digested with the Sigma enzyme at a final temperature of 80–90°C. Apparently, the low swelling of starch granules from wheat, as compared to potato starch, inhibited access of the enzyme to the amylose remaining in the gel phase of the wheat starch paste. At the same time, excessive hydrolysis occurred for the amylose leached from the wheat starch (Shi et al 1991).

When the swelling of wheat starch was increased by increasing the digestion temperature to 95°C, a wheat maltodextrin was produced with gelling properties similar to those of the reference (Fig. 1). A digestion time of 15–20 min at 90–95°C in a glass reactor (8–12 min in a stainless steel reactor) with 5.3 U/g starch of Termamyl gave wheat as well as corn maltodextrins with DE and iodine/iodide color also similar to those of Paselli SA-2 and Maltrin M040 (Table I). The absorbances of the iodine/iodide complexes indicated relatively short linear α -1,4-glucans, because λ_{max} at 546 nm corresponds to DP_n 36 (Banks and Greenwood 1975). The spray-dried wheat and corn maltodextrins appeared snow white and were calculated to contain 0.03% sodium chloride. During the hydrolytic step in the preparation of the maltodextrins with Termamyl, little loss of α -amylase activity occurred, but the final product after acidification was void of activity.

In scaling-up the laboratory procedure for the semipilot plant, the batch size of starch was 1.61 kg and a double-jacketed stainless steel reactor was employed with a swept surface agitator. Because of the improved heat transfer in the metal reactor compared to a glass flask, the digestion period was 8 min/run in the pilot-scale reactor compared to 20 min/run in the laboratory.

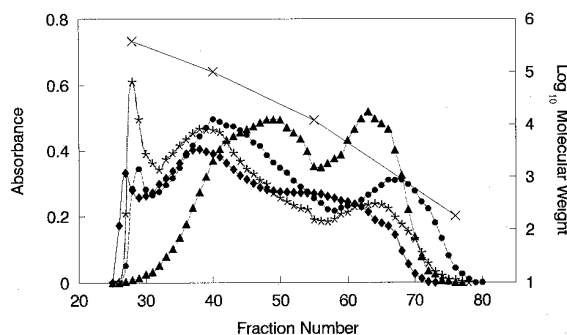


Fig. 3. Size-exclusion chromatograms of wheat maltodextrin W-MD 8 (●), corn maltodextrin C-MD 8 (◆), Paselli SA-2, (*) and Maltrin M040 (▲) pullulan standards (—x—). Flow rate was 0.3mL/min. Fractions were 6 mL.

Scanning Electron Microscopy

The commercial potato maltodextrin (Paselli SA-2) and the normal corn maltodextrin (Maltrin M040) both showed granular structures (Fig. 2). However, fragmented granules also were present in the potato product, which was attributed to high swelling of the granules during manufacturing. High swelling was evident also from the shriveled appearance of the large dry granules in Fig. 2. The largest granules observed in either maltodextrin were almost identical in size to those in the prime starches (Snyder 1984).

The maltodextrins we prepared from wheat and normal corn starch also contained some residual granular structure (left and right sides of Fig. 2). However, substantially fewer large granules were present in our maltodextrins as compared to the commercial products. Up to 30% of the weight of wheat starch is composed of small (<10 μ m) granules (Seib 1994), which could account for some of the small particles seen in Fig. 2. However, we presume that most of the large granules were torn into small particles by a combination of the shear stress in the atomizer of the spray dryer and the warm temperature of the starch paste hydrolyzate.

Excessively fine granulation in a maltodextrin is undesirable, because the fine particles form clumps when the product is added to water, although finely granulated maltodextrins can be agglomerated into larger particles to prevent clumping (Morris 1981). Neither of the commercial maltodextrins clumped when dissolved in hot water, which indicated that our maltodextrins, if dried in a manner that preserved residual granule structure, probably would eliminate the clumping problem.

Size-Exclusion Chromatography

Maltrin M040 is reportedly (Alexander 1991) produced by acid thinning of corn starch followed by enzymic digestion. The molecular weight distribution of Maltrin M040 was unique among the four low-DE maltodextrins (Fig. 3). It contained substantially fewer molecules above a molecular weight of \approx 100,000 Da when compared to the others, even though its DE was comparable (Table I). That result is consistent with a random depolymerization catalyzed by hydronium ion during the liquefaction step. However, the distribution of maltooligosaccharides of DP 2–7 in Maltrin M040 is consistent with α -amylase digestion in the second digestion step.

The maltodextrins produced from wheat and corn starch by high-temperature, α -amylase digestion showed molecular weight distributions resembling that of Paselli SA-2, except at the low and high extremes of size (Fig. 3). The size-distribution patterns of the wheat and corn maltodextrins appear bimodal, respectively, with apparent low molecular weight peaks of 1,000 and 1,500 Da and a high molecular weight peak of \approx 300,000 Da.

High-Performance Anion-Exchange Chromatography

HPAE chromatograms of all four low-DE maltodextrins showed single peaks resolved for oligomers up to DP 20 (not shown). Ammeraal et al (1991) found that maltooligosaccharides with maltosyl or glycosyl stubs were eluted more slowly than the linear saccharides up to DP 23. The low molecular weight material in

TABLE II
Time (days) to Rancid Odor Detection in Stored Maltodextrins

Maltodextrin ^a	Storage Temperature (°C)		
	25	32	63
Paselli SA-2	>30	30	>30
Maltrin M040	>30	30	>30
C-MD 8	>30	10	5
W-MD 8	>30	6	1
W-MD 8 (low-P) ^b	>180	>30	>180

^a W-MD 8 and C-MD are wheat and corn maltodextrins.

^b Wheat starch extracted at pH 12.0 and 25°C before α -amylase digestion.

the fat-mimetic potato maltodextrin consisted of mostly linear maltooligosaccharides (Bulpin et al 1984, Schierbaum et al 1992). The presence of only linear maltooligosaccharides and a peak of $\approx 1,000$ – $1,500$ Da in the size-exclusion chromatograms (Fig. 3) of our products can be explained by the heterogeneous digestion of the nonwaxy starch pastes with α -amylases, as first suggested by Richter et al (1976a). When a nonwaxy starch paste is heated with α -amylase, amylose is digested preferentially, either in the continuous liquid phase or inside the suspended gel phase of the paste. Richter et al (1976a) reasoned that the preferential digestion of the amylose occurred within the granule, because those linear molecules occur in the amorphous phase and should be more accessible to the enzyme in swollen starch granules. Linear maltooligosaccharides also may originate from α -amylase digestion of the A-chains of amylopectin. Compared to Maltrin M040, Paselli SA-2 contained a lower proportion of maltooligosaccharides at $<DP$ 9 but a higher proportion of DP 11–20 (Fig. 4), which is consistent with the higher DE of Maltrin M040.

All four maltodextrins contained elevated weight percentages of maltotriose (G_3) and maltohexaose (G_6) among the maltosaccharides at DP 2–6 (Fig. 4). Robyt (1989) showed that α -amylase from *B. amyloliquifaciens* preferentially produced a higher weight percentages of G_3 and G_6 from amylose, whereas mineral acid to the same extent of hydrolysis gave G_2 and G_3 in almost equal weight percentages and G_4 through G_7 in ever declining percentages. The response of the pulsed amperometric detector to equal weights of maltooligosaccharides from G_2 to G_6 declined steadily

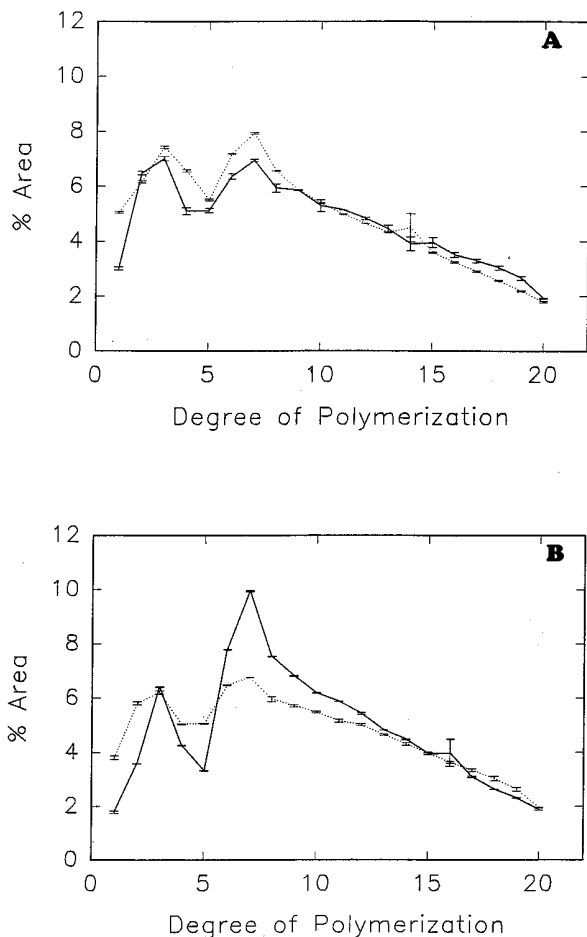


Fig. 4. Chain-length distributions of maltosaccharides determined by high-performance anion-exchange chromatography with pulsed-amperometric detection. **A**, Paselli SA-2 (—) and Maltrin M040 (.....). **B**, Wheat maltodextrin W-MD 8 (—) and corn maltodextrin C-MD 8 (.....). Standard deviations are shown by error bars.

to a total of 20% (Koizumi et al 1989). Decreases in concentrations of G_4 and G_5 as compared to G_3 seen in Fig. 4 are >3 – 6% , the decrease attributable to the difference in detector response.

The product pattern of the *B. amyloliquifaciens* was explained (Robyt 1989) by the combining site of the enzyme containing nine subsites for glucosyl units, with the cleavage point between subsites 3 and 4. The distribution of maltooligosaccharides in Fig. 4 indicates that all four maltodextrins were produced from an α -amylase with nine subsites, probably from a heat-stable *Bacillus* species. Maltrin M040 was somewhat less concentrated in G_3 and G_6 , which is consistent with an acid and α -amylase dual digestion process.

Rheology of Maltodextrin Gels

Wheat starch was digested in the semipilot scale reactor with 5.3 U/g of starch of Termamyl for 8, 10, and 12 min at 95°C to give maltodextrins W-MD 8, W-MD 10, and W-MD 12, respectively. Gels at 25% solids from W-MD 8 and W-MD 10 gave a higher storage modulus (G') compared to Paselli SA-2, whereas W-MD 12 gave a lower modulus (Fig. 5B). A G' value of 10^4 Pa reported by Bulpin et al (1984) for a 35% gel of the fat-mimetic potato maltodextrin appears consistent with the G' of 2.5×10^3 Pa we measured for a 25% gel of Paselli SA-2. Maltrin M040 failed to produce a gel at 25% solids and 4°C , but it did gel at 40% (Fig. 5A). The almost constant value of G' over a frequency sweep of 0.1–10 Hz in Fig. 5 and the high values of G' with low values of $\tan \delta$ (data not given) indicated that all four maltodextrins formed true gels. The corn maltodextrin C-MD 8 produced under the same conditions as the wheat maltodextrin W-MD 8 gave a slightly stronger gel (Fig. 5A).

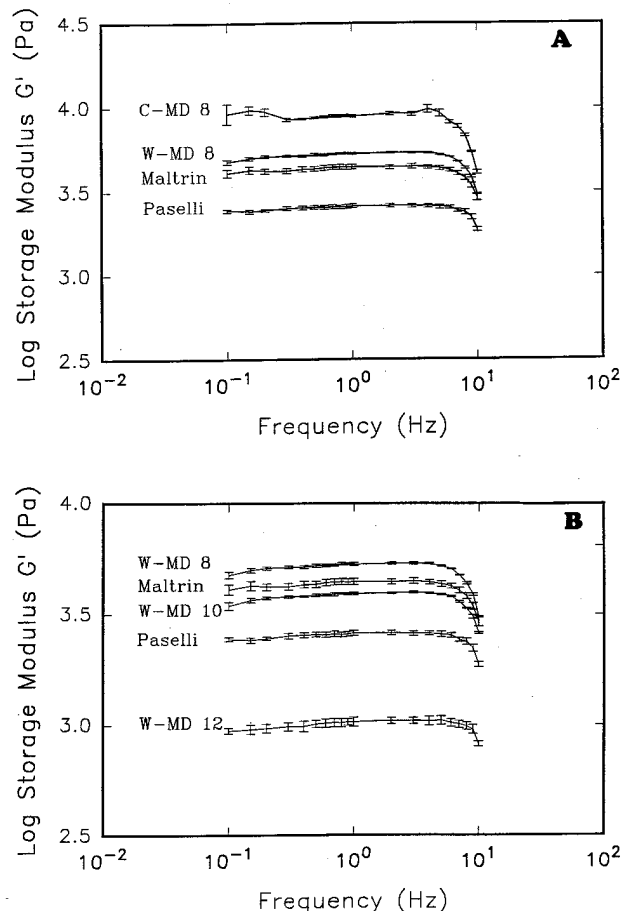


Fig. 5. Storage modulus (G') values. **A**, C-MD 8, W-MD 8, Maltrin M040, and Paselli SA-2. **B**, W-MD 8, W-MD 10, W-MD 12, Paselli SA-2, and Maltrin M040. Standard deviations are shown by error bars.

Elimination of Rancidity in Corn and Wheat Maltodextrins

The corn and wheat starch maltodextrins, W-MD 8 and C-MD 8, developed a rancid odor within one to five days of storage at 63°C (Table II). Under the same conditions, Maltrin M040 and Paselli SA-2 gave no rancid odor for up to 180 days. Upon storage at 32°C, W-MD 8, and C-MD 8 became rancid in <10 days, but both were much more stable at 25°C, producing no noticeable rancid odor >180 days. Paselli SA-2 and Maltrin M040 are reported by the manufacturers to contain 0.06 and 0.1% fat, respectively, and Maltrin M040 is reportedly produced from a nonwaxy corn (Alexander 1992). Prime potato starch contains an average of 0.1% lipids (Mitch 1984), whereas prime corn starch contains 0.7% lipids (Morrison 1988). Somehow, most of the lipids were removed when dent corn was converted to spray-dried Maltrin M040.

In contrast to the low levels of lipids in Paselli SA-2 and Maltrin M040, our products W-MD 8 and C-MD 8 retained the endogenous starch lipids at levels of ≈1.0 and 0.7%, respectively. Because those lipids are largely polyunsaturated (Morrison 1988), they react with oxygen to produce off-odors and off-flavors.

Extractions of the wheat maltodextrin W-MD 8 and corn maltodextrin C-MD 8 with warm hexane or ethyl ether failed to remove the lipids, as evidenced by the same phosphorous levels in the extracted and blank maltodextrins (Table III). The level of phosphorous can be used to indicate lipid content of wheat and corn starches (Morrison 1988). The starch lipids, which consist of >90% monoacyl lipids (Morrison 1988), appear to form a helical complex with the linear α -1,4-glucan chains. The complexes are probably of the amorphous type, as occurs in prime barley starch (Morrison et al 1993). However, no dissociation peak was found for such a complex when the maltodextrins W-MD 8 and C-MD 8 were heated in the differential scanning calorimeter with three parts of water (data not given). Apparently, the reduced molecular weight of the linear molecules and their broad molecular weight distributions gave weak complexes, which resulted in a broad melting range (Seneviratne and Biliaderis 1991). The low dissociation temperatures also would explain why W-MD 8 and C-MD 8 were less stable at >32°C.

Two approaches were used to eliminate the rancidity development in W-MD 8. The warm hydrolyzate just before spray-drying was passed through a bed of granulated, activated charcoal or the starting starch was extracted with aqueous sodium hydroxide. Wheat maltodextrins prepared with either of those steps developed no rancid odor after five months of storage at 63°C, and their gels appeared the same as those from controls. Apparently, free lipid was removed from starch by charcoal treatment, whereas stirring the starch at pH 12.3 for 24 hr at 25°C changed the phospholipid to free fatty acid salts (Matsunaga 1996). The fatty acid salts inside the granules somehow resisted autoxidation upon their digestion followed by spray-drying and storing the product.

TABLE III
Phosphorous Levels (%) in Starch and Maltodextrins

Sample ^a	Phosphorous (%)
W-MD 8	
Blank	0.065 ^b
Extracted with ether	0.065
Extracted with hexane	0.067
Extracted with hot 75% n-propanol	0.012
C-MD 8	
Blank	0.026
Extracted with ether	0.027
Extracted with hexane	0.026
Extracted with hot 75% n-propanol	0.008
Maltrin M040	0.013
Hydroxypropylated wheat starch ^c	0.011

^a W-MD 8 and C-MD are wheat and corn maltodextrins.

^b Duplicate analyses agreed within 0.005% *P*.

^c Hydroxypropylation was done at pH 11.6.

Comparison of Maltodextrins in a Food Product

Trained taste panelists were unable to discern any overall difference ($\alpha = 0.05$) between samples of a pourable salad dressing containing four different maltodextrin fat-replacers. Using Paselli SA-2 as the blind control, salad dressings made with Maltrin M040, W-MD 8, and C-MD 8 received scores of 1.36, 1.83, 1.38, and 1.83, respectively, over a range of 1 (tastes the same) to 9 (tastes very different). However, differences in gel properties between the maltodextrins probably would not be discerned in a pourable dressing.

CONCLUSIONS

Low-DE wheat and corn maltodextrins can be prepared by α -amylase treatment of the starches at 95°C, and they give gels with properties similar to those of commercial, fat-replacing maltodextrin. The wheat and corn maltodextrins undergo oxidative rancidity when stored at >30°C, unless preventive measures are taken. The wheat and corn maltodextrins can replace 25% of the oil in a pourable salad dressing.

LITERATURE CITED

- American Association of Cereal Chemists. 1995. Approved Methods of the AACC, 9th ed. The Association: St. Paul, MN.
- Alexander, R. J. 1991. Maltodextrins: properties, production, and applications. Pages 233-275 in: Starch Hydrolysis Products. F. W. Schenck and R. E. Hebeda, eds. VCH: New York.
- Alexander, R. J. 1992. Carbohydrates as fat replacers. Pages 343-370 in: Developments in Carbohydrate Chemistry. R. J. Alexander and H. F. Zobel, eds. Am. Assoc. Cereal Chem.: St. Paul, MN.
- Ammeraal, R. N., Degardo, G. A., Tenbage, F. L., and Freidman, R. B. 1991. High performance anion exchange chromatography with pulsed amperometric detection of linear and branched oligosaccharides. Carbohydr. Res. 215:179-192.
- Banks, W., and Greenwood, C. T. 1975. Starch and Its Components. Halsted Press: New York.
- Biliaderis, C. G. 1992. Characterization of starch networks by small strain dynamic rheometry, Pages 87-135 in: Developments in Carbohydrate Chemistry. D. J. Alexander and H. F. Zobel, eds. Am. Assoc. Cereal Chem.: St. Paul, MN.
- Bulpin, P. V., Cutler, A. N., and Dea, I. C. M. 1984. Thermally reversible gels from low DE maltodextrins. Pages 475-484 in: Gums and Stabilizers in the Food Industry, Vol. II. G. O. Phillips, D. O. Wedlock, and P. A. Williams, eds. Pergamon Press: New York.
- Dubois, M., Gilles, K. A., Hamilton, J. K., Reber, P. A., and Smith, F. 1956. Colorimetric method for the determination of sugars and related substances. Anal. Chem. 28:350-356.
- Harris, D. W., and Day, G. A. 1993. Structure versus functional relationships of a new starch-based fat replacer. Starch/Staerke 45:221-226.
- Hizukuri, S., Takeda, Y., Yasuda, Y., and Suzuki, A. 1981. Multi-branched nature of amylose and action of de-branching enzymes. Carbohydr. Res. 94:205-213.
- Koizumi, K., Kubota, Y., Tanimoto, T., and Okada, Y. 1989. High-performance anion-exchange chromatography of homogeneous D-gluco-oligosaccharides and -polysaccharides (polymerization ≤ 50) with pulsed amperometric detection. J. Chrom. 464:365-373.
- Ma, W. P., and Robyt, J. F. 1987. Preparation and characterization of soluble starches having different molecular sizes and compositions, by acid hydrolysis in different alcohols. Carbohydr. Res. 166:283-297.
- Matsunaga, N. 1996. Alkali extraction of wheat starch granules. MS thesis. Kansas State University: Manhattan, KS.
- McCleary, B. V., and Sheehan, H. 1987. Measurement of cereal α -amylase: A new assay procedure. J. Cereal Sci. 6:237-251.
- Meilgaard, M., Civille, G. V., and Carr, B. T. 1988. Difference tests. Pages 47-112 in: Sensory Evaluation Techniques. M. Meilgaard, G. V. Civille, and B. Carr, eds. CRC Press: Boca Raton, FL.
- Mitch, E. C. 1984. Potato starch: Production and uses. Pages 479-490 in: Starch Chemistry and Technology, 2nd ed. R. L. Whistler, J. N. BeMiller, and E. F. Paschall, eds. Academic Press: Orlando, FL.
- Morris, C. E. 1981. New form of maltodextrin has unique properties. Food Eng. 53(5):110.
- Morrison, W. R. 1964. A fast, simple, and reliable method for the micro-determination of phosphorous in biological materials. Anal. Biochem. 7:218-224.

- Morrison, W. R. 1988. Lipids in cereal starches: A review. *J. Cereal Sci.* 8:1-15.
- Morrison, W. R., and Coventry, A. M. 1985. Extraction of lipid from cereal starches with hot aqueous alcohols. *Starch/Staerke* 37:83-87.
- Morrison, W. R., Tester, R. R., Snape, C. E., Law, R. E., and Gidley, M. J. 1993. Swelling and gelatinization of cereal starches. IV. Some effects of lipid-complexed amylose and free amylose in waxy and normal barley starches. *Cereal Chem.* 70:385-391.
- Pool, W. O. 1931. Rancidity and stability in shortening products. *Oil Fat Ind.* 8:331-336.
- Reuther, F., Damaschun, G., Gernat, C., Schierbaum, F., Kettlitz, B., Radosta, S., and Nothnagel, A. 1984. Molecular gelation mechanism of maltodextrins investigated by wide-angle x-ray scattering. *Colloid Polym. Sci.* 262:643-647.
- Richter, M., Schierbaum, F., Augustat, S., and Knoch, K.-D. 1976a. Method of producing starch hydrolysis products for use as a food additive. U.S. patent 3,962,465.
- Richter, M., Schierbaum, F., Augustat, S., and Knoch, S.-D. 1976b. Method of producing starch hydrolysis products for use as food additives. U.S. patent 3,986,980.
- Roby, J. F. 1989. Mechanism and product specificity of α -amylases. *J. Jpn. Soc. Starch Sci. (Denpun Kagaku)* 36:287-301.
- Roby, J. F., and Whelan, W. J. 1968. The α -amylase, Pages 430-476 in: *Starch and Its Derivatives*, 4th ed. J. A. Radley, ed. Chapman and Hall: London.
- Schierbaum, F., Radosta, S., Vorwerk, W., Yuriev, V. P., Braudo, E. E., and German, M. L. 1992. Formation of thermally reversible maltodextrin gels as revealed by low resolution H-NMR. *Carbohydr. Polym.* 18:155-163.
- Seib, P. A. 1994. Wheat starch: Isolation, structure and properties. *Oyo Toshitsu Kagaku* 41:49-69.
- Seneviratne, H. D., and Biliaderis, C. G. 1991. Action of α -amylases on amylose-lipid complex superstructures. *J. Cereal Sci.* 13:129-143.
- Setser, C., and Racette, W. 1992. Macromolecule replacers in food products. *Crit. Rev. Food Sci. Nutr.* 32:275-297.
- Shi, Y.C. and Seib, P.A. 1992. The structure of four waxy starches related to gelatinization and retrogradation. *Carbohydr. Res.* 227:131-145.
- Shi, Y. C., Seib, P. A., and Lu, S. P. W. 1991. Leaching of amylose from wheat and cornstarch. Pages 667-686 in: *Water Relations in Foods*. H. Levine and L. Slade, eds. Plenum Press: New York.
- Snyder, E. M. 1984. Industrial microscopy of starches. Pages 661-673 in: *Starch Chemistry and Technology*, 2nd ed. R. L. Whistler, J. N. BeMiller, and E. F. Paschall, eds. Academic Press: Orlando, FL.

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