Comparison of the Effects of Microwave and Conventional Cooking on Starch and β-Glucan in Rolled Oats

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ABSTRACT

Cereal Chem. 68(4):372-375

Rolled-oat porridge was prepared by conventional and microwave cooking to determine and compare the effects of these cooking methods on the texture, viscosity, and amounts of dispersed gelatinized starch and solubilized (1→3)(1→4)-β-D-glucan (β-glucan). The porridge prepared by microwave cooking was generally more grainy and less viscous than that prepared by the conventional method. Microwave cooking produced relatively less dispersed gelatinized starch and less solubilized β-glucan than did conventional cooking. The difference was slight with short cooking duration (1 min) but increased drastically with prolonged cooking (20 min). Thicker oat flakes (regular-cooking rolled oats) released less solubilized β-glucan and gelatinized starch than did thinner oat flakes (quick-cooking rolled oats) upon cooking. Microscopic examination revealed that the two cooking methods had different effects on the structural organization of oats. Rolled oats prepared by microwave cooking contained starch granules that were smaller in volume and less convoluted in structure than those conventionally cooked. Furthermore, the cell wall of the former was less disrupted. These differences may have been due to the effect of stirring; the microwave-heated rolled oats were stirred relatively less than were the conventionally cooked samples.

Rolled oats are rich in complex carbohydrates, which include starch (a predominant constituent) and (1→3)(1→4)-β-D-glucan (β-glucan), a major constituent of the soluble dietary fiber that may be responsible for the hypocholesterolemic effects of oat cereal products (Anderson and Chen 1986). Rolled oats are traditionally consumed as a hot porridge, which can be prepared by cooking in water using conventional or microwave heating. The two methods differ in the way that heat is transferred during cooking. In conventional cooking, heat energy is transferred from a heat source to the food through conduction and convection currents. Microwave heating mainly involves the interaction of the individual molecules of food with the alternating electromagnetic field; rapid orientation of the dipoles results in molecular friction and the generation of heat (Davis 1987). Heat transfer within the food then takes place by conduction after the electromagnetic energy is converted to heat. Microwave cooking has gained acceptance for food preparation because of its convenience and speed.

Solubilized β-glucan and a dispersed gelatinized starch fraction were factors that possibly exerted influence on the texture and mouthfeel of conventionally cooked rolled oats. An earlier study (Yiu et al 1987) showed that short cooking duration (1 min) resulted in a grainy porridge, whereas prolonged cooking (up to 20 min) resulted in a gummy, mushy porridge. Prolonged cooking solubilized more β-glucan and released more of the dispersed gelatinized starch than did short cooking duration. Rate of heating also influenced texture, with gradual heating resulting in more solubilization of β-glucan and dispersion of gelatinized starch. Microwave cooking at normal household power levels (e.g., 600–700 W at 2,450 MHz) involves high heat intensity and short cooking duration. The effects of this method on the amounts of the dispersed gelatinized starch fraction and solubilized β-glucan were not known.

Commercially processed rolled oats are available in several forms, depending on the thickness of the oat flake (Deane and Commers 1986). Quick-cooking rolled oats (recommended cooking time, 1 min) are 0.25–0.38 mm thick on the average, whereas regular-cooking rolled oats (recommended cooking time, >5 min) are 0.5–0.63 mm thick. Thicker oat flakes have more intact cell walls and compound starch granules (Yiu 1986). The influence of flake thickness on solubilization and dispersion of complex carbohydrates in cooked rolled oats is not known.

The present study compares the effects of microwave and conventional cooking methods on the viscosity, starch and β-glucan, and microstructures of rolled oats. The influence of factors such as cooking time and product thickness were also examined.

MATERIALS AND METHODS

Cooking Rolled Oats

Quick- and regular-cooking rolled oats produced by two different manufacturers were purchased from local supermarkets. Samples were cooked according to a previously described method (Yiu et al 1987), in which 15 g of rolled oats were added to 120 ml of water at room temperature. Each experiment was performed at least three times.

For conventional cooking, the above mixture was cooked in a stainless steel vessel covered with a glass lid to restrict evaporation losses. The mixture was brought to a boil on a preheated Ikamag Ret-G heater thermostatically regulated by a thermocouple (Terochem Laboratory Ltd., Mississauga, ON). The mixture was stirred constantly with a magnetic stirrer. After boiling was observed (within 2–3 min), the cooking temperature was reduced to maintain gentle simmering at 90–95°C for 1 or 20 min.

For microwave cooking, the mixture was cooked in a polycarbonate thermoplastic container (Micro-Mac Ltd., Calgary, AB) covered with a lid that had an opening for a temperature probe. The mixture was brought to a boil at full power (600 W) in a microwave oven (Quasar Easy-matic, Matsushita Electric of Canada Ltd., Mississauga, ON). The mixture reached boiling after 1 min 55 sec. The cooking temperature was then reduced to maintain gentle simmering at 93°C (measured with the temperature probe) for 1 or 20 min. The 20-min samples were stirred by hand at regular intervals.

Immediately after cooking, the samples were diluted with 100 ml of cold water. The cooled mixture was then centrifuged at 33,000 × *g* for 90 min. Three distinct layers—a clear but viscous supernatant, a white pastelike middle layer, and a bottom layer chiefly composed of cooked solids—were separated by centrifugation. Each layer was recovered and weighed. Duplicate 1-ml aliguots of the uppermost supernatant layer were measured as described below.

Measurement of β-Glucan and Starch

Solubilized β-glucan was determined using Calcofluor (Wood and Weisz 1984). Precipitates containing β-glucan were hydrolyzed in 1.0*N* trifluoroacetic acid at 125°C for 1 hr. After the trifluoroacetic acid evaporated, each residue was dissolved in 2 ml of distilled water, filtered through a 0.45-μm membrane, and analyzed for glucose by an automated glucose oxidase procedure (Technicon Industrial Autoanalyzer method No. 168-76A). Glu-

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cose values were converted to glucan values by multiplying with a factor of 0.9.

Starch was converted to glucose by α-amylase and amyloglucosidase according to the method of Batey (1982) and determined by the glucose oxidase procedure described above.

Determination of Viscosity

Kinematic viscosities of supernatants from cooked samples of rolled oats were determined at 37°C using calibrated Cannon-Manning semimicro Ubbelohde-type viscometers (size 200, in which the efflux time of water was about 7.4 sec).

Statistical Analysis

Results obtained from rolled oats from the two manufacturers were pooled. The pooled data were analyzed to compare the effects of microwave and conventional cooking and to compare thick and thin products. Analysis of variance was performed using the GLM procedure (for unequal numbers of observations), which was specified with main effects (cooking method and product variety) and crossed effects (product variety and cooking method interaction) and based on a 2×2 factorial model (SAS 1987). The procedure, which used the method of least squares to fit general linear models, also included Duncan's multiple range test (on product variety means) and three CONTRAST (SAS 1987) statements to allow comparison of the differences in the overall effects between microwave and conventional cooking, between 1-min microwave and 1-min conventional cooking, and between 20-min microwave and 20-min conventional cooking. The REG procedure (SAS 1987) was used for linear and multiple regression analysis of the pooled data to test significant correlations between viscosity and β-glucan content, viscosity and solubilized starch content, and viscosity and the interaction of β-glucan and starch contents.

Microscopy

Cooked samples of rolled oats were fixed in 3% glutaraldehyde (in 0.01*M* phosphate buffer, pH 7.2) for 24 hr. Sections embedded in glycol methacrylate (2 μm thick) were prepared from the fixed materials according to the method described by Yiu (1986). Sections were affixed to glass slides and stained with Cellufluor (Polysciences Inc., Warrington, PA) according to the procedure described by Yiu and Mongeau (1987) or with fluorescein-labeled *Lens culinaris* agglutinin (FLCA) according to the method of Yiu et al (1987). Stained sections were then examined by fluorescence optics using a Universal Research Photomicroscope (Carl Zeiss Ltd., Montreal, PQ). The microscope was equipped with a III RS epi-illuminating condenser with an HBO 100-W mercury-arc burner and an exciter-barrier filter system set for maximum transmission at 365/418 nm (for examining Cellufluor fluorescence) and 450–490/520 nm (for FLCA). Micrographs were recorded on 35-mm Ektachrome 400 daylight film from which black and white prints were made.

RESULTS

Effects of Different Cooking Methods on the Amount of Gelatinized Starch Released from Cooked Rolled Oats

The white, pastelike middle layers, representing the major portions of gelatinized starch of rolled oats prepared by the different cooking methods, were removed from the cooked mixtures, weighed, and compared. The effect of 1-min microwave cooking on the amount of the middle layer was not significantly different from the effect of 1-min conventional cooking. However, 20-min microwave and 20-min conventional cooking produced significantly different amounts of dispersed gelatinized starch ($P < 0.001$). The overall mean value from microwave cooking and pooled from the two manufacturers was significantly different from the overall mean from conventional cooking ($P < 0.001$).

Extended cooking had a greater impact on the outcome of conventional cooking than on the outcome of microwave cooking. The increase in the amount of the middle layer obtained with conventional cooking after 20 min was about double, on the average, compared with an increase of less than one third obtained with microwave cooking (Table I). Although the thinner, quick-cooking oats produced slightly more dispersed gelatinized starch than did the thicker, regular-cooking oats after cooking, product variety did not significantly influence the amount of the middle layer.

Effects of Different Cooking Methods on the Viscosity of Cooked Rolled Oats

The results of viscosity determination on the supernatants of rolled oats produced by the two manufacturers were pooled and the means compared. The effect of 1-min microwave cooking on viscosity was marginally different ($P < 0.05$) from the effect of 1-min conventional cooking. Samples prepared by 20-min microwave cooking were significantly less viscous than were those prepared by 20-min conventional cooking ($P < 0.001$). Prolonged cooking had a greater impact on the viscosity of the conventionally prepared samples than on the viscosity of samples prepared by microwave (Table II). When cooking was extended from 1 to 20 min, the increase in viscosity was on average more than twofold in the conventionally prepared thin (quick-cooking) samples but was only 2% in the microwave-cooked samples. In thick (regular-cooking) rolled oats, prolonged cooking by the conventional method resulted in an average of 89% increase in viscosity, compared with an average of 19% increase in porridges prepared by microwave. Product variety and the combined effect of product variety and cooking method significantly affected the viscosity of cooked rolled oats ($P < 0.01$ in each case).

Effects of Different Cooking Methods on the Concentrations of Solubilized Starch and β-Glucan in Cooked Rolled Oats

The concentrations of starch in the supernatants of cooked

TABLE I
Weight (g ± SD) of Middle Layers of Centrifugally Separated Cooked Rolled Oats Prepared by Two Cooking Methods

Cooking Time (min)	Product Thickness	Manufacturer 1		Manufacturer 2	
		Conventional	Microwave	Conventional	Microwave
1	Thin	26.2 ± 7.44	23.5 ± 1.45	26.3 ± 0.44	24.1 ± 1.02
	Thick	25.8 ± 2.30	20.9 ± 1.32	23.0 ± 2.10	22.7 ± 0.85
20	Thin	51.0 ± 3.81	32.2 ± 0.65	48.1 ± 2.37	26.8 ± 1.44
	Thick	45.0 ± 9.03	28.0 ± 0.67	42.4 ± 4.55	26.8 ± 1.44

TABLE II
Viscosities of (cS ± SD) of Supernatants of Cooked Rolled Oats Prepared by Two Cooking Methods

Cooking Time (min)	Product Thickness	Manufacturer 1		Manufacturer 2	
		Conventional	Microwave	Conventional	Microwave
1	Thin	1.82 ± 0.63	1.75 ± 0.16	1.98 ± 0.03	1.89 ± 0.21
	Thick	1.87 ± 0.26	1.11 ± 0.07	1.93 ± 0.27	1.38 ± 0.04
20	Thin	5.20 ± 0.11	1.87 ± 0.37	4.11 ± 0.38	1.86 ± 0.50
	Thick	4.29 ± 1.24	1.44 ± 0.23	2.91 ± 0.55	1.50 ± 0.17

rolled oats were determined and their means compared. The overall mean of pooled data obtained from conventional cooking was significantly different from the mean obtained from microwave cooking ($P < 0.001$), although no obvious difference was noted between the effects of conventional and microwave cooking of thin rolled oats for 1 min (Table III). Prolonged conventional cooking induced marginal increases in solubilized starch (less than 17% on average). The increase in solubilized starch induced by prolonged microwave heating was less uniform, ranging from 0% in thin rolled oats to an average of 45% in thick rolled oats. Oats from manufacturer 1 consistently released more solubilized starch upon cooking than did those from manufacturer 2 (Table III).

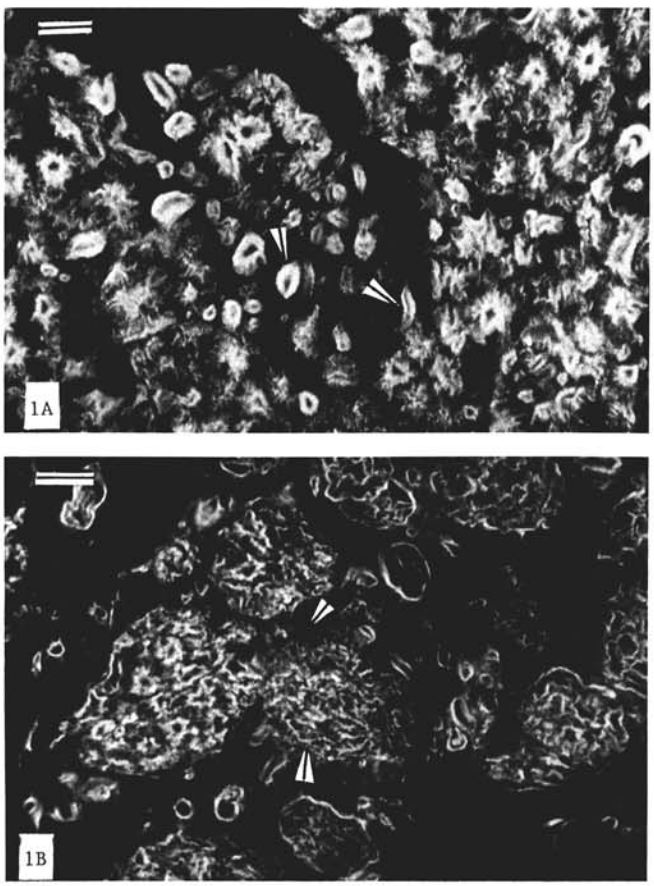

Fig. 1. Glycol methacrylate-embedded sections of thick (regular-cooking) rolled oats prepared by microwave (**A**) and conventional cooking (**B**) for 20 min and stained with fluorescein-labeled *Lens culinaris* agglutinin to show the difference in the structural organization of starch (arrows). Bar scales represent 10 μm.

The concentrations of solubilized β-glucan were also determined. The effect of 1-min microwave cooking on the release of β-glucan was significantly different ($P < 0.05$) from the effect of 1-min conventional cooking. The difference between β-glucan contents obtained with the two methods was slight after cooking for 1 min but more than double ($P < 0.001$) after cooking for 20 min (Table IV). Cooking duration also influenced the release of β-glucan. On average, β-glucan content doubled when conventional cooking was extended to 20 min (Table IV). Results of statistical analysis on the pooled data indicate that the amounts of solubilized β-glucan released from thin cooked rolled oats were significantly greater than the amounts released from the thick cooked rolled oats ($P < 0.05$).

Effects of Different Cooking Methods on the Microstructures of Rolled Oats

Oat flakes, sedimented in the bottom layer by centrifugation, were analyzed by fluorescence microscopy, which focused mainly on the effects of the two cooking methods on the structural organization of starch and cell walls where β-glucan was located. Cooked oat flakes retained most of their starch structure, which was microscopically detectable by staining with FLCA. Unlike the dispersed gelatinized starch, which appeared as a gel-like material sedimented in the middle layer after centrifugation, starch in the cooked oat flakes retained a recognizable granular appearance and characteristic compound structure. Microwave cooking for 1 min resulted in slight swelling and folding in many starch granules. The swelling and folding increased as cooking was extended to 20 min (Fig. 1A). By comparison, conventional cooking resulted in relatively more structural changes in starch. Oat flakes conventionally cooked for 20 min contained starch that appeared mostly as aggregates of convoluted structures, many of which still retained their compound structural identity (Fig. 1B).

Cell walls subjected to microwave heating remained relatively intact even after 20 min of cooking (Fig. 2A). By comparison, cell walls subjected to conventional heating expanded more. As conventional cooking was prolonged, the cell wall in the starchy endosperm became partially to completely disrupted, resulting in the dispersion of minute cell-wall fragments throughout the rolled-oat endosperm (Fig. 2B).

DISCUSSION

Conventional and microwave cooking differed in their effects on the amounts of starch and β-glucan released from rolled oats. Apart from differences in the mode of heat transfer in food, slight variations between the conventional and microwave methods occurred even though the experimental conditions were designed

TABLE III
Solubilized Starch (mg/ml ± SD) in Supernatants of Cooked Rolled Oats Prepared by Two Cooking Methods

Cooking Time (min)	Product Thickness	Manufacturer 1		Manufacturer 2	
		Conventional	Microwave	Conventional	Microwave
1	Thin	3.09 ± 0.73	3.10 ± 0.20	2.52 ± 0.30	2.29 ± 0.18
	Thick	3.09 ± 0.80	1.77 ± 0.18	2.12 ± 0.16	1.56 ± 0.18
20	Thin	3.81 ± 1.20	2.94 ± 1.03	2.76 ± 0.75	2.39 ± 0.29
	Thick	3.95 ± 0.72	2.67 ± 0.33	2.30 ± 0.38	2.19 ± 0.25

TABLE IV
Solubilized β-Glucan (mg/ml ± SD) in Supernatants of Cooked Rolled Oats Prepared by Two Cooking Methods

Cooking Time (min)	Product Thickness	Manufacturer 1		Manufacturer 2	
		Conventional	Microwave	Conventional	Microwave
1	Thin	0.40 ± 0.04	0.32 ± 0.02	0.46 ± 0.05	0.35 ± 0.06
	Thick	0.39 ± 0.11	0.15 ± 0.02	0.44 ± 0.07	0.26 ± 0.01
20	Thin	1.27 ± 0.22	0.49 ± 0.07	1.13 ± 0.30	0.46 ± 0.18
	Thick	0.94 ± 0.36	0.33 ± 0.13	0.98 ± 0.39	0.30 ± 0.10

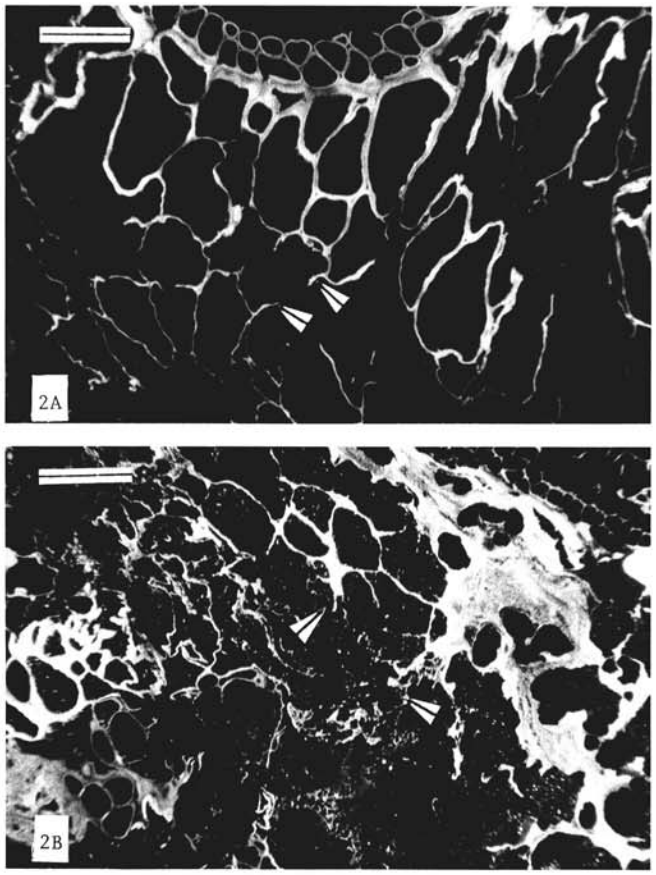

Fig. 2. Glycol methacrylate-embedded sections of thick (regular-cooking) rolled oats prepared by microwave (**A**) and conventional cooking (**B**) for 20 min and stained with Cellufluor to demonstrate the different degree of cell-wall breakdown (arrows) in the inner endosperm of oats. Bar scales represent 100 μm.

to eliminate as many differences as possible during cooking. For instance, at the same water-to-solid ratio, rolled-oat mixtures prepared by conventional cooking took about 1 min longer to reach a boil than did mixtures heated by microwave. Furthermore, the conventionally cooked samples were stirred gently and continuously during simmering to minimize clumping and sticking to the bottom of the cooking vessel. Constant stirring was difficult to achieve in the microwave oven. These differences may have affected the impact of cooking on the release of β-glucan and starch from cooked rolled oats.

The effects of cooking method and product thickness on the viscosity of cooked rolled oats paralleled their effects on the amount of solubilized β-glucan resulting from cooking. When data were pooled and compared, a positive correlation ($r = 0.77$) was noted between the amount of β-glucan solubilized and the viscosity of the cooked mixture ($P < 0.001$); at the low concentrations involved, viscosity is proportional to the concentration of β-glucan. A significant ($P < 0.05$) correlation ($r = 0.91$) was noted between viscosity and the β-glucan content in conventionally prepared rolled oats, and a nonsignificant correlation was noted between the two in samples prepared by microwave. When the data were pooled and compared, the correlation coefficient for viscosity and the amount of solubilized starch in the supernatant of the cooked mixture was 0.66 ($P < 0.05$). Furthermore, a significant correlation ($r = 0.89$) was noted between viscosity of the cooked mixture and the combined effect of the concentration of starch and β-glucan ($P < 0.001$).

The release of starch and β-glucan from cooked rolled oats was further affected by the integrity of the structural components of oats. The compound starch granules and the endospermic cell wall were susceptible to the impact of mechanical processing (Lookhart et al 1986, Yiu 1986). The more cutting and flaking involved during processing, as in the production of quick-cooking rolled oats (Deane and Commers 1986), the more structural damage resulted (Yiu 1986). Such microstructural changes may influence the cooking properties and the release of constituents from the rolled oats (Yiu 1989). Hence, the thinner, quick-cooking rolled oats generally released more β-glucan upon cooking than did the thicker, regular-cooking variety. The present findings indicate that the release of β-glucan was enhanced by choosing a rolled-oat product composed of thin flakes, using the conventional cooking method, and extending the cooking time.

Microscopic examination also revealed considerably more broken compound starch granules in the rolled oats produced by manufacturer 1 than in those produced by manufacturer 2. This observation may account for differences in the contents of dispersed, gelatinized, and solubilized starch between products of the two manufacturers. Microstructural differences resulting from the two cooking methods may reflect differences in the degree of water imbibition of the starch granules. The starch granules in the microwave-cooked porridge were smaller in volume and less convoluted than those in the conventionally cooked porridge. In addition, less dispersion took place during gelatinization in the starch structures of the former than in those of the latter.

ACKNOWLEDGMENT

We thank Gillian Cooper for technical assistance.

LITERATURE CITED

ANDERSON, J. W., and CHEN, W. J. L. 1986. Cholesterol-lowering properties of oat products. Pages 309-334 in: Oats: Chemistry and Technology. F. H. Webster, ed. Am. Assoc. Cereal Chem.: St. Paul, MN.

BATEY, I. L. 1982. Starch analysis using thermostable α-amylase. Starch/Staerke 34:125-127.

DAVIS, E. A. 1987. Microwave baking. Cereal Foods World 32:341.

DEANE, D., and COMMERS, E. 1986. Oat cleaning and processing. Pages 371-412 in: Oats: Chemistry and Technology. F. H. Webster, ed. Am. Assoc. Cereal Chem.: St. Paul, MN.

LOOKHART, G., ALBERS L., and POMERANZ, Y. 1986. The effect of commercial processing on some chemical and physical properties of oat groats. Cereal Chem. 63:280-282.

SAS INSTITUTE. 1987. SAS/STAT Guide for Personal Computers, Version 6 edition. The Institute: Cary, NC.

WOOD, P. J., and WEISZ, J. 1984. Use of Calcofluor in analysis of oat beta-D-glucan. Cereal Chem. 61:73-75.

YIU, S. H. 1986. Effects of processing and cooking on the structural and microchemical composition of oats. Food Microstruct. 5:219-225.

YIU, S. H. 1989. Cereal structure and its relationship to nutritional quality. Food Microstruct. 8:99-113.

YIU, S. H., and MONGEAU, R. 1987. Fluorescence and light microscopic analysis of digested oat bran. Food Microstruct. 6:143-150.

YIU, S. H., WOOD, P. J., and WEISZ, J. 1987. Effects of cooking on starch and β-glucan of rolled oats. Cereal Chem. 64:373-379.

[Received April 18, 1990. Accepted December 30, 1990.]