Infrared processing of oat groats in a laboratory-scale electric micronizer

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Cenkowski, S., Ames, N. and Muir, W.E. 2006. **Infrared processing of oat groats in a laboratory-scale electric micronizer**. Canadian Biosystems Engineering/Le génie des biosystèmes au Canada **48**: 3.17 - 3.25. Micronization (high-intensity infrared heating) with a lab-scale micronizer was studied as an alternative method of heat treatment for oat groats. The objective of the study was to select the micronization conditions necessary to inactivate the peroxidase without discoloring the oat groats and to determine the effect of such micronization conditions on water absorption of oat groat flakes and the viscosity characteristics of flour slurries made from oat groats and flakes. Prior to micronization, the oat groats were tempered to 30% wb (wet basis) moisture content. Two micronization protocols were examined: (1) where the surface temperature of the groats was controlled by spraying with water (spraying tests) and (2) where the temperature of the oat groats was controlled by restricting the infrared (IR) intensity (voltage control tests). Processing conditions were evaluated based on negative peroxidase results for both protocols. The total processing time for the first protocol was in the range of 3.5 min with a final moisture of the oat groats of 5% wb. For the second protocol, the total processing time was between 5 to 7 min with corresponding final moisture of 2.0 to 2.5% wb. The total color value (ΔE) for whole oat groats processed following the commercial procedure changed from 60.0 to a range between 63.9 and 65.8 for the micronized oat groat. When micronized oat groats were processed further by flaking, the final superficial color was darker (for flakes, ΔE = 70.1 - 74.2 range, and for the flour produced from the flakes ΔE = 55.7 - 56.2 range) in comparison with the product produced commercially (ΔE = 76.5 ±0.2 and 57.5 ±0.2 for the whole flakes and ground flour from the flakes, respectively). The highest increase in the water absorption capacity was observed in flakes micronized by controlling the IR intensity by adjusting the voltage on the IR lamps (range, 49.6 – 52.8 $gH_20/25g$ of flakes) in comparison to the commercial product (35.5 ±0.5 $gH_20/25g$ of flakes), or the micronized samples with water spraying (range 35.5 – 39.5 $gH_20/25g$ of flakes). The level of beta-glucan in oat groats before and after micronization remained the same for the voltage control tests (range 4.69 – 4.95% dry basis). Differences were observed in pasting profiles for raw, kiln, and micronized oat groats at three characteristic stages of pasting. These differences diminished in the final stage of the viscosity tests.

La micronisation (chauffage infrarouge à haute intensité) dans un microniseur à l'échelle pilote a été étudiée en tant que méthode de traitement thermique alternative pour le gruau d'avoine. L'objectif de cette étude était de sélectionner les conditions de micronisation nécessaires pour inactiver le peroxydase sans décolorer le gruau d'avoine ainsi que de déterminer les effets de telles conditions de micronisation sur l'absorption d'eau par les flocons de gruau d'avoine de même que les caractéristiques de viscosité des bouillies de farine faites de gruau et de flocons d'avoine. Avant la micronisation, la teneur en eau du gruau d'avoine était ajusté à 30% bh (base humide). Deux protocoles de micronisation ont été étudiés: (1) température de surface du gruau contrôlée en vaporisant de l'eau (tests de vaporisation) et (2) température du gruau d'avoine contrôlée en restreignant l'intensité de rayonnement infrarouge (tests par contrôle de tension). Les conditions de traitement étaient évaluées sur les résultats négatifs de peroxydase pour les deux protocoles. Le temps total de traitement pour le premier protocole était d'environ 3,5 minutes avec une teneur en eau finale du gruau d'avoine de 5% bh. Pour le second protocole, le temps de traitement total variait entre 5 et 7 minutes avec une teneur en eau finale de 2,0 à 2,5% bh. La valeur de couleur totale (ΔE) pour les grains entiers de gruau d'avoine traités suivant une procédure commerciale est passée de 60,0 à une plage variant de 63,9 à 65,8 pour le gruau d'avoine micronisé. Lorsque le gruau d'avoine micronisé était traité pour obtenir des flocons, la couleur finale superficielle était plus foncée (pour les flocons, ΔE = 70,1 – 74,4 et pour la farine produite à partir des flocons ΔE = 55.7 - 56.2) par rapport aux produits obtenus par des méthodes commerciales (ΔE = 76,5 ± 0,2 et 57,5 ± 0,2 respectivement pour les flocons entiers et la farine moulue à partir de flocons). La plus grande augmentation au niveau de la capacité d'absorption d'eau a été observée pour les flocons micronisés en contrôlant l'intensité des IR en ajustant la tension sur les lampes IR (49,6 – 52,8 $gH_20/25g$ de flocons) par rapport au produit commercial (35,5 ± 0,5 $gH_20/25g$ de flocons), ou en micronisant les échantillons en vaporisant de l'eau (35,5 – 39,5 $gH_20/25g$ de flocons). Le niveau de beta glucan dans le gruau d'avoine avant et après la micronisation est demeuré le même lors des essais de contrôle de tension (4,69 – 4,95% base sèche). Des différences ont été observées dans les profils de collage pour le gruau cru, traité à l'étuve et micronisé et ce à trois stades caractéristiques de collage. Ces différences diminuaient dans le stade final des tests de viscosité.

INTRODUCTION

The popularity of oats for human consumption increased in North America in the 1990s. In Manitoba over the last ten years, annual cash receipts from the oat sector increased from $29.7 million in 1993 to a record of $124.7 million in 2002 (Manitoba Agriculture and Food 2003).

Most oat cultivars are harvested with their hulls on and after the hulls are removed they are referred to as groats (Hoseney 1986). After cleaning, oats destined for human consumption are heat-treated or dried to inactivate the lipolytic enzymes (Ekstrand et al. 1992, 1993).

Traditional oat processing involves treating oat groats with heat in combination with elevated moisture conditions to inactivate endogenous enzymes and alter functional and sensory properties of the oat products (Dendy and Dobraszczyk 2001; McCurdy 1992). Heat treatment also results in the development of a slightly roasted flavor. It is important to inactivate the

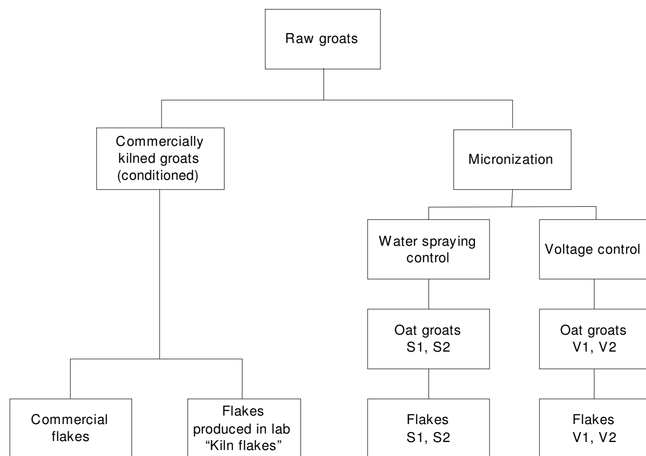

Fig. 1. Commercial, lab conditioned, and micronized samples used in the experiments.

lipolytic enzymes as they can produce an intense rancid flavor, which reduces quality and shortens the shelf life of the oats (Ekstrand et al. 1993). There are unpublished reports that suggest the use of dry heat treatments can produce unique properties desirable for certain end-product applications. To successfully utilize dry heat processes to produce specialty oat products, more research is needed to determine the effects on lipase enzymes and fats. For example, using traditional kiln temperatures in the absence of added moisture presents the risk of off-flavor development due to fat breakdown. On the other hand, temperatures too low may not be sufficient to inactivate lipase, which is necessary to prevent enzymatic rancidity.

Micronization is a high-intensity infrared-heat process which exposes processed material to electromagnetic radiation in the wavelength range of 1.8 to 3.4 µm (Cenkowski et al. 2006; Fasina et al. 1999; Cenkowski and Sosulski 1997, 1998). Food industry applications of micronization include reducing microbial activity, inactivation of enzymes, creating faster cooking products from lentils (Arntfield et al. 1997; Cenkowski and Sosulski 1997; Scanlon at al. 1998, 2005), dry peas (Wray and Cenkowski 2002) and beans (Bellido et al. 2003), or increasing digestibility of food products (Audet et al. 1992; Arntfield et al. 2004).

There are several reasons to consider micronization of oats. The first relates to the need to inactivate lipolytic enzymes, which cause rancidity, in order to create whole grain or germ containing oat products with acceptable shelf stability. The second reason is related to the positive effect of steam heat treatments on beta-glucan extractability and viscosity, which could result in improved nutritional benefits. The importance of this is that beta-glucan gum within oats promotes positive responses in blood glucose and insuline levels (Marshall and Sorrells 1992). This highly desirable level of beta glucan after processing is of interest to food manufacturers. The third reason is related to new product development. Optimizing the infrared heat processing conditions will result in oat groats with modified physio-chemical properties which can be utilized to create new markets for oats. There is potential to use this product as a whole grain side dish or in snack foods and granola bars and as an ingredient in bread.

The micronization process involves the use of relatively small scale equipment which is economical and easy to operate (Fasina et al. 1999). The simplicity of construction and operation and the relatively low energy input required by micronization compared to other grain processing systems could create new on-farm processing opportunities for Canadian grain producers. Even though the lipase enzyme is the main target when using heat to stabilize oat groats, the oat processing industry uses the peroxidase activity test in evaluating the adequate heating for inactivation of lipase. Therefore, the objectives of this study were to select the micronization conditions to inactivate peroxidase and to determine the effects of such conditions on (1) the oat groats discoloration during processing, (2) water absorption of oat groat flakes, (3) the level of beta-glucan, and (4) the viscosity characteristics of flour slurry made from oat groats and flakes.

MATERIALS and METHODS

Oat samples

A commercial oat sample was obtained from Can-Oat Milling Inc., Portage La Prairie, Manitoba. The oat sample was first dehulled in the commercial facility and is hereafter referred to as "raw groats". A portion of the raw groats was commercially conditioned (or "kilned") using a moist heat treatment to inhibit enzyme catalyzed reactions that could lead to rancidity. Subsequently, a portion of the conditioned groats was processed into flakes in the commercial facility. The raw groats were stored at –40ºC to maintain shelf life until the time of testing. Conditioned groats and flakes were considered enzymatically stable and, therefore, stored at room temperature.

A block diagram of commercial and processed samples used in our experiments is shown in Fig. 1. Samples were: (1) commercially dehulled and commercially conditioned (heat treated) oat groats and commercial flakes, (2) kiln flakes produced in our laboratory from commercially conditioned oat groats, and (3) raw dehulled oat groats which were moisture/heat treated using two micronization procedures (water spraying and voltage control). The groats were evaluated for color before and after the heat treatments. The micronized groats were ground into flour prior to conducting peroxidase, rapid viscosity, and color analyses. Micronized groats were used to make flakes. Flake quality was measured using water absorption.

Moisture content of oat samples

The initial moisture content of the raw groats was 10.2 % wb (wet basis). The moisture content was determined following the AACC 44-15A, one stage moisture method (AACC 2003). Moisture after tempering was verified following AACC 44-15A, two stage moisture method (for moisture over 13%).

Tempering

Prior to micronization, moisture content of oat groats was raised to 30% moisture using a tempering process. The tempering process involved adding a pre-calculated amount of water to an oat sample, placing it in a sealed plastic bag for 4 h, and tumbling it periodically to evenly distribute the water throughout the sample.

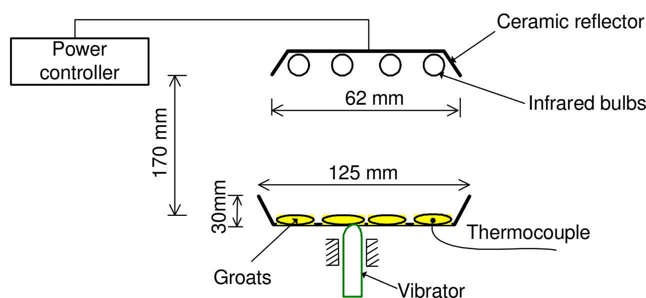

Fig. 2. Experimental set-up.

Equipment

A lab-scale micronizer (Model 4553 High Density Infrared Pryopanel Strip Heater, Research Inc., Eden Prairie, MN) was used for the experiments. The unit consists of four tungsten-filament lamps rated at 500 W each with a low resistance at room temperature. The lamps were connected to a Model 5620 Power Controller (Research Inc., Eden Prairie, MN) to eliminate high inrush currents when turned on. The heater was a perforated ceramic reflector bonded to a metal plate with covered electrical connections.

Micronization with water spraying

An approximately 10 to 12-g sample of tempered oat groats was placed in a circular aluminum dish (125 mm diameter and 30 mm high) and placed under the infrared lamp positioned 170 mm away from the sample surface (Fig. 2). The voltage on the micronizer was set at ten and the oat groats were sprayed with water at predetermined times. Each spray deposited approximately 1.0 g of water on the sample surface. Initial spraying times, overall processing time, and spraying frequencies were selected based on the preliminary experiments that effectively deactivated peroxidase (Cenkowski et al. 2004). Two protocols had an overall processing of 3.5 min with water spraying at: (1) 2.0 and 3.0 min (Treatment S1), and (2) 2.0, 2.5, and 3.0 min (Treatment S2).

Temperatures of individual oat groats were monitored every second using copper-constantan thermocouples connected to a data acquisition system (Hewlett Packard 3421 Data Acquisition Control Unit). A soldered, 1-mm tip of a thermocouple was inserted into the geometric centre of individual oat groats to monitor their interior temperature (Fig. 2). The groats containing the thermocouples were also positioned 170 mm from the infrared lamp and were continuously turned about their longitudinal axis during heating to ensure uniform heating. This set of experiments was done in triplicate.

Micronization by controlling infrared intensity

Micronization procedures followed that of the previous experiments in which 10 to 12 g of the tempered oat groats were used except the groat temperature was controlled by reducing the intensity of the IR lamps instead of spraying with water. The overall processing times and voltage levels supplied to the IR lamp were selected based on the preliminary experiments, which showed effective deactivation of the peroxidase (Cenkowski et al. 2004). Two protocols were used: (1) the voltage was set to level 10 during the processing time from 0.0 to 2.5 min and then set to 2 during 2.5 to 7.0 min (Treatment V1), and (2) the voltage was set to 9 for the first minute, 7 for the time between 1.0 and 3.0 min, and level 1 for the last 2 min of processing (Treatment V2). The criteria for setting the voltage were based on the fact that high-intensity IR causes rapid evaporation of moisture from the groat surface and over-drying. As soon as the surface temperature of the groats reaches the critical moisture point, the first drying period with its corresponding wet bulb point ends. Below the critical moisture, a falling drying rate period begins and the temperature of the surface rapidly increases (Pabis et al. 1998) causing surface burning. Even if there is enough moisture in the interior of a kernel, this moisture cannot move fast enough to the surface of the kernel to wet it and keep the surface at the wet bulb point. Eventually, the temperature of the surface rapidly increases causing surface burning. By reducing the voltage supplied to the IR lamps by 80% (level 2) and 90% (level 1), we were able to reduce the heat transfer rate, control the surface temperature, and avoid surface burning. It was also noticed in the preliminary investigations that maintaining the lamp at a high voltage alone until discoloration of the groat surface was noticeable was not sufficient to inactivate the peroxidase. Therefore, it was necessary to consider a combination of heat intensity and duration to fully inactivate peroxidase without browning the groats.

Qualitative peroxidase analysis confirmation

Oat products destined for human consumption should be peroxidase free. Peroxidase activity is often used to determine whether the heating was adequate for inactivation of lipase (Ekstrand et al. 1992).

The AACC (2003) method (22-80) for the qualitative analysis of peroxidase was followed to determine if enzymes had been effectively deactivated during the micronization. A Retsch grinder with a 0.5 mm screen (ZM 100 Ultra Centrifugal Miller, Retsch, Haan, Germany) was used to grind a 10-g groat sample for 10 s in preparation for the peroxidase test. After the sample had been prepared a 1-g sample was taken and placed in an Erlenmeyer flask for enzyme testing.

Fifty milliliters of deionized water, at room temperature, was added to the flask containing 1 g of milled sample and then mixed. Two milliliters of ascorbic acid solution (0.5 g in 500 mL of water), 3 mL of sodium 2,6-dichloro-indophenol solution (0.1 g in 500 mL of water) and 0.1 mL of hydrogen peroxide (4 mL of 30% H_2O_2 plus 96 mL of water) were added and thoroughly mixed. The flask was then placed in a water bath (38°C) for 5 min, swirled, and replaced in the water bath for an additional 5 min. If no color change was noticed after 10 min the test was negative and the sample was considered free of active peroxidase.

Beta-glucan content

Standard enzymatic determination of beta-glucan was carried out as described by AACC Method 32-23 (AACC 2003).

Flour slurry viscosity

Viscosity of ground whole meal flour was determined using the Rapid Visco Analyser (RVA™) (series 4, Newport Scientific, Warriewood, Australia) according to two temperature profiles. The first profile involved heating a 3.5-g sample (corrected to 14% moisture) and 25 g of deionized water from 50°C to 95°C

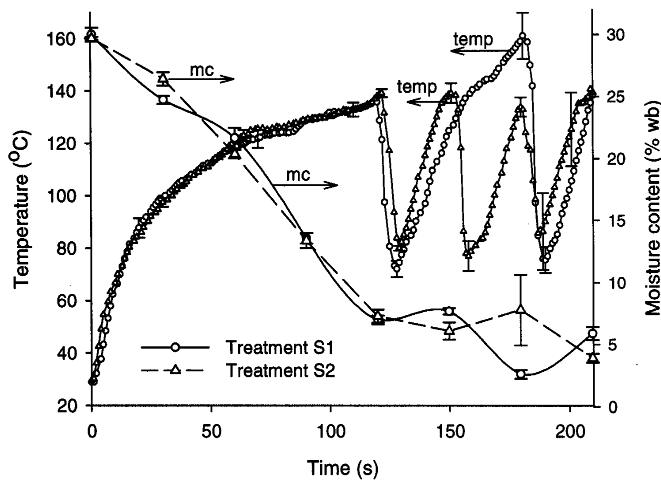

Fig. 3. Temperature (temp) and moisture (mc) characteristics for treatments S1 and S2 with standard deviations (vertical bars, n=3). The arrows assigned to individual curves point to the location of corresponding axes.

and cooling back down to 50°C, which is referred to as the Standard 1 Pasting Profile in AACC Method 76-21 (AACC 2003).

A modified version of Whalen (1998) was used to differentiate samples further by measuring viscosity at or close to the gelatinization temperature of oat starch. This profile, referred to as critical pasting, uses 8.0 g of sample (corrected to 14% moisture) and 20.75 g of deionized water to which 100 µL of 10% cellulase enzyme (Multifect CL, Genencor International Inc. Palo Alto, CA) was added. The slurry was heated from 25 to 60°C over 5 min and then held at 60°C for 15 min. Data on the viscosity of the sample were gathered using Thermocline for Windows software.

Approximately 1 g of the milled sample was used for moisture determination following the AACC 44-15A standard procedure (AACC 2003).

Flake preparation

Between 40 and 50 g of the micronized oat groats were placed in a small plastic container with a lid. The lid contained several slots to inject and exhaust steam from the container. The container was then inverted and the oat groats were steamed for 30 s using a steam pot (Steam Bullet, P.O.T. Inc., Concord, ON). After steaming, the slotted lid was removed and another lid without holes was placed on the container. The container was then placed in a steam bath (Flavor Scenter Steamer, Black and Decker, Shelton, CT) for 14.5 min (14.5 min started as soon as the initial steaming was complete). Following steaming, the oat groats were poured slowly into a flaking machine (Bench Top Flaking Machine, Cereal Research Centre, Winnipeg, MB), which crushed the oat groats into flakes. The speed of the rolls was 100 rpm; the roll diameter was 8.13 mm; and the gap between the rolls was set between 0.6 and 0.7 mm (Ames and Rhymer 2003). Once the flakes had been produced they were removed from the flaking machine and allowed to dry and cool before further testing.

Moisture absorption of flakes

Moisture absorption was tested following AACC method 56 – 40 (AACC 2003) with adjustments made to accommodate a reduced sample size of 25 g instead of 50 g. One hundred milliliters of distilled water at 23°C were poured into a 600-mL beaker containing 25 g of the oat groat flakes. Once water had been added, the flakes were allowed to soak for 5 min. The mixture was not stirred but the flakes were pressed down using a spoon to ensure the sample was fully submerged. After 5 min, the oat groat flakes were transferred to a pre-weighed US no. 20 sieve and spread evenly over the upper 2/3 of it. The sieve was then placed at an approximate 45° angle and the flakes were drained for 5 min. Cumulative time was not stopped during the process of transfer, therefore, the total test time equaled 10 min. After allotted draining time elapsed, the bottom edge of the sieve was wiped and the sieve was weighed. The moisture absorbed was expressed in grams of water uptake per 25 g of flakes at their initial moisture.

Color testing

Color of raw, commercially conditioned, lab conditioned, and infrared conditioned oat groats and whole meal flour from the groat samples was evaluated using a Minolta Colorimeter (Chroma Meter CR – 410, Minolta Canada Inc., Mississauga, ON) and the *L*, *a*, and *b* values after standardization with a white color standard were recorded. A sample was placed in a granular-materials attachment of 50-mm diameter and 10-mm depth. Following the instrument manual, the measuring head was placed vertically above the glass cover of the attachment and readings of *L*, *a*, and *b* values were taken. The sample was poured into a container, remixed, and then placed back in the dish and the next readings of the color values were taken. These experiments were conducted in triplicate.

The total color difference was calculated from means using Eq. 1 (Cenkowski and Sosulski 1998):

$$\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2} \quad (1)$$

where:

ΔE = total color difference, and

ΔL, Δa, Δb = difference between standard and sample readings for *L*, *a*, *b* color values, respectively.

Statistical analysis

All tests of significance and statistical analyses were performed with SigmaStat Statistical Software Package (version 2.0, Jandel Scientific, San Rafael, CA).

RESULTS and DISCUSSION

All four micronization experiments (V1, V2, S1, and S2) gave negative peroxidase results indicating the deactivation of the lipolytic enzymes (Ekstrand et al. 1992).

Micronization with water spraying

The average temperature and moisture changes of oat groats during micronization when the oat groat surface was sprayed with water are given in Fig. 3. Symbols indicate average measured values from three experiments. The vertical bars indicate the standard deviations. The sudden drops in

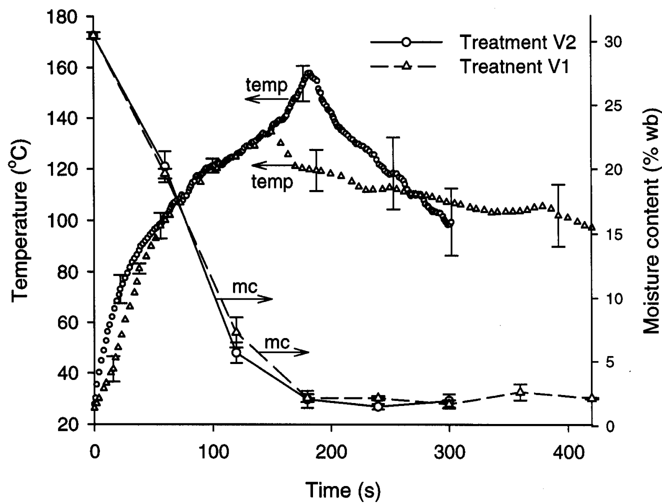

Fig. 4. Temperature (temp) and moisture (mc) characteristics for treatments S1 and S2 with standard deviations (vertical bars, n=3). The arrows assigned to individual curves point to the location of corresponding axes.

temperature occurred when spray water was applied. In these two sets of experiments, the first spraying time was the same; therefore, the temperature and moisture initially followed a similar pattern. In Treatment S2 the spraying was applied more frequently than for Treatment S1 restricting the maximum temperature of oat groats to approximately 140°C for only a few seconds. In Treatment S1, as a result of longer rest periods between spraying, the temperature reached 160°C. This was also reflected in a substantial drop in moisture content (2.5% wb) and a moisture gain due to spraying in the last 30 s of micronization. However, in both sets of tests (Treatment S1 and S2) the final moisture was in the range of 5% wb.

Typically, (in the industrial set up) the final moisture content is in the range of 7-10%. Decreasing the final moisture below that level lowers the economics of processing. The final moisture obtained in our experiments was lower than the desired final moisture. Adjusting the final moisture could be done by introducing additional spraying as was done by Cenkowski et al. (2004) or by introducing the first spraying 15 to 20 s earlier when the moisture content of the groats was still approximately 15% while the groat temperature was just above the 120°C mark. Also, the amount of deposited spray on the surface can affect the temperature drop of the material, and the desired level would be to have the temperature drop to 105°C instead of 70°C as in our experiments. Keeping the groat temperature above 105°C during processing and particularly during spraying would probably shorten the processing time while the peroxidase results would still be negative.

Micronization by controlling infrared intensity

The experimental results in which the oat groat temperature was controlled by adjusting the intensity of the micronization are shown in Fig. 4. The total exposure to IR was different in the two sets of tests. Treatment V1 had a total of 420 s allowing the oat groats to reach a temperature of approximately 138°C (voltage set to 10) and then by setting the voltage to 2 the groat temperature decreased over the next 150 s to 105°C. In Treatment V2 the oat groats were micronized for 300 s only, but the maximum temperature reached was 160°C. By reducing the voltage twice from 9 to 7 after the first minute of processing and from 7 to1 after the third minute of micronization, a gradual drop in groat temperature was obtained reaching 100°C at the end of micronization. Moisture changes for the two treatments followed the very same pattern, reaching the equilibrium moisture range of 2.0 to 2.5% wb after the first 190 s of processing.

From the scale-up point of view, controlling the groat temperature by adjusting the IR lamp heat intensity seems to be a more convenient way then controlling groat surface temperature by spraying with water. It would be desirable to eliminate the temperature peak which could be accomplished by better tuning while ensuring the negative peroxidase results and the proper level of final moisture. This could be accomplished by aerating the processed groat with higher humidity air that would slow down the evaporation of moisture from the surface of the groats. Cenkowski et al. (2004) used processing conditions in which for the first minute voltage rate was at 9, in the second minute the voltage was brought down to the 1.5 level, and for the next 3 min was kept at level one. The final moisture of the groat was 18% and the peroxidase test was light positive. Even though the peroxides were still not acceptable, that was an indication that further tuning of the radiation intensity through the voltage control could lead to negative peroxidase results with lower final moisture.

Color testing

One of the quality factors for processed oat groats is its color. Color could be an indicator of roasting, changes in taste and textural properties, an alteration of milling characteristics, changes in stability during storage, and a modification of viscosity of the paste slurry made from processed oat groats.

The color *L*, *a*, and *b* values of the processed and unprocessed oat groats, flakes, and flour are given in Table 1. The change in color on the surface of the ground groats and ground flakes was significant for the micronized products. The letters in each column in Table 1 give detailed statistical information on the differences between *L*, *a*, *b*, and ΔE values. The seventh row of the table shows the *L*, *a*, *b*, and ΔE values for flaked samples of the product processed commercially (Commercial flake). For reasons of reproducibility of our laboratory results, Table 1 also indicates the color results for flakes produced in our laboratory following a procedure used by a commercial processing plant (Kiln flake; row 8). The kiln flakes were prepared from commercially kilned oat groats (row 2, Conditioned groats). The same letters in each column indicate no significant difference ($p>0.05$) between sample means.

Generally, the *a* and *b* color values for the whole and ground groats increased after micronization indicating toasting and the enhancement of the red and yellow color, respectively. But in two cases (S1 and S2 treatments) when the micronized product was flaked (Table 1, rows 11 and 12), there was no significant change in the *a* and *b* color values with respect to the commercial flakes (row 7), although the loss in the lightness value (*L*) affected significantly the total color ΔE for these two cases (70.1 and 71.6 for S1 and S2 treatments, respectively).

Table 1. Color values for raw and commercially processed oat groats and for micronized oat groats and flakes. The color values are given for milled and whole product.

No.	Groat samples	Whole groats				Ground groats			
		L	*a*	*b*	*ΔE*	*L*	*a*	*b*	*ΔE*
1	Raw groats (n = 6, 12)*	61.5 a[†] (0.4)	5.16 a (0.10)	16.1 a (0.2)	63.8 a (0.4)	56.5 a (0.2)	-0.11 a (0.06)	5.05 a (0.22)	56.7 a (0.2)
2	Conditioned groats (n = 6, 12)	56.5 b (0.3)	5.92 b (0.08)	19.4 b (0.3)	60.0 b (0.4)	56.4 a (0.2)	-0.23 b (0.06)	5.04 a (0.12)	56.6 a (0.2)
3	Micronized V1** (n = 3, 6)	62.7 c (0.2)	6.09 c (0.08)	19.1 b (0.1)	65.8 c (0.3)	55.1 b (0.3)	0.20 c (0.03)	6.13 b (0.06)	55.4 b (0.3)
4	Micronized V2 (n = 3, 6)	60.4 d (0.4)	7.35 d (0.15)	19.5 b (0.2)	63.9 ad (0.3)	55.1 b (0.1)	0.31 d (0.05)	6.41 cd (0.15)	55.5 b (0.1)
5	Micronized S1 (n = 3, 6)	60.0 d (0.4)	6.96 e (0.07)	21.2 c (0.4)	64.0 ad (0.5)	55.5 c (0.2)	0.18 c (0.01)	5.86 c (0.12)	55.8 c (0.2)
6	Micronized S2 (n = 3, 6)	60.6 d (0.5)	6.69 f (0.05)	21.2 c (0.3)	64.6 ad (0.5)	55.5 c (0.2)	0.20 c (0.04)	6.30 d (0.13)	55.9 c (0.2)
	Flake samples	Whole flakes				Ground flakes			
		L	*a*	*b*	*ΔE*	*L*	*a*	*b*	*ΔE*
7	Commercial flake (n = 3)	74.2 a (0.5)	2.71 a (0.11)	18.3 a (0.2)	76.5 a (0.2)	57.3 a (0.1)	-0.46 a (0.10)	4.46a (0.24)	57.5 a (0.2)
8	Kiln flake (n = 3)	70.4 b (0.4)	3.85 b (0.11)	19.8 b (0.1)	73.2 b (0.4)	57.4 a (0.1)	-0.40 b (0.02)	4.36 a (0.13)	57.6 a (0.2)
9	Micronized V1 (n = 4)	72.1 c (0.3)	3.88 b (0.04)	17.1 c (0.4)	74.2 c (0.4)	55.7 b (0.2)	0.13 c (0.03)	5.96 b (0.08)	56.0 b (0.2)
10	Micronized V2 (n = 4)	68.9 d (1.3)	4.96 c (0.51)	17.0 c (1.5)	71.1 d (0.9)	55.3 c (0.2)	0.43 d (0.05)	6.52 c (0.01)	55.7 c (0.2)
11	Micronized S1 (n = 4)	67.6 e (0.4)	4.39 d (0.09)	18.1 a (0.5)	70.1 c (0.5)	55.9 b (0.3)	0.06 e (0.04)	5.49 d (0.14)	56.2 b (0.2)
12	Micronized S2 (n = 6)	69.2 d (0.4)	4.16 bd (0.09)	17.8 a (0.3)	71.6 d ((0.3)	56.0 b (0.3)	-0.06 f (0.07)	5.28 e (0.20)	56.3 b (0.3)

* n = number of samples; where there are two numbers, the first refers to whole groat samples and the second to ground groat samples.
† Same letters in one column indicate no significant difference (p>0.05) between sample means in the same group (groats, rows 1 to 6 and flakes, rows 7 to 12. Numbers in parentheses are standard deviations.
** V1 = micronization with voltage control (time: 0-2.5 min, VL=10; time: 2.5-7 min, VL=2) where VL = voltage level
V2 = micronization with voltage control (time: 0-1 min, VL=9; time: 1-3 min, VL=7; time: 3-5, VL=1)
S1 = micronization with water spraying (VL=10, total processing time = 3.5 min, spraying times 2 and 3 min)
S2 = micronization with water spraying (VL=10, total processing time = 3.5 min, spraying times 2, 2.5, and 3 min)

The total color *ΔE* increased for the processed product from a low 63.8 for raw groats (Table 1, row 1) to 76.5 and 73.2 for commercial flakes (row 7) and kiln flakes (row 8), respectively. The lightness of the color (*L*) was primarily responsible for that change. The total color value (*ΔE*) for oat groats processed in our laboratory following the commercial procedure (conditioned groats; Table 1, row 2) decreased to 60.0 after processing. This change was significant at $p \leq 0.05$ with respect to the raw groats. Also, a change in *ΔE* for micronized whole groats using protocols V1 was determined as significant (65.8 ±0.3) with respect to the conditioned groats (row 2); but the V2, S1, and S2 micronization protocols (rows 4, 5, and 6, respectively) did not show any significant change ($p>0.05$) in *ΔE* with respect to the raw groats (row 1) but these changes were significant ($p \leq 0.05$) in the comparison to the commercially conditioned (kilned) oat groats (row 2).

When micronized oat groats were processed further by conditioning and flaking, the final superficial color became darker for the flakes (*ΔE* = 70.1-74.2 range) and the flour produced from the flakes (Ground flakes; *ΔE* = 55.7-56.3 range)

Table 2. Means and standard deviations of water absorption for commercial flakes, kiln flakes, and micronized oat groats with different protocols (V1,V2, S1, and S2) and then flaked.

Sample	Initial moisture (% wb)	g water absorbed per 25g flakes
Commercial flake (n=6)*	9.9 ± 0.12	35.5 ± 0.5
Kiln flake (n=3)	13.7 ± 0.8	25.2 ± 1.0
Micronized V1 (n=2)**	7.4 ± 0.2	52.8 ± 0.4
Micronized V2 (n=2)	9.1 ± 0.1	49.8 ± 2.5
Micronized S1 (n=2)	11.9 ± 0.7	35.5 ± 2.1
Micronized S2 (n=3)	11.8 ± 0.5	39.5 ± 1.0

* n = number of samples
** See Table 1.

Table 3. Means and standard deviations of beta-glucan content of unprocessed (raw) oat groats and micronized oat groats with water spray treatment (S) and voltage control (V).

Micronized oat groat sample	Beta-glucan (% dry basis)
Raw oat groats (n=4)*	4.95 ± 0.06 a†
Micronized V1 (n=4)**	4.73 ± 0.09 ab
Micronized V2 (n=2)	4.69 ± 0.21 ab
Micronized S1 (n=2)	4.58 ± 0.01 b
Micronized S2 (n=2)	4.68 ± 0.02 b

* n = number of samples
** See Table 1.
† Same letters in one column indicate no significant difference ($p>0.05$) between samples.

in comparison to the commercial whole flakes (76.5 ±0.2) and ground flakes (57.5±0.2), respectively (Table 1, row 7).

Moisture absorption by flakes

Water absorption tests for flakes on the commercial product, micronized and conditioned samples in our laboratory simulating the commercial procedure (Kiln flake) are given in Table 2. The table also includes the results on the initial moisture content of flakes before the absorption tests. The commercial flakes were at 9.9% moisture but the flakes made in our laboratory (Kiln flake) from the commercial oat groats were at 13.7% wb moisture. The initial moisture for the micronized product depended on the micronization protocol used and was between 7.4 and 11.9% moisture. The absorption test requires that a sample be taken 'as is' (no initial moisture adjustment), therefore, the dry mass of the commercial flakes was higher than the others. Kiln flakes which were produced in our laboratory showed lower absorption capacity in comparison to flakes produced commercially. Micronization increased substantially the water absorption capacity of flakes in comparison to the commercial product. The highest absorption capacity was obtained for micronization protocols where the intensity of infrared heat was controlled by adjusting the voltage on the infrared lamps (52.8 and 49.8 g/25g flakes in Treatment V1 and V2, respectively). Also, Bellido et al. (2003) noticed that the hydration capacity can be affected by the final temperature of a micronized product. Infrared processing causes gelatinization of starch within the processed product which results in a change of the product's cell structure. This change in structure improves water uptake during cooking (Scanlon et al. 1999, 2005).

Beta-glucan content

Beta-glucan contents of raw oat groats and micronized samples are shown in Table 3. Differences in beta-glucan were insignificant ($p>0.05$) for the protocol in which the temperature of the oat groats was controlled by restricting the infrared intensity (voltage control tests; V1 and V2). Very small differences in beta-glucan levels were noticed for the protocol in which the surface temperature of the oat groats was controlled by spraying with water (S1 and S2 tests). These differences were probably attributed to a small sample pool (n=2) and, therefore, further investigation is required.

Flour slurry viscosity

A typical pasting profile obtained from the RVA instrument for raw, kiln, and micronized oat groats for two treatments (S1 and S2) is shown in Fig. 5. In the initial stage the pasting characteristics followed the same pattern. The characteristics separated just before reaching their peaks. Then, during the hot paste stage up to the final stage, the viscosity of the micronized product was somewhat in between the raw product characteristic and the kiln oat groats. The summary of the viscosity mean values with standard deviations at three characteristic points on the pasting curve for oat groats and flakes (peak, hot paste, and final) is given in Tables 4 and 5, respectively. The means values were compared using the one-way analysis of variance test for

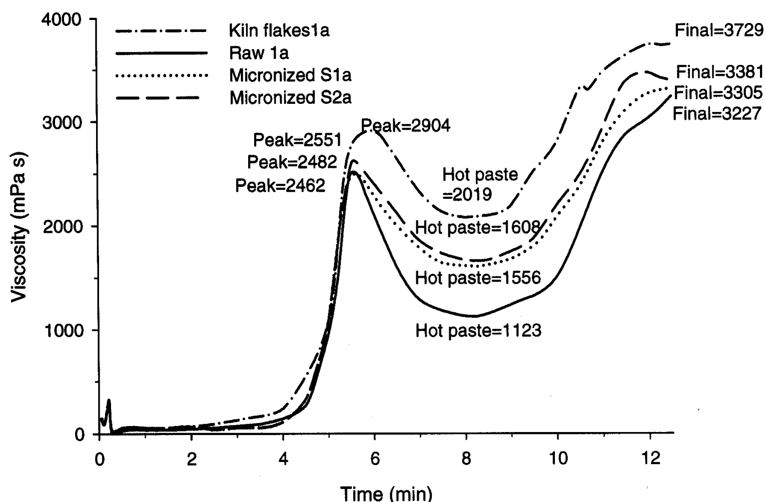

Fig. 5. Pasting profile for raw oat groats and kiln oat groat flakes and for the groat samples exposed to miconization treatments (spray treatments S1a and S2a - a small "a" Associated with tests indicates a specific run).

Table 4. Means and standard deviations of standard pasting at three selected points (peak, hot paste, and final viscosity - see Fig. 4) for raw, commercially processed, and micronized oat groats.

Sample	Viscosity (mPa s)		
	Peak	Hot paste	Final
Raw oat groats (n=6)*	2443 ad ± 101	1150 a ± 85	3187 a ± 166
Kiln oat groats (n=3)	2885 b ± 28	2021 b ± 2	3705 b ± 48
Micronized V1 (n=3)**	2356 ac ± 68	1553 c ± 26	3393 c ± 45
Micronized V2 (n=3)	2334 ac ± 100	1460 c ± 107	3280 ac ± 164
Micronized S1 (n=3)	2462 acd ± 32	1542 c ± 12	3316 ac ± 7
Micronized S2 (n=3)	2525 d ±24	1591 c ± 17	3393 c ± 11

* n = number of samples
** See Table 1.
† Same letters in one column indicate no significant difference (p>0.05) between samples.

Table 5. Means and standard deviations of standard pasting at three selected points (peak, hot paste, and final viscosity - see Fig. 4) for commercially processed and micronized oat groat flakes.

Sample	Viscosity (mPa s)		
	Peak	Hot paste	Final
Commercial flake (n=2)*	3210 a ± 11	2120 a ± 18	3644 a ± 320
Micronized V1 (n=2)**	2583 c ± 28	1680 c ± 35	3422 a ± 105
Micronized V2 (n=2)	2436 b ± 76	1572 b ± 64	3569 a ±15
Micronized S1 (n=3)	2771 d ± 58	1800 d ± 5	3584 a ± 52
Micronized S2 (n=3)	2765 d ± 52	1772 d ± 44	3609 a ± 74

* n = number of samples
** See Table 1.
† Same letters in one column indicate no significant difference (p>0.05) between samples.

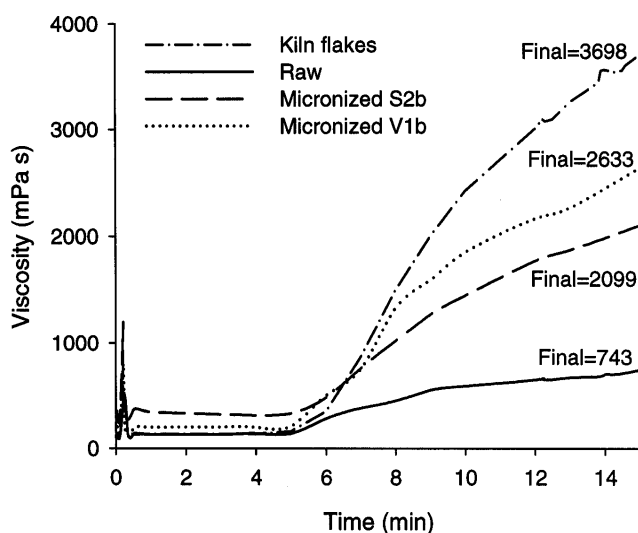

Fig. 6. Comparison of critical pasting profiles of raw oat groats, kiln oat groat flakes, and micronized oat groat flakes with two treatments (S2b - spray treatment, and V1b - voltage control. A small "b" associated with tests indicates a specific run).

unbalanced data. The same letters in a column indicate no significant difference (p>0.05) between sample means. Significant differences were observed between the kiln and micronized product and between the kiln and the raw groats for all three characteristic points (stages). There was no significant difference between the peak viscosities of the raw product and three micronized samples V1, V2, and S1 (Table 4) and for the samples that have a shared letter. The differences between commercial flakes and micronized and flaked oat groats diminished in the final stage of the viscosity tests (Table 5).

The pasting profile at 60ºC revealed more vividly the differences between raw, kiln, and micronized oat groats sprayed with water (S2), and with adjusting the level of the infrared intensity (V1) (Fig. 6). The statistical information on the final viscosity is summarized in Table 6. There are significant differences ($p \leq 0.05$) between the viscosities of commercially produced groat flakes (Kiln flake) and flakes produced from micronized oat groats. There were no differences in the pasting characteristics (p>0.05) between samples that were sprayed more often (Treatment S1 vs S2) or where the voltage controlling the infrared intensity was adjusted differently (Treatment V1 vs V2).

CONCLUSIONS

The peroxidase enzymes in oat groats were successfully inactivated by micronization using two different protocols: (1) where the surface temperature of the groats was controlled by spraying with water, and (2) where the temperature of the oat groats was controlled by restricting the infrared intensity. The total processing time of the groats for the first protocol was in the range of 3.5 min with a minimum of

Table 6. Means and standard deviations of critical pasting final viscosity (see Fig. 5) for unprocessed oat groat (raw groats), commercially produced oat groats and flaked in our laboratory following the commercial procedure (kiln flake) and flakes produced from micronized oat groats (spray treatment and voltage control).

Sample	Viscosity (mPa s)
Raw groats (n=4)*	752 a ± 25
Kiln flakes (n=3)	3583 b ± 152
Micronized V1 (n=2)**	2654 c ± 30
Micronized V2 (n=2)	2572 c ± 9
Micronized S1 (n=2)	2247 d ± 25
Micronized S2 (n=2)	2125 d ± 38

* n = number of samples
** See Table 1.
† Same letters in one column indicate no significant difference (p>0.05) between samples.

two sprayings. For the second protocol, the groats were micronized for more than 5 min while the IR intensity was lowered after the groat surface temperature peaked at 140 to 160ºC. The total color value (ΔE) after micronization using either protocol was between 63.9 and 65.8 and was higher in comparison to commercially processed oat groats (60.0). When the micronized groats were flaked, the final superficial color of the flakes was darker (ΔE = 70.1 - 74.2) in comparison to the commercially produced whole flakes (ΔE = 76.5 ±0.2). The flour produced from the micronized groats that were flaked was also darker (ΔE = 55.7 - 56.3) than the flour from the flakes processed commercially (ΔE = 57.5 ±0.2). The levels of beta-glucan in oat groats before and after micronization were unaffected ($p>0.05$) in the voltage control tests. Micronization increased water absorption capacity of flakes up to 52.8 g water/25g flakes in comparison to 35.3 g water/25 g flakes for commercial flakes. Significant differences ($p \leq 0.05$) were observed between the raw, kiln, and micronized products in the pasting profile at the peak and the hot paste stages but these differences diminished in the final stage of the viscosity tests.

ACKNOWLEDGEMENTS

This project was partially supported by the Natural Sciences and Engineering Research Council of Canada. The authors acknowledge the technical support of Mr. Jordan Wyatt.

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