Effect of Drying Treatment Conditions on Sensory Profile of Germinated Oat

R.-L. Heiniö,[1,2] K.-M. Oksman-Caldentey,[1] K. Latva-Kala,[1] P. Lehtinen,[3] and K. Poutanen[1]

ABSTRACT

Germination and subsequent drying of oat produced significantly different sensory profiles depending on processing parameters such as drying speed and temperature profile. The most salient sensory attributes for processed oat were roasted odor and flavor, sweet taste, intense odor, intense aftertaste, and hard, crisp, brittle texture ($P < 0.05$). High temperatures (>85ºC) were necessary to produce these sensory attributes, and quick drying after germination resulted in higher levels of intensity of favorable sensory attributes. The total amount of volatile compounds was higher in native (ungerminated) oat than in processed oat. During germination, and particularly during the drying treatment, the profile of volatile compounds changed. The most abundant volatile compounds responsible for odor were dimethyl sulfide, hexanal, pentanal, and isobutanal. The relative amount of dimethyl sulfide increased as a function of temperature in drying, whereas hexanal, pentanal, and isobutanal disappeared during heating, as did several other small ketones, alcohols, and esters. The germinated oat dried at high temperatures (65–93°C and 65–85°C) was perceived as being roasted, sweet, and nutty. Sensory and instrumental profile analyses of selected volatile compounds using partial least squares (PLS) regression techniques showed that these sensory attributes were clearly related to dimethyl sulfides and isobutanol. A moist and earthy odor was related to cymene, limonene, and isobutanal. Phenolic compounds significantly influenced oat flavor, whereas lipids had a negligible effect.

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Oat is perceived as a tasty cereal with a positive health image, but bitter off-flavor and tendency to rancidity limits its use. Currently, oat is generally used in cereals and flaked products but its use could be extended to entirely new food applications such as convenience foods. Sensory quality is an important criterion in consumer food choice; tailoring of sensory attributes improves the acceptability of oat ingredients in different applications.

Oat flavor is mainly formed during processing. It is important to know the impact of precursors and enzymes of the native oat on flavor formation. Important volatile compounds identified in native oat include 3-methylbutanal, 2,4-decadienal, and benzaldehyde which are associated with raw oat, weed-hay, and grass-like flavors (Heydanek and McGorrin 1986). The flavor of processed oat is a complex, precursor- and heat-dependent combination of volatile compounds. The flavor of cooked oat is reportedly more oat-like, nutty, browned, or burnt. The nutty flavor of toasted oat originates mainly from carbonyl compounds and amines (Heydanek and McGorrin 1986). Maillard reaction products such as heterocyclic pyrazines, pyrroles, furans, and sulfur-containing compounds are abundant in high-temperature, low-moisture extruded oats and produce toasted or roasted flavors (Pfannhauser 1993; Parker et al 2000). Volatile pyrazines and oxidation products of lipids are also important for the flavor of other cereals (Pfannhauser 1993).

At lower processing temperatures and higher moisture levels, other types of volatile compounds influence oat flavor. The composition of volatile compounds responsible for the perceived odor and flavor varies depending on the analysis method used and the type of processing. The major volatile compounds found in moistened, extruded oat flour stored at 32°C were hexanal, decane, 2-pentylfuran, and nonanal (Sjövall et al 1997). Depending on the drying treatment used, the most important volatile compounds influencing oat flavor were terpenes, alkylbenzenes, aldehydes, alcohols, and heterocyclic compounds (Dimberg et al 1996). In addition, some nonvolatile substances such as phenolic compounds, free fatty acids, reducing sugars, and free amino acids might influence oat flavor. Even very small amounts of phenolic acids, phenolic aldehydes, vanilline, and avenanthramides influence oat flavor. Their release is dependent on humidity, time and temperature during processing, and oat cultivar (Molteberg et al 1996b). Rancid, bitter, intense flavor may be enhanced by moisture level and phenolic compounds; while fresh oat-like odor and flavor may be decreased. Avenanthramides may be related to low flavor intensity and rancidity; and caffeic acid and fat acidity may be related to less sweetness and aftertaste.

The mouthfeel of oat is mainly affected by β-glucan and pentosans which are responsible for its rheological properties. The perceived textural properties of cooked oatmeal from different oat cultivars were significantly different, whereas no differences were found in odor and flavor attributes (Lapveteläinen and Rannikko 2000).

Germination is well known to intensify both the color and flavor of grain products. To date, it has been used mostly for barley. Germination of barley has been shown to change its flavor profile significantly from fruity, hay-like (native barley), to burnt, bread-like, malty, and chocolate-like (germinated-dried barley) (Beal and Mottram 1993). There is little data in the literature on the effect of germination on oat. We previously studied the microbiological and chemical changes during germination of oat (Wilhelmson et al 2001). In this investigation, we wanted to specify how the sensory profile of oat is altered by the germination process followed by drying treatment, and why these changes occur.

MATERIALS AND METHODS

Oat Samples

Two oat cultivars, hulled Veli and hull-less (naked) Lisbeth, harvested in summer 1997 in Finland, were used in the present study. Germination conditions have been described elsewhere (Wilhelmson et al 2001). Several drying treatments (Table I) were tested. Native (ungerminated) Veli or Lisbeth grains were used as a control. The Veli cultivar was always dehulled before sensory evaluation.

To analyze the effect of the germination process, native, germinated-undried, and germinated-dried oat grains of both cultivars were profiled by a trained sensory panel. To determine the effect of the drying temperature, four drying treatments were used for the germinated oat: 65–93, 65–85, 30–50°C, and freeze-dried. Also compared were two alternative drying treatments: slow stepwise temperature increase over 17 hr from 65 to 100°C, or raising the temperature quickly over 40 min from 65 to 100°C (Table I).

Sensory Analysis

The sensory profiles of the oat grains were evaluated by a trained panel (n = 6–17) with proven skills using descriptive analysis (Stone et al 1974; Stone and Sidel 1993, 1998). The vocabulary of

[1] VTT Biotechnology, P.O. Box 1500, FIN-02044 VTT Finland.
[2] Corresponding author. E-mail: raija-liisa.heinio@vtt.fi Phone: +358 9 456 5178. Fax: +358 9 455 2103.
[3] Helsinki University of Technology, P.O. Box 1000, FIN-02015 TKK Finland.

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the sensory attributes was developed by describing differences among 17 widely varied oat products by a six-member expert panel. Attribute intensities were rated on continuous unstructured intensity scales. The scales were verbally anchored at each end: lowest or opposite intensity (value 0) and highest intensity (value 10). The samples were presented to the panelists in random order as whole grains (labeled by 3-digit code) out of plastic containers covered by lids. The closed containers were prepared 1–2 hr before evaluation. Water was provided for cleansing the palate between the samples. The samples were analyzed on sequential days in two sensory replicates.

Chemical Analysis

Volatile compounds were determined by dynamic headspace gas chromatograph mass spectrometry (HS/GC/MS). Ground oat samples (0.5 g) were equilibrated at room temperature overnight in vials sealed with a septum (PTFE/Butyl). The volatile compounds from the headspace of the vials were analyzed using a Tekmar 3000 dynamic headspace interfaced to GC/MS equipment (Carlo Erba 8000[TOP]/Automass II, Finnigan Mat). The column was 50 m HP-PONA (0.25 mm, i.d., film thickness 0.5 µm). The oven temperature program started at 0°C where it was held for 3 min, and then it was raised by 5°C/min to 50°C and then continued directly at 25°C/min to 300°C. The final temperature was maintained for 5 min. Compounds were identified on the basis of mass spectra.

The concentration of phenolic compounds was determined as gallic acid equivalents using the Folin-Ciocalteu method (Singleton and Rossi 1965) with some minor modifications. Methanol was used as a solvent, and the total volume of the reaction was 1 mL. The hull was removed mechanically from the Veli samples before preparation of the extract.

For lipid extraction, the flour samples were extracted twice in 19 volumes of dichloromethane and methanol (2:1) as described by Liukkonen et al (1992). After shaking for 2 hr (250 rpm, 28°C), the mixtures were centrifuged (1,460 × *g*, 10 min) and the pellet was reextracted over 2 hr. The extracts were combined and evaporated to dryness under N_2. These samples were used for lipid class separation and for fatty acid composition analysis. The lipid class separation of major lipid classes was done by thin-layer chromatography as described by Liukkonen et al (1992). The samples were supplemented with a standard mixture containing known amounts of dipentadecanoylphosphatidylcholine, heptadecanoic acid, dipentadecanoin, and triheptadecanoin. The mixture was applied on silica plates and the plates were developed. The identified spots were scraped off and used for fatty acid analysis. Fatty acid com-

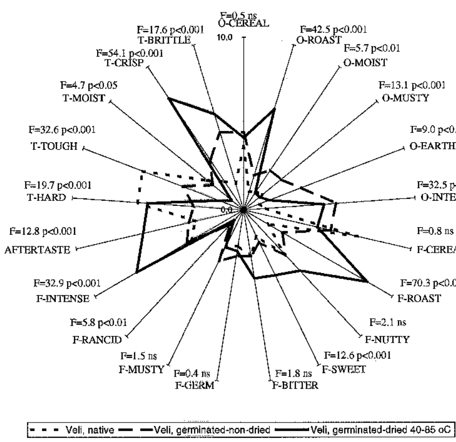

Fig. 1. Effect of germination process on sensory profile of oat cultivar Veli (experiment MB002, *n* = 12, two replicates assessed on sequential days). F = flavor, O = odor, T = texture.

TABLE II
Effect of Germination and Drying Treatment on Sensory Quality of Oat Cultivar Veli (experiment MB003)[a]

	Drying Temperature			
Sensory Quality	**65-95°C**	**65-85°C**	**30-50°C**	**Freeze-Dried**
Odor				
Cereal	5.5	6.0	5.3	5.5
Roasted	5.5b[b]	5.7b	3.2a	2.2a
Moist	1.2a	0.8a	1.9ab	3.1b
Musty	1.9a	1.7a	2.9a	5.0b
Earthy	1.4a	1.2a	2.2ab	3.6b
Intense	4.8b	4.8b	3.0a	5.0b
Flavor				
Cereal	6.3	6.0	5.9	5.3
Roasted	6.1c	7.0c	3.9b	1.9a
Nutty	5.2b	5.2b	3.7ab	2.4a
Sweet	4.2ab	4.8b	4.0ab	2.4a
Bitter	2.8	2.7	2.6	2.6
Germ-like	1.2	1.4	1.5	1.6
Musty	2.0	2.0	2.8	2.9
Rancid	0.7	0.7	0.9	1.3
Intense	5.8b	5.9b	3.8a	2.4a
Aftertaste	4.4b	4.8b	3.4ab	2.2a
Texture				
Hard	6.5b	6.4b	6.1ab	4.6a
Tough	2.2ab	2.0a	3.2ab	3.8b
Moist	0.8	0.8	1.4	1.9
Crisp	7.3b	7.4b	6.0ab	5.0a
Brittle	5.0	5.4	4.7	5.4

[a] Mean descriptive analysis ratings on a scale of 0–10 of germinated Veli dried at different temperatures (*n* = 10, two replicates).
[b] Values followed by the same letter in the same row are not significantly different ($P < 0.05$).

TABLE I
Drying Treatments Used in Four Different Experiments of Germinated Veli and Lisbeth Cultivars

Sample Code	Oat Cultivar	Drying Treatment	
MB002	Veli	Native	
		Nondried	
		40–85°C	40°C 3 hr, 50°C 7 hr, 60°C 6 hr, 85°C 3 hr
MB003	Veli	Freeze-dried	
		30–50°C	30°C 8 hr, gradually to 50°C within 2 hr, 50°C 14 hr
		65–85°C	65°C 5 hr, 70, 75, 80 and 85°C, each for 4 hr
		65–93°C	65°C 5 hr, gradually to 75°C within 6 hr, 75°C 2 hr, gradually to 85°C within 4 hr, 85°C 1 hr, gradually to 93°C within 1 hr
MB004	Lisbeth	Freeze-dried	
		30–50°C	30°C 8 hr, gradually to 50°C within 2 hr, 50°C 14 hr
		65–85°C	65°C 5 hr, 70, 75, 80, and 85°C, each for 4 hr
		65–93°C	65°C 5 hr, gradually to 75°C within 6 hr, 75°C 2 hr, gradually to 85°C within 4 hr, 85°C 1 hr, gradually to 93°C within 1 hr
MB005	Veli	65–100°C	65°C 10 min, 65°C 30 min with air circulation, 100°C 4 hr
		65–100°C	65°C 2 hr, gradually to 75°C within 4 hr, 75°C 2 hr, gradually to 85°C within 4 hr, 85°C 2 hr, gradually to 100°C within 2 hr, 100°C 1 hr

position analysis of extracts and separation into the lipid classes were done by converting the fatty acids to methyl esters and analyzing the latter by gas chromatography essentially as described by Suutari et al (1990). Lipids were saponified by heating in NaOH and fatty acid methyl esters were prepared using HCl as the catalyst.

Statistical Analysis

Analysis of variance (ANOVA) and Tukey's honestly significant difference (HSD) test ($P < 0.05$) were executed using statistical software (v. 8.0.2, SPSS Science, Chicago, IL) for the sensory results. Two-way ANOVA was used to test statistical differences in sensory attributes between oat samples, and statistical difference between the two sessions. When the difference in ANOVA among the samples was statistically significant, pairwise comparisons of attributes between the oat samples were analyzed using Tukey's test.

The multivariate methods, principal component analysis (PCA) and partial least squares (PLS) regression, were performed using statistical software (Unscrambler v. 7.5, CAMO ASA, Oslo, Norway). PCA was used to analyze the sensory data and PLS was used to compare the sensory data with the most relevant volatile compounds. The relative peak areas of the volatile compounds as a percentage of contribution from the total peak area were used instead of the actual peak areas to produce more reliable results.

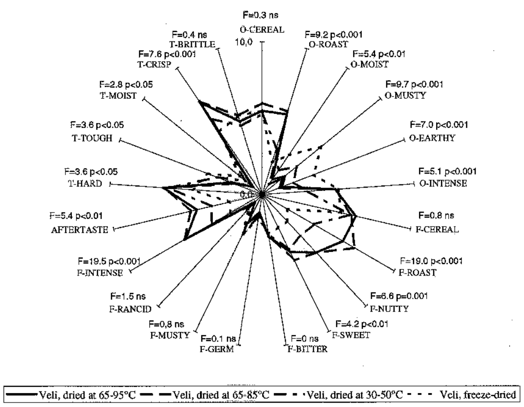

Fig. 2. Effect of drying process on sensory profile of germinated oat cultivar Veli (experiment MB003, $n = 10$, two replicates assessed on sequential days). F = flavor, O = odor, T = texture.

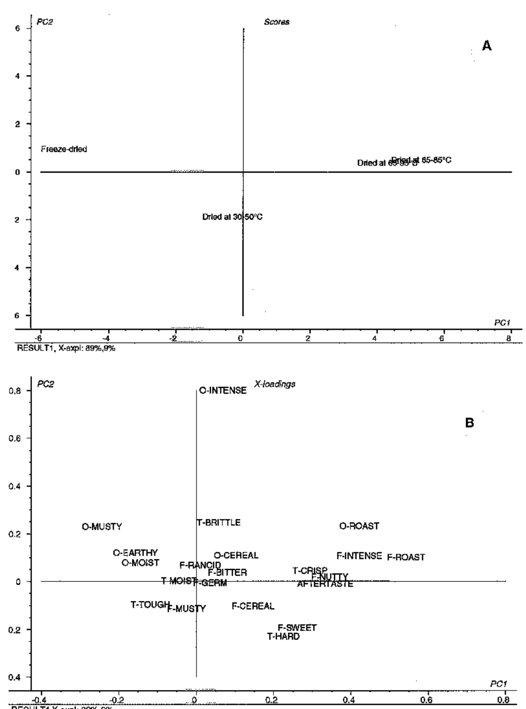

Fig. 3. Principal component analysis (PCA) score plot (**A**) and loading plot (**B**) of the sensory attributes of germinated-dried oat cultivar Veli (experiment MB003).

RESULTS

Germination

Very small differences were found between the sensory profiles of Veli and Lisbeth, the two oat cultivars studied, when native, germinated-undried, and germinated-dried (40–85°C) forms were compared. However, native, germinated-undried, and germinated-dried grains of Veli were different in most of the sensory attributes evaluated, especially in odor and textural properties (Fig. 1).

The influence of processing on oat was obvious. Germination produced an negative effect described as a moist, musty, and earthy odor that disappeared during the drying treatment, resulting in a roasted, sweet odor and flavor, an intense aftertaste, and a less tough but more crisp texture than the other treatments. In the native Veli, an intense cereal flavor and hard, tough, moist texture was perceived, compared with germinated-undried or germinated-dried Veli ($P < 0.05$). Germinated-undried samples had a significantly moister, more musty, earthy and intense odor and a more brittle texture

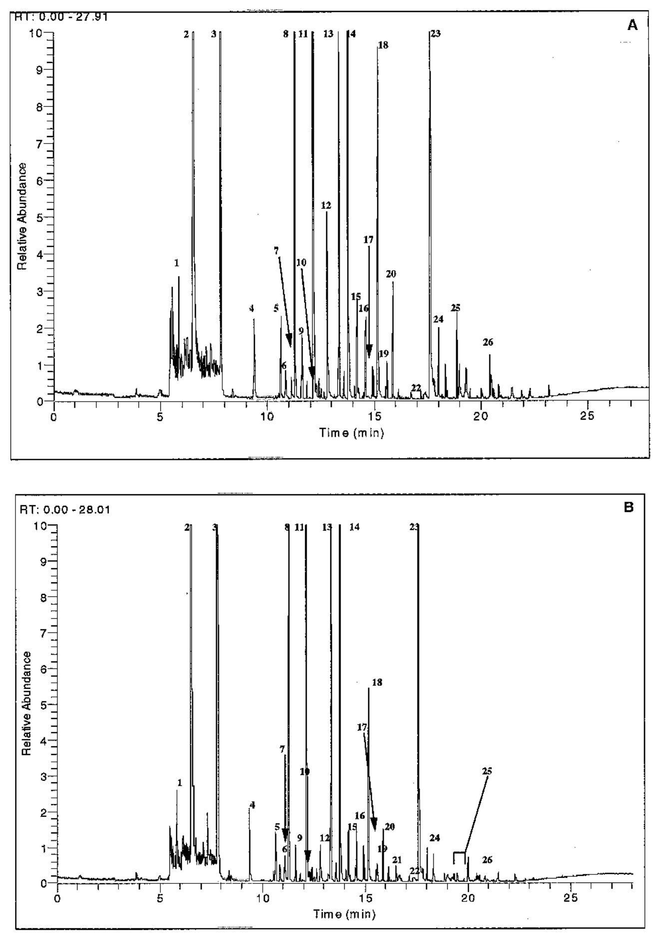

Fig. 4. Total ion graphs of volatile compounds of oat cultivar Veli (experiment MB003) germinated-dried at 30–50°C (**A**) and 65–93°C (**B**) determined by dynamic headspace gas chromatograph mass spectrometry (HS/GC/MS). 1. Ethanol, 2. Acetone, 3. Dimethyl sulfide, 4. Isobutanal, 5. 2-Methylpentane, 6. Butanal, 7. Butanone, 8. 3-Methylpentane, 9. Hexene, 10. 2-Methylfuran, 11. Hexane, 12. Tetrahydrofuran, 13. Methylcyclopentane, 14. 3-Methylbutanal, 15. 2-Methylibutanal, 16. Cyclohexane, 17. 2-Pentanone, 18. Pentanal, 19. 2-Ethylfuran, 20. Heptane, 21. Dimethyl disulfide, 22. Toluene, 23. Hexanal, 24. Octane, 25. Xylens, 26. 2-Pentylfuran.

than the other samples processed ($P < 0.05$). Germinated-dried samples had the most roasted odor and flavor, the most intense odor, the sweetest and strongest aftertaste, and the hardest, crispest, and most brittle texture ($P < 0.05$). The drying temperature and treatment (65–93, 65–85, 30–50°C, or freeze-dried) of germinated oat had the most influence on the sensory attributes of Veli (Table II and Fig. 2). Although the native oat cultivars did not have identical sensory profiles, the treatment caused similar changes in both sensory profiles.

Drying Treatment

A strong roasted odor was noticed in the oat samples of both cultivars dried at high temperatures when compared with oat dried at low temperatures ($P < 0.05$). Drying at low temperatures caused a low intensity of odor and only a mild roasted or nutty flavor in Veli, but a very musty, earthy, and intense odor in Lisbeth ($P < 0.05$). Freeze-dried Veli had a moister, more musty, and more earthy odor compared with the samples from other drying treatments ($P < 0.05$). Lisbeth dried at a low temperature or freeze-dried had a less intense roasted and nutty flavor compared with samples dried at high temperatures ($P < 0.05$). Lisbeth dried at a low temperature had the mustiest and most rancid flavor and the hardest texture ($P < 0.05$). The perceived sweetness was most intense in Veli dried at 65–85°C and in Lisbeth dried at 65–93 and 65–85°C ($P < 0.05$). Drying at high temperatures produced intense flavor and aftertaste and a hard, crisp texture in Veli, whereas only the texture attributes of the Lisbeth were influenced, and were perceived as being less moist and more crisp ($P < 0.05$). The freeze-dried Veli had a tough texture according to the sensory panel ($P < 0.05$). The drying speed seemed to influence the intensity of the roasted odor and the odor intensity. Quick drying resulted in higher attribute intensities ($P < 0.05$) (data not shown).

While comparing the sensory scores and loading plots of Veli drying treaments using PCA (Fig. 3), the most relevant sensory descriptors of germinated oat dried at high temperatures were roasted odor and flavor, nutty flavor, intense aftertaste, and crisp texture. However, germinated oat dried at 30–50°C was perceived as being musty in flavor and tough in texture, and freeze-dried oat was perceived as being musty, earthy, and moist in odor. The first factor of the PCA model explained 89% and the second factor 9% of the variation within the sensory attributes of the four drying treaments.

Chemical Analysis

Volatile compounds. Both the type of processing and the oat cultivar influenced the amount and composition of the volatile compounds. The profile of the HS/GC/MS total ion chromatograms was strongly dependent on the oat cultivar and the processing method. Examples of corresponding GC/MS chromatograms of the germinated Veli dried at 30–50°C and at 65–93°C are presented in Fig. 4A and B. The relative peak areas of germinated oat dried at different temperatures are shown in Table III. The total amount of volatile compounds was the highest in native Veli. The relative amount of substances with low boiling points was also higher in native oat than in germinated-undried or germinated-dried oat. Germination and especially drying caused evaporation of the compounds, and the profile of the volatile compounds changed. In spite of a low boiling point (36°C), the relative amount of dimethyl sulfide increased during germination and drying. Dimethyl sulfide, which causes a putrefied, sewage-like odor, is formed as a breakdown product of amino acids containing sulfur. Drying germinated oat removed butadione, isobutanol, 2-penten-1-ol, 3-hydroxy-2-butanol, 3-methylbutanol, and 2-methyl-1-butanol (Veli) or butadione, ethyl acetate, 3-hydroxy-2-butanone, 3-methyl-1-butanol, and 2-methyl-1-butanol (Lisbeth) (Table III). Hexanal is an oxidation product of fatty acids, and its relative amount increased during the drying treatments for Veli, whereas the relative amount of dimethyl sulfide increased in Lisbeth.

Phenolic compounds. The concentration of phenolic compounds of dehulled Veli was ≈300 to 500 mg/kg (dry weight) (Fig. 5). The

TABLE III
Relative Peak Areas (%) of Volatile Compounds of Germinated-Dried Oat Cultivars Veli (experiment MB003) and Lisbeth (experiment MB004)

	Veli				Lisbeth			
	65–93°C	65–85°C	30–50°C	Freeze-Dried	65–93°C	65–85°C	30–50°C	Freeze-Dried
2-Ethylfuran	0.33	0.22	0.98	1.69	0.48	0.33	0.63	0.81
2-Methylbutanal	0.04	0.01	0.09	0.21	0	0.01	0.04	0.06
2-Methylfuran	0.12	0.08	0.37	0.57	0.07	0.05	0.08	0.12
2-Methylpentane	0.26	0.32	0.66	0.93	0.68	0.17	0.47	1.33
2-Pentanone	0.09	0.05	0.11	0.15	0.04	0.02	0.06	0.11
2-Pentylfuran	0.20	0.12	1.41	1.09	0.25	0.23	0.31	0.31
3-Methylbutanal	0.27	0.20	0.28	0.41	0.05	0.08	0.11	0.06
3-Methylpentane	8.04	7.17	17.09	20.97	17.61	4.06	11.26	26.92
Acetone	12.38	6.16	36.97	21.87	5.49	1.28	18.79	14.35
Benzene	0.09	0.09	0.17	0.22	0.20	0.16	0.15	0.50
Butanal	0.09	0.05	0.29	0.67	0.04	0.04	0.16	0.19
Butanone	0.15	0.12	0.25	0.33	0.08	0.05	0.25	0.20
Dimethyl disulfide	0.14	0.04	0.01	0.03	0.01	0.05	0.11	0.04
Dimethyl sulfide	68.48	78.28	17.73	2.68	61.43	77.50	48.24	12.12
Ethanol	2.76	2.59	4.89	3.99	2.87	11.79	8.48	13.26
Hexane	1.98	1.81	4.66	5.98	5.58	1.28	3.44	8.34
Hexanal	1.72	0.46	6.16	23.60	0.29	0.39	1.69	1.27
Hexene	0.05	0.03	0.13	0.18	0.11	0.03	0.08	0.20
Heptane	0.02	0.01	0.08	0.18	0.13	0.11	0.33	0.27
Isobutanal	0.44	0.25	0.99	2.48	0.17	0.23	0.97	1.89
Isobutanol	0	0	0	0	0.03	0.11	0	0
Xylens	0	0	0.02	0.06	0	0	0	0.07
Limonene	0	0	0	0	0	0	0	0.33
Methylcyclopentane	0.45	0.41	0.97	1.28	1.13	0.28	0.76	1.87
Octane	0.08	0.04	0.24	0.39	0.43	0.47	0.99	0.98
Pentanal	1.04	0.34	2.69	7.76	0.25	0.32	1.11	1.01
Cyclohexane	0.33	0.27	0.65	0.87	0.80	0.29	0.57	1.28
Cymene	0	0	0	0	0.05	0	0.05	1.22
Tetrahydrofuran	0.28	0.76	1.89	1.13	1.49	0.48	0.66	10.48
Toluene	0.14	0.12	0.23	0.28	0.26	0.18	0.19	0.42
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

phenolic concentration of the Veli hulls (500–700 mg/kg, dry weight) was higher than that of the grains. The concentration of phenolic compounds of the hull-less Lisbeth was ≈400 to 1,400 mg/kg (dry wt), which was significantly higher than that of Veli. Drying considerably increased (three- to fourfold) the amount of phenolic compounds in Lisbeth, whereas the increase was only moderate in Veli. The different behavior of the oat cultivars is most probably due to their different genetic background. The most important phenolic acids of germinated oat were ferulic, vanillic, caffeic, and syringic acids. Avenanthramides were also detected.

Lipids. Hulled Veli had a lower lipid content (72 mg/g) compared with hull-less Lisbeth (95 mg/g). The two cultivars differed also in lipolytic activities. Over 75% of the triglycerides were hydrolyzed when hulled Veli was steeped in water for 15 hr, compared with 15% for hull-less Lisbeth. The differences in the distribution of fatty acids in the different lipid classes between the oat cultivars or drying treatments were insignificant. In all cases, the polar lipids represented ≈12%, triglycerides ≈79%, diglycerides ≈4%, and free fatty acids ≈5% of total lipids. The lipolytic activity of germinated oat flour was lower than that of ungerminated oat, judging from the amount of free fatty acids formed when these samples were steeped in water.

Correlation Between Sensory Profile and Chemical Analysis

The volatile compounds used in statistical analysis were selected on the basis of appearance and odor thresholds. Individual correlation coefficients between sensory attributes and the 17 selected volatile compounds, phenolic compounds, and free fatty acids are presented in Table IV. The volatile compounds, especially butanal and dimethyl sulfide, but also butanone, isobutanal, and phenolic compounds correlated highly positively or negatively with the sensory attributes ($r \geq 0.70$, $P < 0.05$). The total phenolic content correlated with cereal-like and moist odor and with bitter and germ-like flavor when all the drying treatments of both oat cultivars were considered. For the Veli drying treatments, phenolic compounds correlated highly with all other sensory attributes except cereal odor, nutty flavor, and brittle texture, whereas the correlations between sensory attributes and volatile compounds were different and slightly lower for Lisbeth (data not shown). The bitter flavor was the only sensory attribute correlating significantly with total phenolic content, regardless of cultivar or drying treatment. Free fatty acids did not correlate significantly with any of the sensory attributes evaluated. Roasted odor and flavor correlated mainly with butanone, dimethyl sulfide, isobutanal, and butanal. Cereal flavor had high correlation with isobutanal, dimethyl sulfide, methylcyclopentane, and butanal. Most correlations of the selected volatile compounds were statistically significant for the perceived flavor intensity, and often for the intensity of aftertaste. When the two cultivars or four drying treatments were analyzed separately, the correlation coefficients were highly dependent on both cultivar and drying treatment (data not shown).

In this study, the first factor of the PLS model explained 65% of the variation of the chemical results, and 29% of the variation of the sensory data within the eight drying treatments of both cultivars, and the second factor explained 23 and 12%, respectively (Fig. 6A and B). For both oat cultivars, the germinated oat dried at high temperatures (and for Lisbeth, the germinated oat dried at low temperature), the roasted odor and flavor as well as the sweet, nutty flavor was closely related to dimethyl sulfides and isobutanol. The flavor of Veli samples dried at lower temperatures (30–50°C and freeze-dried) was closely related to hexanal, 2-pentylfuran, pentanal, and methylbutanal. For freeze-dried Lisbeth, moist and earthy odors were linked to cymene and limonene as well as to isobutanal. In the PLS plot (Fig. 6B), dimethyl sulfides appeared particularly near aftertaste and roasted odor and flavor; and isobutanol was near cereal flavor; and 2-pentanone was near musty odor.

DISCUSSION

This study pointed out the importance of processing on the flavor of oat foods. In addition, the combination of sensory evaluation and chemical analysis showed relationships between the sensory descriptors and the volatile compounds in oat.

Sample handling is of the utmost importance both in sensory evaluation and chemical analysis of the flavor compounds. In contrast to previous sensory investigations of oat, whole oat grains (processed or unprocessed) were evaluated. In many other studies, only the water extract of the product was subjected to sensory evaluation (Heydanek and McGorrin 1981, 1986; Molteberg et al 1996a,b). The objective in the evaluation of oat as whole grain was to gain reliable knowledge about natural perception of the sensory attributes of the product.

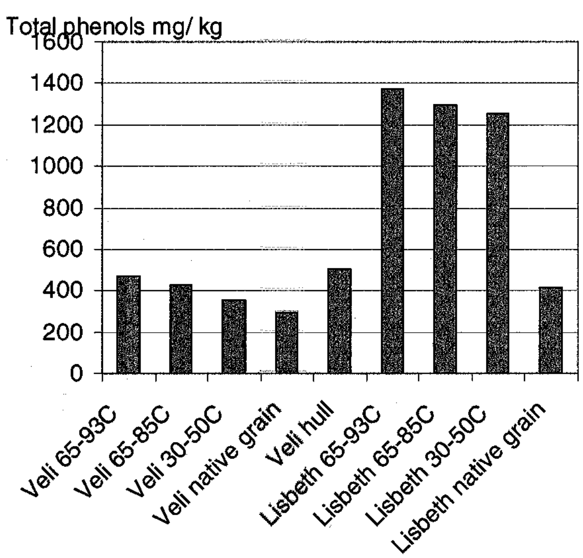

Fig. 5. Phenolic compound content (mg/kg) of native and germinated-dried oat cultivars.

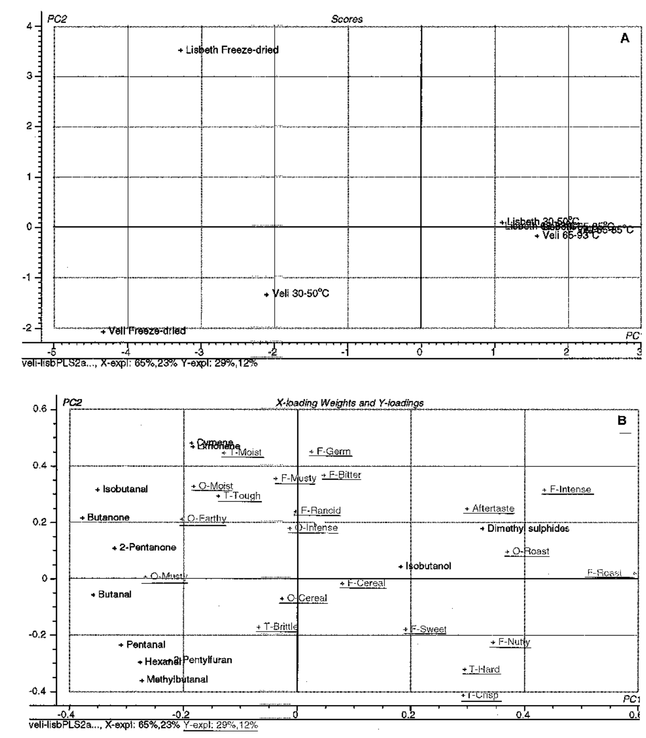

Fig. 6. Partial least squares (PLS) score plot (**A**) and loading plot (**B**) of sensory and headspace data of germinated-dried oat cultivars Veli and Lisbeth (experiments MB003 and MB004).

TABLE IV
Coefficients of Correlation (r)[a] Between Scores of Sensory Attributes and Analysis of Volatile Compounds, Phenolic Compounds, and Free Fatty Acids (FFA) in Germinated-Dried Oat Cultivars Veli and Lisbeth

Chemical	Odor					
	Cereal	Roast	Moist	Musty	Earthy	Intense
2-Methylbutanal	0.21	–0.69	0.22	0.47	0.27	0.09
2-Pentanone	0.30	–0.59	0.16	0.33	0.19	0.06
2-Pentylfuran	0.14	–0.60	0.03	0.24	0.08	–0.44
3-Methylbutanal	0.55	–0.25	–0.37	0.05	–0.18	–0.13
Acetone	0.00	–0.67	0.13	0.37	0.28	–0.22
Butanal	0.16	**–0.73**	0.27	0.52	0.32	0.11
Butanone	0.00	**–0.84**	0.36	0.68	0.54	0.29
Dimethyldisulfide	–0.25	0.12	–0.03	0.19	0.20	0.53
Dimethyl sulfide	0.03	**0.83**	–0.52	–0.54	–0.46	–0.03
Ethanol	–0.56	–0.26	0.64	0.40	0.49	0.25
Hexanal	0.24	–0.60	0.13	0.40	0.18	0.08
Isobutanal	0.01	**–0.79**	0.55	0.64	0.53	0.33
Isobutanol	–0.27	0.38	–0.06	–0.21	–0.21	–0.23
Limonene	–0.08	–0.20	0.51	0.15	0.27	0.21
Methylcyclopentane	–0.12	–0.62	0.66	0.37	0.43	0.12
Pentanal	0.22	–0.64	0.16	0.43	0.22	0.07
Cymene	–0.11	–0.21	0.54	0.17	0.30	0.23
Phenolic compounds	**–0.78**	–0.25	**0.77**	0.44	0.51	0.37
FFA (% of total)	0.32	–0.13	–0.14	–0.04	–0.09	–0.08

[a] For all correlations $P < 0.05$. For values in bold $r \geq 0.70$ (positive or negative).

Descriptive analysis is a sensory method only recently applied to oats (Molteberg et al 1996a,b; Lapveteläinen and Rannikko 2000; Parker et al 2000; Zhou et al 2000). Because of the nature of descriptive methods, the sensory glossary is generated separately for each study, and the descriptors used in this study therefore differed from the attributes used in other studies conducted on different products. Sensory attributes such as a roasted odor, nutty odor and flavor, and a crisp, hard texture were obvious. Other studies used sensory descriptors such as raw, hay-like, or paint-like odor (Molteberg et al 1996a, 1996b) or attributes named for cereal-based foods such as Weetflakes cereal, digestive biscuit, toasted sunflower seed, oatmeal, cooked rice, wholemeal flour, or other food-based terms such as stale oil, apple puree, chicken bones and broth (Parker et al 2000).

As expected, germination alone did not have a significant effect on the desired sensory attributes, but most of the positive attributes were formed during drying for both cultivars. Steeping in water during germination produced a change in the odor and the texture of native oat: it became moister, more musty, and more earthy in odor, and softer, less tough, more crisp, and more brittle in texture. A strong roasted, sweet odor and flavor was developed in the germinated-dried oat, and the moist, must, and earthy odor disappeared. A strong aftertaste developed as well. Textural changes were significant in germinated-dried oat in comparison to the undried products, where a hard, crisp, brittle texture was produced; and moistness and toughness were reduced. Textural changes probably originated from the germination phase of malting, when most of the β-glucan degrades, resulting in lower viscosity (Peterson 1998).

The end temperature of the drying treatment was significant for flavor development. Higher end temperatures resulted in a high intensity of roasted, nutty, sweet, and intense odor and flavor; a strong aftertaste; and a hard, crisp texture. The higher the temperature, the higher the attribute intensity. The intensity of the cereal odor or flavor; bitterness, germ-like, musty, or rancid flavor; or moistness or brittleness were not affected by the drying treatment. The speed of the drying treatment of the germinated oat was important for certain sensory attributes: quick drying produced a more roasted and intense odor than did slow drying. In general, these results are in accordance with those reported previously (Parker et al 2000; Zhou et al 2000), although drying treatment of oat flours reduces the intensity of some negatively perceived attributes, particularly bitterness and astringency, and increases the oat-like flavor and hexanal concentration (Molteberg et al 1996a). High temperatures also influence roasted odor and flavor: Maillard reaction products after extrusion were described as toasted and cereal (Parker et al 2000).

In the present study, the total amount of volatile compounds was higher in native oat than in processed oats, regardless of cultivar. During germination, and particularly during drying treatment, volatile compounds disappeared, changing the volatile compounds profile. The relative amount of hexanal (Veli) or dimethyl disulfide (Lisbeth) increased as a function of temperature in germinated-dried oat. Several minor ketones, alcohols, and esters disappeared during heating of germinated oat.

The method of analyzing volatile compounds from cereals can significantly influence the compounds recovered, and the results obtained using different methods should be considered carefully (Zhou et al 1999). In particular, the volatile compounds identified showed multiplicity when solvent extraction was used. In addition, the volatile compounds identified did not necessarily explain the perceived flavor of the grain.

Most volatile compounds have specific odors and odor thresholds. The perceived odor is never a sum of different volatile compounds identified in a product; complex synergistic and other reactions are involved. However, efforts have been made to correlate certain odors to certain volatile substances (Molteberg et al 1996b; Zhou et al 2000). PLS has been used to relate sensory attributes to chemical data (Molteberg et al 1996b; Tamime 1997). When correlating the results of sensory evaluation and volatile compounds determined by headspace techniques, high-level expertise in sensory, headspace, and statistical methods is required with jointless cooperation between all participants.

When correlating volatile compounds detected from oatmeal with sensory data, 43–94% of the variation in sensory attributes accounted for chromatographic peak areas of volatile compounds (Zhou et al 2000). However, the peak area, or even the relative peak area as used in this study, does not necessarily account for all of the perceived odor. Many long-chain hydrocarbons do not produce any odor perception. In addition, there may be several unidentified volatile compounds in amounts too small to detect using HS/GC/MS, but despite their low odor thresholds, they may still have considerable influence on the sensory profile. Each volatile compound has its own odor threshold, and the total composition of volatile compounds does not necessarily correlate with the odor profile or intensity perceived because of the synergistic effects of different combinations of volatile compounds. In addition, the relationship between the results of the perceived sensory and instrumental head-

TABLE IV (continued)
Coefficients of Correlation (*r*)[a] Between Scores of Sensory Attributes and Analysis of Volatile Compounds, Phenolic Compounds, and Free Fatty Acids in Germinated-Dried Oat Cultivars Veli and Lisbeth

Flavor									
Cereal	Roast	Nutty	Sweet	Bitter	Germ	Musty	Rancid	Intense	Aftertaste
–0.66	**–0.73**	–0.47	–0.39	–0.39	–0.31	–0.06	–0.10	**–0.94**	**–0.85**
–0.50	**–0.70**	–0.44	–0.30	–0.39	–0.32	–0.09	–0.17	**–0.87**	**–0.79**
–0.32	–0.55	–0.29	–0.11	–0.48	–0.38	–0.13	–0.22	**–0.85**	**–0.74**
–0.10	–0.30	0.03	0.14	**–0.81**	**–0.79**	–0.42	–0.49	**–0.73**	–0.69
–0.26	–0.66	–0.45	–0.24	–0.30	–0.22	0.15	0.00	–0.66	–0.49
–0.70	**–0.75**	–0.51	–0.43	–0.35	–0.26	–0.01	–0.04	**–0.93**	**–0.83**
–0.64	**–0.89**	**–0.70**	–0.55	–0.19	–0.11	0.31	0.20	**–0.76**	–0.55
0.33	0.01	–0.01	–0.14	0.17	0.00	0.28	0.27	0.44	0.49
0.75	**0.87**	**0.72**	0.57	0.04	–0.08	–0.20	–0.14	**0.87**	**0.73**
–0.30	–0.25	–0.48	–0.56	**0.76**	0.66	0.49	0.59	0.14	0.26
–0.62	–0.60	–0.35	–0.30	–0.46	–0.37	–0.14	–0.15	**–0.89**	**–0.83**
–0.84	**–0.87**	–0.74	–0.66	0.01	0.08	0.22	0.21	**–0.82**	–0.68
0.27	0.51	0.35	0.15	0.24	0.13	–0.14	0.02	0.38	0.29
–0.38	–0.31	–0.44	–0.39	0.49	0.49	0.22	0.25	–0.11	–0.08
–0.75	–0.68	–0.66	–0.56	0.28	0.43	0.26	0.24	–0.56	–0.52
–0.62	–0.65	–0.39	–0.33	–0.45	–0.36	–0.11	–0.13	**–0.91**	**–0.84**
–0.40	–0.32	–0.46	–0.41	0.52	0.53	0.26	0.29	–0.09	–0.06
–0.63	–0.12	–0.38	–0.62	**0.89**	**0.89**	0.54	0.67	0.56	0.49
0.10	–0.30	–0.10	0.02	–0.33	–0.38	–0.19	–0.29	–0.40	–0.36

space analysis are challenged by differences in sample-handling procedures. (Sample handling in sensory evaluation is more susceptible to evaporation of volatile compounds than it is in instrumental analysis.) Despite all of these challenges, statistical tools for correlating sensory and instrumental headspace data are very useful when the results are evaluated carefully.

The concentration of phenolic compounds had a tendency to increase slightly with drying temperature. Avenanthramides correlate positively with the fresh flavor of oat (Molteberg et al 1996b). Drying treatment influenced the sensory profile of oat, and the phenolic compounds explained 29% of the variation in perceived sensory odor and flavor attributes (Molteberg et al 1996b).

Because oat is rich in lipids, it is sensitive to lipolytic activity and subsequent rancidity, and the bitter flavor is caused by lipid oxidation products (Biermann and Grosch 1979). An increase in the amount of free fatty acids indicates the hydrolysis of lipids, while a decrease in the degree of unsaturation indicates the oxidation of lipids. Only very minute changes were detected in the lipid composition upon germination of the oat cultivars. The lipase activity of the germinated oat was lower than that of the ungerminated oat. A slight hydrolysis of lipids was observed during the hot air drying treatment. Lipid oxidation was also initiated during drying. In this study, the cultivar or drying treatment used did not cause any significant differences in lipid composition between the samples analyzed, although the lipase activity varied between the cultivars. Although lipids did not affect the flavor of fresh oat products due to the small amount of free fatty acids, they are known to have an essential role in the flavor of stored oat manifesting as rancidity (Molteberg et al 1996a).

According to the PLS analysis, the germinated oats dried at higher temperatures (65–93 and 65–85°C) were perceived to be roasted, sweet, and nutty. These attributes were mainly related to dimethyl sulfides and isobutanol. Cymene, limonene, and isobutanal were linked to a moist and earthy odor.

The composition of volatile compounds obtained in different studies is dependent on the drying treatment used. For example heterocyclic Maillard reaction products such as pyrazines, pyrroles, and furans, which mainly affect the roasted flavor, have been identified in other studies of oat heat processing (Pfannhauser 1993; Parker et al 2000). As a consequence of relatively low temperatures and high moisture levels in our studies, these compounds were not formed through the Maillard reaction, which occurs at high temperature and low humidity.

CONCLUSIONS

The sensory profiles of the two oat cultivars studied were quite similar. Processing clearly influenced the sensory attributes perceived in oat. The native grain had a cereal-like flavor and a tough, hard texture, whereas the germinated-undried grain had a moist, musty, and earthy flavor and a soft, moist texture. The drying treatment and temperature had a significant effect on the sensory attributes formed. In the present study, a roasted odor and flavor developed without any apparent Maillard reaction Heating at higher temperatures improved the sensory quality of oat compared with oat dried at lower temperatures or freeze-dried. Quick drying after germination of oat resulted in higher intensities of generally positive sensory attributes.

Several of the volatile compounds correlated significantly with the sensory attributes evaluated. Dimethyl sulfides and isobutanol were associated with the roasted, sweet, and nutty flavors observed in germinated oat dried at higher temperatures, and cymene, limonene, and isobutanal were associated with the moist and earthy odor. Phenolic compounds particularly influenced the perceived bitter flavor. Free fatty acids are generally supposed to affect the sensory quality. However, in this investigation, they did not have a significant influence on perceived odor or flavor.

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LITERATURE CITED

Beal, A. D., and Mottram, D. S. 1993. An evaluation of the aroma characteristics of malted barley by free-choice profiling. J. Sci. Food Agric. 61:17-22.

Biermann, U., and Grosch, W. 1979. Bitter-tasting monoglycerides from stored oat flour. Z. Lebensm. Forsch. 1:22-26.

Dimberg, L. H., Molteberg, E. L., Solheim, R., and Frölich, W. 1996. Variation in oat groats due to variety, storage and heat treatment. I:

Phenolic compounds. J. Cereal Sci. 24:263-272.
Heydanek, M. G., and McGorrin, R. J. 1981. Gas chromatography-mass spectroscopy investigations on the flavor chemistry of oat groats. J. Agric. Food Chem. 29:950-954.
Heydanek, M. G., and McGorrin, R. J. 1986. Oat flavor chemistry: Principles and prospects. Pages 335-369 in: Oats: Chemistry and Technology. F. H. Webster, ed. Am. Assoc. Cereal Chem.: St. Paul, MN.
Lapveteläinen, A., and Rannikko, H. 2000. Quantitative sensory profiling of cooked oatmeal. Lebensm. Wiss. Technol. 33:374-379.
Liukkonen, K. H., Montfoort, A., and Laakso, S. 1992. Water-induced lipid changes in oat processing. J. Agric. Food Chem. 1:126-130.
Molteberg, E. L., Magnus, E. M., Bjørge, J. M., and Nilsson, A. 1996a. Sensory and chemical studies of lipid oxidation in raw and heat-treated oat flours. Cereal Chem. 73:579-587.
Molteberg, E. L., Solheim, R., Dimberg, L. H., and Frölich, W. 1996b. Variation in oat groats due to variety, storage and heat treatment. I: Sensory quality. J. Cereal Sci. 24:273-282.
Parker, J. K., Hassell, G. M. E., Mottram, D. S., and Guy, R. C. E. 2000. Sensory and instrumental analyses of volatiles generated during the extrusion cooking of oat flours. J. Agric. Food Chem. 48:3497-3506.
Peterson, D. M. 1998. Malting oats: Effects on chemical composition of hull-less and hulled genotypes. Cereal Chem. 2:230-234.
Pfannhauser, W. 1993. Volatiles formed during extrusion cooking of cereals. Flav. Fragr. J. 8:109-113.
Singleton, V. L., and Rossi, J. A. 1965. Colorimetry of total phenolics with phosphomolybdiphosphotungstic acid reagents. Am. J. Enol Vitic. 16:144-158.
Sjövall, O., Lapveteläinen, A., Johansson, A., and Kallio, H. 1997. Analysis of volatiles formed during oxidation of extruded oats. J. Agric. Food Chem. 45:4452-4455.
Stone, H., and Sidel, J. 1993. Sensory Evaluation Practices. 2nd Ed. Academic Press: Orlando, FL.
Stone, H., and Sidel, J. 1998. Quantitative descriptive analysis: Developments, applications and the future. Food Technol. 8:48-52.
Stone, H., Sidel, J., Oliver, S., Woolsey, A., and Singleton, R. C. 1974. Sensory evaluation by quantitative descriptive analysis. Food Technol. 28:24-34.
Suutari, M., Liukkonen, K., and Laakso, S. 1990. Temperature adaption in yeast: The role of fatty acids. J. Gen. Microbiol. 136:1469-1474.
Tamime, A. Y., Muir, D. D., Barclay, M. N. I., Khaskheli, M., and McNulty, D. 1997. Laboratory-made Kishk from wheat, oat, and barley: 2. Compositional quality and sensory properties. Food Res. Int. 5:319-326.
Wilhelmson, A., Oksman-Caldentey, K.-M., Laitila, A., Suortti, T., Kaukovirta-Norja, A., and Poutanen, K. 2001. Characterization of microbiological and chemical changes during germination of hulled and naked oat. Cereal Chem. 78:715-720.
Zhou, M., Robards, K., Glennie-Holmes, M., and Helliwell, S. 1999. Analysis of volatile compounds and their contribution to flavour in cereals. J. Agric. Food Chem. 10:3941-3953.
Zhou, M., Robards, K., Glennie-Holmes, M., and Helliwell, S. 2000. Contribution of volatiles to the flavour of oatmeal. J. Sci. Food Agric. 80:247-254.

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