Relationships of Selected Physical, Chemical, and Sensory Parameters in Oat Grain, Rolled Oats, and Cooked Oatmeal—A Three-Year Study with Eight Cultivars

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ABSTRACT

Eight Scandinavian oat cultivars were studied as grains, groats before and after kiln drying, rolled oats, and oatmeal for 62 physical, chemical, and sensory parameters over three consecutive crop years. The objectives were to study cultivar and year differences, and the relationships between parameters to find out the cultivars most suitable for rolled oats production and to understand how grain parameters are reflected on groat, rolled oat, and oatmeal characteristics. The cultivars and crop years differed ($P < 0.05$) in most of the parameters. In addition, many groat, rolled oats, and oatmeal variables showed a significant year by crop interaction. Several grain variables were significantly interrelated but only two, moisture and amount of dark and damaged grains, had a strong correlation ($r > 0.70$) to rolled oat parameters, the former correlating negatively to crude fat and the latter positively with maximum viscosity value. However, some weaker ($r < 0.70$) negative associations were found such as those between kernel size value and β-glucan content and water binding capacity of rolled oats. In general, the variables analyzed at different processing stages correlated strongly, indicating good retention of groat properties during processing. Various associations were found between the physicochemical parameters of rolled oats and sensory properties of oatmeal. In principal component analysis, factor 1 mostly represented rolled oat parameters such as crude fat, color values *L* and *a*, and oatmeal parameters such as toasted aromatics, coarseness, and size of swollen particles. Factor 2 represented properties that pertain to structure and water and rolled oats interactions. The cultivars were also grouped according to these properties. The results suggest that the rolled oat process deserves optimization on a cultivar basis, particularly when specific product properties such as good water binding capacity are required.

Human consumption of oats (*Avena sativa* L.) has recently gained increased attention due to its beneficial nutritional properties related to soluble fiber and protein composition (Janatuinen et al 1995; Welch 1995; FDA 1996). In Finland, where ≈4% of world oats are produced (FAO 1996), oats for human consumption are primarily used as rolled oats and cooked oatmeal. So far, none of the Scandinavian cultivars have been developed specifically for human consumption. Selection of raw material for milling purposes is generally based on criteria such as the absence of foreign material and grain, sound appearance and odor characteristics, husk or hull content, test weight, 1,000 grain weight, grading, and moisture content (Ganssmann and Vorwerck 1995). Although cultivar differences in the parameters directing oat breeding and cultivation such as seed size, yield, lodging resistance, and nutritional attributes such as protein, oil, and β-glucan are widely studied, knowledge concerning the suitability of cultivars for rolled oats production is limited. Lindner and Tönnerfors (1991) studied critical manufacturing criteria for Swedish oat cultivars and reported parameters such as degree of dehulling, flake strength, viscosity, and sensory quality to be of special importance for rolled oats. Based on these and other attributes (e.g., oil and β-glucan content), three cultivars were reported to be most appropriate for industrial oats.

The suitability of eight oat cultivars for rolled oat production on a large-scale process was investigated. Oat cultivars already identified for human consumption were studied for various physical and chemical parameters as grain, groats before and after kiln drying, and as rolled oats. Sensory characteristics of the corresponding cooked oatmeal were also determined. The objectives were to study cultivar differences at different stages of processing. The main question to be answered concerning differences between the grains was whether these differences were still evident in rolled oat parameters and in the sensory characteristics of the corresponding cooked oatmeal. We also studied the relationships between the parameters to find out whether there are grain parameters that can predict chemical or physical properties of rolled oats or the sensory properties of cooked oatmeal.

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MATERIALS AND METHODS

Oat Samples

The samples consisted of five Finnish (C2, C3, C4, C5, C6) and three Swedish (C1, C7, C8) oat cultivars from three consecutive crop years 1993–95. All samples were cultivated in southern Finland by contract growers of Melia Ltd. The cultivars involved in the study represent the most commonly grown cultivars in Finland.

Grains (GR): Grain samples were taken from delivery trucks according to the normal sampling procedures of the manufacturer.

Rolled oats (RO): Rolled oats were produced in the commercial oat mill of Melia Ltd. located in Nokia, Finland. Each cultivar batch manufactured varied between 40,000 and 100,000 kg. Processing steps involved cleaning, grading by size, dehulling, kiln drying (Bühler Miag, Germany), cutting, and rolling. In addition, groat samples were taken before and after kiln drying (GBK and GAK, respectively) to monitor various parameters at different stages of processing. Groat and rolled oat samples were stored in 1-kg paper bags at room temperature until analyzed (one month maximum). For sensory analyses, rolled oats were packaged in 200-g portions into 500-mL glass bottles and stored covered at –28°C.

The large amount of raw material required for producing the rolled oat samples limited the number of cultivars included in the study. In addition, large amounts of all cultivars were not available every year. Thus, only cultivars C1, C2, and C3 could be processed and analyzed in all three consecutive crop years. Cultivar C4 was analyzed in years 1993 and 1994, cultivar C5 in 1993 and 1995, cultivar C6 in 1993, cultivar C7 in 1994, and cultivar C8 in 1995.

Chemical and Physical Analyses

Table I lists the chemical and physical analyses performed in the study. Total dietary fiber and β-glucan contents were analyzed in duplicate measurements at The Technical Research Center of Finland (Espoo, Finland) and starch content at The Municipal Food Laboratory of Turku, Finland. All other chemical and physical analyses were made in at least duplicate samples at the laboratories of Raisio Yhtymä, Raisio, Finland.

Sensory Evaluation

A quantitative sensory profiling method developed specifically for oatmeal samples (Lapveteläinen and Rannikko 2000) was used to analyze the sensory characteristics of rolled oat samples grown in 1994 and 1995. Duplicate evaluations were made in March 1995 (samples of crop year 1994) and November 1995 (samples of crop year 1995) using 14 assessors experienced in evaluating oatmeal samples.

Oatmeal was prepared in a double boiler (stainless steel, 3L, Kombi-Double Pan, Opa, Mikkeli, Finland) by mixing 130 g of rolled oats (11%, mb) into 1L of boiling, filtered tap water, and cooking for 10 min. The samples were served in randomized order in 40-mL covered glass cups coded with three-digit random numbers. The glass cups were held on heated (80°C) plates until sample assessment. All evaluations were made in individual booths in the sensory laboratory of The University of Turku (Turku, Finland).

The assessors quantified two odor characteristics (total intensity of odor, intensity of toasted odor), two mechanical texture characteristics (thickness, adherence to spoon), two flavor characteristics (total intensity of flavor, intensity of toasted flavor), and four oral texture characteristics (uniformity of mass, size of swollen flake particles, slipperiness, and coarseness) on a 10-cm line scale. For samples of 1995, the darkness of color was also quantified using a numerical scale (1–10) anchored with photographs at the values 1, 4, 7, and 10. The definitions of the characteristics evaluated and the reference samples used for training of assessors have been described previously (Lapveteläinen and Rannikko 2000).

TABLE I
Chemical and Physical Measurements

Measurement[a]	Samples[b]	Equipment, Description, Reference
Moisture, %	GR, GBK, GAK, RO	DICKEY-john GAC 2000 (Auburn, IL). GR measurement calibrated by determination of the moisture content of cereals and cereal products (practical method). ICC Standard 110/1.[c]
Protein, %	GR, RO	Infratec (Tecator, Höganäs, Sweden). GR measurement calibrated by determination of crude protein (N × 5.7) in cerals and cereal products for food and for feed. ICC Standard 105/1.[c]
Test weight, kg/hL	GR	250-mL measuring container, filling time 8 sec. Determination of bulk density, called mass/hL. ISO International Standard 7971-2(E).[d]
Total amount of extraneous materials, %	GR	Determination of besatz of wheat. ICC-Standard 102/1.[c] Determination of besatz of rye. ICC Standard 103/1.[c]
1,000 grain weight, g	GR	Numigral Seed Counter (Villeneuve, France). Determination of weight of 1,000 grains.
Sieving test (>2.5 mm, >2.2 mm, <2.2 mm)	GR, GBK	Sortimat sieving machine (Huddinge, Sweden) for 100 g of grains or groats. Grading of barley and malt. Method 3730.[e]
Kernel size value	GR	Calculated value from sieving test: 1.4 (amount of grains >2.5 mm) + 0.8 (amount grains >2.2 mm) + 0.4 (amount of grains <2.2 mm).[f]
Yield, %	GR	Laboratory huller (Streckel & Schrader, Hamburg, Germany). Weight of groats after dehulling 100 g of grains for 2 min.
1,000 groat weight, g	GR	Laboratory huller (Streckel & Schrader, Hamburg, Germany). Weight of 1,000 groats after dehulling 100 g of grains for 2 min.
Unhulled grains, %	GR	Laboratory huller (Streckel & Schrader, Hamburg, Germany). % of unhulled grains in groat sample after dehulling for 2 min.
Damaged and dark grains, %	GR	Laboratory huller (Streckel & Schrader, Hamburg, Germany). % of damaged and dark grains in groat sample after dehulling for 2 min.
Falling number, sec	GBK, GAK, RO	Determination of falling number according to Hagberg–Perten as a measure of the degree of α-amylase activity in grain and flour. ICC Standard 107.[c]
Ash, %	GBK, RO	Determination of ash in cereals and cereal products. ICC Standard 104.[c]
Maximum viscosity, BU	GBK, GAK, RO	Brabender Amylograph. ICC Standard 126/1.[c]
Maltose value, mg/10 g	GBK, RO	Maltose value (Method Rumsey-Ritter).[g]
Damaged starch, %	GBK, RO	AACC Approved Method 76-30A.[h]
Water binding capacity, %	GBK, RO	Bestimmung der Wasserbindevermögens und der Löslichkeit der Stärke.[i]
1,000 groat weight, g	GBK	Numigral Seed Counter (Villeneuve, France). Determination of weight of 1,000 groats after hulling was completed during rolled oat processing.
Color (*a*, *b*, *L* values)	GBK, RO	Minolta CR-300 (Osaka, Japan) chromameter. Values of *a* (–green +red), *b* (– blue + yellow), and *L* (lightness) for unground samples.
Other grains, %	GBK	Amount of other grains in the groats after the hulling was completed during rolled oat processing.
Unhulled grains, %	GBK	Amount of unhulled grains in the groats after the hulling was completed during rolled oat processing.
Dark and damaged grains, %	GBK	Amount of dark and damaged grain in the groats after the hulling was completed during rolled oat processing.
Crude fat, %	RO	AOAC Method 922.06.[j]
Total dietary fiber, %	RO	AOAC Method 985.29.[j]
β-glucan, %	RO	AACC Approved Method 32-22.[h]
Starch, %	RO	Enzymatic determination in foods. Method 145.[k]
Flake thickness, mm	RO	Measured with μm-screw (Johansson, Eskilstuna, Sweden). Given as mean of 10 flakes.
Damaged flake particles, %	RO	100 g of rolled oats sieved (Santasalo Sohlberg 1 × 20″) and weight of particles passing through sieve.
Weight/volume, g/L	RO	Weight of rolled oats in 1,000-mL graduated cylinder.
Fatty acids, rel. proportion, %	RO	Analysis of fatty acid methyl esters with high accuracy and reliability. Bannon et al (1982).[l]

[a] Wet basis, except for protein and ash, which are given on dry matter basis.
[b] GR = grains, GBK = groats before kiln drying, GAK = groats after kiln drying, RO = rolled oats.
[c] Standard Methods of the Int. Assoc. for Cereal Chem. ICC: Detmold.
[d] International Organization for Standardization: Geneva.
[e] Technical Research Centre of Finland, Espoo.
[f] Oeding (1996).
[g] Pages 9-99 in: Standard Methods for Cereal, Meal and Bread, 6th ed. Moriz Schäfer: Detmold.
[h] Approved Methods of the AACC, 10th ed. Am. Assoc. Cereal Chem.: St. Paul, MN.
[i] Page 110 in: Ausgewählte Methoden der Stärkechemie. Richter et al (1968).
[j] Official Methods of Analysis of the Association of Official Analytical Chemists, 15th ed. AOAC: Arlington, VA.
[k] Starch and Glucose, 2nd ed. Nordic Committee on Food Analysis: Oslo, Norway.
[l] Bannon et al (1982).

Statistical Analyses

Two-way analysis of variance was applied to determine the differences between the crop years and cultivars. Statistical differences between the means were analyzed using Tukey's test at $P < 0.05$. Pearson's correlation coefficients were calculated to show the relationship among the variables. Principal component analysis (PCA) was also applied using the mean data (mean across the years for each cultivar) of selected variables. Data were analyzed using procedures of the Statistical Analyses System (version 6.11, SAS Institute, Cary, NC).

TABLE II

ANOVA and Range of Means for Eight Cultivars and Crop Years 1993-95

Parameter	Abbreviation	Results from ANOVA[a]			Range of Cultivar (n=8) Means		Means of Crop Years[d]		
		Cultivar	Year	C*Y[b]	$Mean_{Min.}$	$Mean_{Max.}$	1993	1994	1995
Grain (GR) variables:									
Moisture	GR-moist	-	-		10.5	12.7	10.9A	11.7A	n.a.[f]
Protein	GR-prot	-	X[c]		10.7	12.1	11.8A	11.2AB	10.6B
Test weight	GR-test.wt	-	-		57.4	63.4	58.7A	57.7A	60.0A
Extraneous material	GR- em	XXX	-		0.3	1.9	0.8A	0.3A	n.d.
1000 grain weight	GR-gra.wt	XX	X		27.3	35.9	35.7A	30.7B	32.3B
% grains >2.5 mm	GR>2.5	XXX	XXX		4.7	50.5	41.9A	12.4B	30.4A
% grains >2.2 mm	GR>2.2	XX	X	X	36.0	54.0	40.1A	47AB	50.3B
% grains<2.0 mm	GR<2.0	-	X		2.4	20.8	5.8B	14.4A	5.5B
Kernel size value	GR-size	XXX	XXX		51.9	103.2	95.9A	65.9B	88.3A
Yield	GR-yield	X	X		67.8	77.0	75.7A	72.3B	73.4B
1000 groat weight	GR-gro.wt	XX	XXX		21.5	32.3	29.3A	23.3B	25.9C
Unhulled grains	GR-ug	-	-		0.1	0.5	0.3A	0.3A	0.3
Dark and damaged grains	GR-dd	X	-		0.1	2.0	0.3A	0.9A	n.d.
% groats>2.5 mm	GR-gro>2.5	XX	n.d.[e]		1.3	11.6	n.d.	n.d.	3.9
% groats>2.2 mm	GR-gro>2.2	-	n.d.		14.5	52.0	n.d.	n.d.	29.1
% groats<2.0 mm	GR-gro<2.0	-	n.d.		12.5	39.7	n.d.	n.d.	26.7
Variables measured for groats before kiln drying (GBK):									
Moisture	GBK-moist	XXX	XXX	XX	10.1	13.1	10.8A	11.6B	12.7C
Falling number	GBK-fno	XXX	XXX	XX	80.3	314.0	135.6A	112.8B	344.0C
Ash	GBH-ash	-	-	X	2.0	2.2	2.1A	2.0A	2.1A
Maximum viscosity	GBK-maxv	XXX	XXX	XXX	241.7	460.0	233.6A	344.5B	333.9B
Maltose value	GBK-mv	XX	XX	X	1.0	3.9	1.3A	2.2B	-
Damaged starch	GBK-dsta	-	XX		3.8	14.4	n.d.	3.4A	9.9B
Water binding capacity	GBK-wbc	-	XX		1.0	1.3	n.d.	1.2A	1.0B
Groat weight	GBK-gro.wt	XXX	XXX		23.7	30.4	28.7A	25.4B	27.2C
% groats>2.5 mm	GBK>2.5	XXX	XXX	XXX	0.9	9.8	5.8A	1.9B	3.7C
% groats>2.2 mm	GBK>2.2	XXX	XXX		7.9	48.1	38A	18.6B	33.6A
% groats<2.0 mm	GBK<2.0	XXX	XXX	X	11.4	48.7	19.5A	40.4B	33.8C
Color value L	GBK-L	-	-		58.6	65.0	56.9A	60.5A	58.9A
Color value a	GBK-a	X	-	X	5.3	5.8	5.6A	5.7A	5.5A
Color value b	GBK-b	-	-		21.2	21.8	20.7A	21.4A	21.8A
Other grains	GBK-oth	XXX	XXX	XXX	0.0	0.3	0.0A	0.2B	0.4C
Unhulled grains	GBK-ug	-	X		0.0	0.2	0.0A	0.1A	0.1A
Dark and damaged grains	GBK-dd	XXX	-		0.1	2.2	0.3A	1.0A	0.4A
Variables measured for groats after kiln drying (GAK):									
Moisture	GAK-moist	-	XXX		8.5	10.7	8.8A	10.0B	11.2C
Falling number	GAK-fno	XXX	XXX	X	253.4	412.0	319.5A	283.7B	424.9C
Maximum viscosity	GAK-maxv	XXX	-	XXX	370.0	625.0	406.8A	465.5A	426.4A
Rolled oats (RO) variables:									
Moisture	RO-moist	XXX	XXX	XXX	8.5	10.9	8.5A	9.7B	11.6C
Protein	RO-prot	XXX	XXX	XXX	12.8	14.7	14.3A	13.9B	13.5C
Ash	RO-ash	X	X		2.0	2.2	2.1A	2.1A	2.1A
Dietary fiber	RO-dfib	XXX	-	XX	9.4	10.3	9.6A	9.9A	9.5A
β-glucan	RO-βgl	X	XX		4.1	5.7	4.2B	5.0A	4.1B
Starch	RO-sta	-	-		45.0	51.0	49.9A	49.0A	47.4A
Maltose value	RO-mv	X	X	XXX	0.5	1.8	0.8A	1.3B	n.d.
Damaged starch	RO-dsta	-	-		10.1	17.8	16.3A	15.9A	14.2A
Falling number	RO-fno	XXX	XXX		334.0	513.0	343.5A	323.0B	472.7C
Maximum viscosity	RO-maxv	XXX	XXX	XXX	450.0	735.0	462B	544.5A	531.7A
Water binding capacity	RO-wbc	X	XXX	X	1.7	2.1	1.6A	2.1B	1.9C
Color value L	RO-L	X	X	XXX	77.1	79.8	n.d.	78.1A	79.1B
Color value a	RO-a	X	XXX		1.6	2.2	n.d.	2.1A	1.7B
Color value b	RO-b	-	-		18.5	19.7	n.d.	19.3A	18.9A
Thickness of flake	RO-thi	XXX	-		0.5	0.6	0.6A	0.6A	0.6A
Weight/volume	RO-w/v	X	XXX		308.0	355.5	344.9A	337.2A	311.4B
Damaged flake particles	RO-dfp<1.0	-	X		16.0	22.0	19.5AB	21.4A	17.4B
Crude fat	RO-fat	XXX	XXX	XXX	6.4	8.4	7.0A	6.7B	7.8C
Myristic acid	RO-C14:0	XXX	XXX	XXX	0.2	0.2	0.2A	0.2B	0.2A
Palmitic acid	RO-C16:0	XXX	XXX	XXX	14.4	16.6	15.2A	15.7B	14.9C
Palmitoleic acid	RO-C16:1	XXX	XXX	XXX	0.7	1.8	0.9A	1.7B	1.7B
Stearic acid	RO-C18:0	XXX	XXX	XXX	1.2	1.6	1.3A	1.4B	1.6C
Oleic acid	RO-C18:1	XXX	XXX	XXX	36.6	41.5	38.3A	37.1B	39.7C
Linoleic acid	RO-C18:2	XXX	XXX	XXX	37.1	39.9	39.1A	38.5B	37.6C
Linolenic acid	RO-C18:3	XXX	XXX	XXX	1.7	3.0	2.6A	3.3B	2.1C
Eicosenoic acid	RO-C20:1	XXX	XXX	XXX	0.8	0.9	0.8A	0.8A	0.8B
Erucic acid	RO-C22:1	XXX	XXX	XXX	0.5	1.0	0.7A	0.4B	n.d.
Monounsaturated fatty acids	RO-mufa	XXX	XXX	XXX	39.4	43.7	41.0A	40.0B	42.2C
Polyunsaturated fatty acids	RO-pufa	XXX	XXX	XXX	40.0	43.4	41.8A	42.1A	41.0B
Saturated fatty acids	RO-safa	XXX	XXX	XXX	16.1	18.8	17.2A	17.6B	16.8C
Oatmeal (OM) variables:									
Total intensity of odor	OM-totod	-	-		4.3	5.8	n.d.	5.4A	4.6A
Toasted odor	OM-toastod	X	XXX	X	1.7	5.4	n.d.	4.5A	2.0B
Total intensity of flavor	OM-tf	-	-		3.8	4.5	n.d.	4.1A	4.1A
Toasted flavor	OM-toastfl	XXX	XXX	X	0.8	3.4	n.d.	2.8A	1.1B
Adherence to spoon	OM-adh	X	-	X	3.1	7.7	n.d.	5.3A	5.7A
Thickness	OM-thi	-	-		5.6	7.2	n.d.	6.4A	6.0A
Uniformity of mass	OM-uni	X	-	X	3.2	6.4	n.d.	4.6A	5.2A
Size of swollen flake particles	OM-size	-	XXX	X	2.2	4.9	n.d.	4.2A	2.7B
Slipperiness	OM-slip	-	-	X	3.9	5.8	n.d.	4.8A	5.2A
Coarseness	OM-coar	-	XX		2.8	4.7	n.d.	4.3A	2.9B
Darkness of color	OM-dark	-	n.d.		2.0	2.8	n.d.	n.d.	2.4

[a] Analysis of Variance

[b] Cultivar * Crop Year Interaction. Significance of interaction as designated below. For undesignated parameters, the interaction not significant at p<0.05.

[c] X, XX, XXX = means were significantly different at p<0.05, 0.01, and 0.001, respectively. The means of parameteres designated with (-) did not differ at p<

[d] Means designated with the same letter did not differ at p<0.05

[e] not determined

[f] not available

RESULTS AND DISCUSSION

Cultivar and Year Differences

The range of means for the cultivars and crop years together with the results from the analysis of variance are given in Table II. In general, the cultivars included in this study fulfilled the recommended physical quality requirements for industrial oats as given by Ganssmann and Vorwerck (1995), except that in 1994, the amount of grain <0.2 mm was somewhat higher than recommended, especially with C2, C3, C4, and C7. The protein content of the grains was in accordance with earlier reports (Peltonen-Sainio and Peltonen 1993; Welch 1995). The composition of rolled oats also matched the compositional information given in Food Tables (Welch 1995).

Both cultivar and crop year significantly influenced ($P < 0.05$) several grain (GR) variables including 1,000 g grain weight, kernel size value, yield, and 1,000 groat weight. Main effects were also significant for groat weight in GBK and for parameters such as β-glucan, falling number, color value *a*, and weight/volume in rolled oat (RO) samples. In 1993, the 1,000 grain weight and yield (GR) were higher than the other two years. In 1994, the kernel size

TABLE III

Pearson's Correlation Coefficients (*r*)

Significance levels: * (p<0.05), ** (p<0.01), *** (p<0.001). Squared Coefficients Denote Cases where r^2>0.5.

GRAINS (GR)

		n	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10
X1	GR-Moisture	18	1,00									
X2	GR-Protein	27	-.11	1,00								
X3	GR-Test Weight	27	-.16	-.01	1,00							
X4	GR-Extraneous material	18	-.35	.37	.06	1,00						
X5	GR-1000 grain weight	27	-.17	.16	.14	.37	1,00					
X6	GR-Kernel size value	27	-.13	.00	.20	.35	.69***	1,00				
X7	GR-Yield	27	-.13	.24	.54**	0,36	.53**	.65***	1,00			
X8	GR-Groat weight	27	.22	.31	.34	.48*	.74***	.85***	.74***	1,00		
X9	GR-Unhulled grains	17	-.17	.10	-.07	.08	-.38	-.43	-.30	-.41	1,00	
X10	GR-Dark and damaged grains	17	.01	-.28	-.56*	-.40	-.64**	-.59*	.78***	-.66**	.06	1,00
X11	GBK-Moisture	30	.18	-.48*	.12	-.37	.16	.32	-.06	.03	-.32	-.20
X12	GBK-Falling number	30	-.29	-.49*	.15	.22	.01	.30	-.22	.04	-.34	.34
X13	GBK-Ash	29	-.37	.16	.33	.23	.41	.19	.39	.24	.28	-.38
X14	GBK-Max. viscosity	30	.07	-.38	-.24	-.26	-.45*	.26	-.50**	-.43*	-.04	.61**
X15	GBK-Maltose value	14	.42	-.07	.66*	-.23	-.14	-.38	-.23	-.18	.31	-.32
X16	GBK-Damaged starch	19	-.07	-.19	.14	-.40	.39	.46	-.04	.21	.43	.02
X17	GBK-Water binding capacity	19	-.25	.18	-.18	-.03	-.24	-.80**	-.42	-.48*	.31	.13
X18	GBK-Groat weight	30	-.13	.04	.14	.32	.80***	.84***	.54**	.84***	-.43	-.58*
X19	GBK-% groats>2.5 mm	30	-.33	-.13	-.03	.16	.65***	.78***	.38	.62***	-.38	-.37
X20	GBK-% groats>2.2 mm	30	-.01	-.05	.04	.25	.56**	.93***	.56**	.78***	-.47	-.54*
X21	GBK-% groats<2.0 mm	30	.06	-.13	-.00	-.28	-.51**	.79***	.66***	.75***	.39	.62**
X22	GBK-Color value L	18	-.25	-.13	-.42	-.36	-.30	-.52*	-.65**	-.41	.24	.38
X23	GBK-Color value a	18	.23	.21	-.09	.01	.02	-.47	-.20	-.35	.20	-.18
X24	GBK-Color value b	18	-.23	-.30	-.08	-.72*	.09	.06	-.19	-.19	.40	.06
X25	GBK-other grains	27	.55*	-.58**	.29	-.35	-.33	-.17	-.22	-.41	-.07	.23
X26	GBK-Unhulled grains	22	.05	-.60**	-.16	-.34	-.32	-.38	-.46	-.51*	.02	.60*
X27	GBK-Dark and damaged grains	26	.09	-.12	-.41	-.29	-.42*	-.47*	.67***	-.41	-.04	.94***
X28	GAK-Moisture	28	.36	-.53**	.15	-.42	-.17	.06	-.18	-.18	-.07	-.22
X29	GAK-Falling number	28	-.02	-.40	-.14	.11	-.04	.44	-.17	.11	-.26	.30
X30	GAK-Max. viscosity	28	-.08	-.18	-.30	-.14	-.40*	-.33	-.37	-.33	-.03	.70**
X31	RO-Moisture	31	.41	-.52**	.17	-.28	-.13	.13	-.21	-.15	-.13	.02
X32	RO-Protein	31	-.15	.50**	.12	-.00	-.08	-.31	.16	.03	.46	.02
X33	RO-Ash	31	.44	.07	.15	-.21	.03	-.15	.16	.02	.11	-.12
X34	RO-Dietary fiber	32	.16	.12	-.31	.07	-.28	-.30	-.38	-.19	0,22	.53*
X35	RO-β-glucan	32	.21	-.08	-.28	-.24	-.42*	-.50**	-.55**	-.43*	.08	.59*
X36	RO-Starch	15	.33	-.31	-.10	-.19	.43	.45	.33	.26	-.19	-.21
X37	RO-Maltose value	14	.54	-.09	-.11	-.14	-.56	-.40	-.51	-.54	.57	.55
X38	RO-Damaged starch	29	.16	-.15	-.18	-.46	.08	.22	.08	.07	.04	-.26
X39	RO-Falling number	31	-.12	-.43*	.27	.14	-.06	.33	-.06	.11	-.32	.30
X40	RO-Max. viscosity	29	-.14	-.36	-.16	-.28	-.37	-.31	-.48*	-.41*	.05	.76***
X41	RO-Water binding capacity	31	.45	-.26	-.10	-.47	-.51**	.64***	-.45*	.61***	-.05	.48*
X42	RO-Color value L	20	-.14	-.47*	.37	.16	.24	.25	.09	.18	-.64*	.07
X43	RO-Color value a	20	.08	.42	-.35	-.21	-.36	-.66**	-.24	-.53*	.69*	-.16
X44	RO-Color value b	20	.26	.53*	-.21	-.00	-.35	-.23	-.03	-.16	.63	-.35
X45	RO-Flake thickness	31	.08	-.08	-.30	.12	.16	.50**	.08	.27	.04	-.34
X46	RO-Weight/volume	31	-.29	.42*	-.20	-.24	.13	.03	.20	.19	.01	-.26
X47	RO-Damaged flake particles	31	.26	.06	-.23	-.04	-.09	-.41*	-.11	-.22	.03	.19
X48	RO-Crude fat	32	.77***	-.22	.40*	.04	-.04	.25	.04	.18	.28	.07
X49	RO-MUFA	32	-.44	.01	.47*	.32	-.19	-.12	.01	-.01	.32	.07
X50	RO-PUFA	32	.10	-.22	-.41*	-.30	.30	.35	.15	.14	-.48*	-.21
X51	RO-SAFA	32	.51*	.35	-.08	.08	.03	-.12	.04	-.05	.20	-.22
X52	OM-Total intensity of odor	20	.14	.22	-.30	.02	-.03	-.64**	-.34	-.42	-.10	.49
X53	OM-Toasted odor	20	.28	.39	-.35	.20	-.18	-.61**	-.21	-.32	.15	-.03
X54	OM-Total intensity of flavor	20	.07	.04	.03	-.25	-.10	-.36	-.35	-.24	-.19	.52
X55	OM-Toasted flavor	20	.32	.34	-.34	-.11	-.13	-.62**	-.35	-.31	-.08	.48
X56	OM-Adherence to spoon	20	-.24	-.24	-.05	.16	-.05	-.10	-.34	.10	-.20	.29
X57	OM-Thickness	20	-.11	.14	-.20	-.17	-.41	-.58**	-.40	-.32	-.35	.46
X58	OM-Uniformity of mass	20	-.28	-.33	-.04	.18	.03	.01	-.37	.13	-.23	.36
X59	OM-Size of swollen flake particles	20	.52	.39	-.36	-.18	-.07	-.33	-.03	-.30	.11	-.29
X60	OM-Slipperiness	20	.03	.14	.13	-.17	.06	.30	.27	.05	.33	-.30
X61	OM-Coarseness	20	-.02	.54	-.50*	.16	-.20	-.43	-.19	-.33	.34	-.23
X62	OM-Darkness of color	10	-	.22	.01	-	.40	-.27	-.25	-.36	-	-

GROATS BEFORE KILN DRYING (GBK)

	X11	X12	X13	X14	X15	X16	X17	X18	X19	X20	X21	X22	X23	X24	X25	X26	X27
X11	1,00																
X12	.53**	1,00															
X13	-.10	-.08	1,00														
X14	.28	.38	-.39	1,00													
X15	.08	-.28	.41	.08	1,00												
X16	.56	.76**	.36	-.01	.69	1,00											
X17	.75***	-.64**	-.03	.05	.60	-.52*	1,00										
X18	.28	.13	.26	-.32	-.05	.36	-.53*	1,00									
X19	.31	.19	.23	-.19	-.24	.40	-.53*	.79***	1,00								
X20	.24	.21	.03	-.23	-.25	.29	.74***	.79***	.70***	1,00							
X21	-.02	.06	-.01	.33	.29	-.06	.57*	.67***	.57***	.87***	1,00						
X22	-.43	-.02	-.28	.73***	-.42	-.19	.71**	-.39	0.33	-.49*	.43	1,00					
X23	-.07	-.41	-.11	.26	.04	-.44	.52*	-.42	-.33	-.47*	.50*	.24	1,00				
X24	.48*	.64**	.41	.07	.31	.59*	-.40	-.05	.09	-.03	.26	-.03	-.06	1,00			
X25	.26	.33	-.05	.10	.66**	.11	-.17	-.24	-.13	-.20	.39*	-.11	-.19	.12	1,00		
X26	.36	.32	-.20	.29	-.08	.49	-.05	-.35	-.27	-.41	.39	-.17	-.24	.18	.28	1,00	
X27	-.23	.05	.63***	.51**	-.16	-.29	.49	-.45*	-.27	-.32	.35	.58*	.01	-.28	.04	.13	1,00
X28	.85***	.49**	-.12	.34	.43	.70**	-.60*	.04	.10	.09	.04	-.31	-.41	.41	.44*	.51*	-.19
X29	.42*	.83***	-.22	.42*	-.38	.59*	-.72**	.24	.27	.48**	-.21	-.10	-.43	.47	.15	.13	.06
X30	-.13	.11	-.31	.78***	-.21	-.15	.32	-.39*	-.29	-.33	0,28	.61*	.06	-.34	-.10	.33	.65***
X31	.83***	.74***	-.16	.49***	.40	.69**	.74***	.05	.01	.10	.13	-.28	-.20	.70**	.44	.47*	-.11
X32	.61***	-.49**	.54**	-.35	.22	-.23	.41	-.21	-.36	-.35	.22	.02	-.05	-.16	-.24	-.20	-.03
X33	-.03	-.23	.31	-.02	.71**	-.05	.22	-.00	-.13	-.17	.07	-.33	-.21	-.02	-.08	.51*	-.18
X34	-.18	-.07	-.21	.43*	.32	-.36	.22	-.16	-.21	-.19	.08	.23	-.08	-.39	-.06	.16	.40*
X35	-.15	-.17	-.43*	.60***	.40	-.62**	.64**	-.40*	-.35	-.41*	.35	.60**	.35	-.44	.08	.16	.68***
X36	.03	-.17	.20	-.10	.03	-.39	.28	.29	.61*	.50	-.57*	-.17	-.06	-.39	-.51	-.09	-.04
X37	.14	-.21	.11	.52	.88***	.33	-.12	-.32	-.32	-.38	.35	.30	-.08	.63	.59*	-.42	-.09
X38	.02	-.19	.11	-.07	-.14	-.06	.03	.17	.29	.29	-.09	.07	-.04	.14	.12	-.35	.06
X39	.50**	.92***	-.05	.30	-.20	.71**	.73***	.13	.08	.31	-.07	-.17	-.57*	.52*	.28	.21	.02
X40	-.01	.26	-.25	.84***	-.07	-.02	.24	-.46*	-.23	-.37	.36	.64**	-.10	-.21	.07	.36	.72***
X41	.15	-.05	-.30	.45*	.43	-.54*	.65*	-.56*	-.49**	-.57**	.53**	.33	.15	-.16	.36	.54*	.41*
X42	.18	.53*	-.26	-.18	-.53	.25	-.25	.13	.10	.19	-.14	.10	-.26	.01	.52*	-.01	-.07
X43	-.48*	.83***	-.01	.14	.58	-.60**	.69***	-.45	-.37	-.60**	.46*	.21	.66**	-.36	-.30	-.09	.26
X44	-.18	-.49	.14	.12	.67	-.15	.19	-.12	-.17	-.02	-.23	-.01	.01	-.18	-.52	-.49	.13
X45	.46*	.31	.19	.25	.27	.38	-.55*	.51**	.51**	.53**	-.35	-.31	-.23	.40	-.15	-.03	-.31
X46	-.43	.71***	.23	-.42*	-.13	.82***	.51*	.20	.25	.15	-.37*	.12	.29	-.51*	-.50**	-.51*	-.10
X47	-.47**	-.47*	-.17	-.28	-.06	-.50*	.57*	-.33	-.28	-.41*	.36	.26	.27	-.24	.09	.08	.25
X48	.34	.73***	.09	.17	-.65*	.57*	-.57	.05	.04	.15	-.01	.02	-.48*	.51*	.06	.03	-.04
X49	-.19	.46**	.10	-.09	-.32	.36	-.23	-.25	-.36	-.21	.24	.07	-.38	.30	.20	-.01	-.01
X50	.31	-.26	-.09	.02	-.24	-.26	.05	.38*	.57***	.42*	-.42*	-.02	.31	-.17	-.26	-.06	-.11
X51	-.03	-.43*	.08	-.10	.81***	-.25	.16	.01	-.14	-.14	.06	-.38	.24	-.21	.06	.06	-.32
X52	-.34	-.46*	.26	.09	.56	-.36	.56*	-.18	-.52*	-.61**	.55*	.31	.61**	-.05	-.21	.02	.33
X53	-.46*	.85***	.00	.09	.77	-.69**	.72***	-.20	-.38	-.50*	.33	.30	.61**	-.47	-.32	-.13	.38
X54	.08	.01	.22	-.10	.29	.14	.20	.10	-.27	-.38	.53*	-.04	.36	-.05	.00	.56	.15
X55	-.53*	-.70	-.01	.03	.72	-.61**	.74***	-.21	-.36	-.54*	.52*	.36	.60*	-.38	-.25	-.12	.54*
X56	-.28	.36	-.33	-.08	-.14	.02	.09	.03	.01	.12	-.10	.35	-.39	-.15	.14	-.18	.52*
X57	-.67**	-.19	-.42	-.11	-.13	-.46*	.41	-.45	-.42	-.36	.22	.31	.03	-.42	-.00	-.20	.63*
X58	-.11	.49*	-.26	-.06	-.18	.17	.00	.14	.14	.17	-.06	.28	-.38	-.05	.22	.03	.43
X59	-.19	.81***	-.01	.11	.02	-.49*	.43	-.18	-.16	-.34	.22	.10	.51*	-.32	-.31	-.10	.15
X60	.44	.03	.28	.35	.09	.23	-.24	.13	.12	.11	-.03	-.17	.40	.36	-.23	-.02	-.47
X61	-.39	.84***	-.12	.18	.05	-.62**	.58**	-.26	-.17	-.34	.14	.30	.52*	-.40	-.44	-.29	.31
X62	.44	.37	.40	.83**	-	.26	.59	-.18	-.03	-.54	.83**	.38	.84**	.59	-.14	-.01	-.31

GROATS AFTER KILN DRYING (GAK)

	X28	X29	X30
X28	1,00		
X29	.34	1,00	
X30	-.05	0,21	1,00
X31	.88***	.62***	.00
X32	-.55**	-.52**	.02
X33	.16	-.40*	-.03
X34	-.16	-.00	.49**
X35	-.06	-.09	.59***
X36	-.10	.02	.05
X37	.36	-.06	.15
X38	-.13	-.08	-.18
X39	.56**	.86***	.07
X40	.10	.28	.92***
X41	.39*	-.19	.32
X42	.27	.32	-.11
X43	-.57*	-.72**	.17
X44	-.04	-.40	.06
X45	.42*	.52**	-.11
X46	-.57**	-.52**	-.19
X47	-.42*	-.56**	-.12
X48	.31	.56**	.07
X49	-.13	.16	.01
X50	.19	.01	-.06
X51	.03	-.35	-.24
X52	-.58*	-.49*	.27
X53	-.58*	-.72**	.19
X54	-.11	-.06	.10
X55	.73***	-.63**	.18
X56	-.14	.20	.11
X57	-.70**	-.31	.18
X58	-.01	.34	.10
X59	-.36	-.61**	.06
X60	.36	.21	.03
X61	-.49*	-.59*	.18
X62	-.22	.36	-.40

ROLLED OATS (RO)

	X31	X32	X33	X34	X35	X36	X37	X38	X39	X40	X41	X42	X43	X44	X45	X46	X47	X48	X49	X50	X51
X31	1,00																				
X32	.57***	1,00																			
X33	.07	.35	1,00																		
X34	-.42	.28	.23	1,00																	
X35	-.04	-.03	.03	.67***	1,00																
X36	-.20	-.30	-.04	-.11	.06	1,00															
X37	.57*	.10	.60*	.58*	.55*	-.06	1,00														
X38	-.18	-.02	-.08	-.17	-.10	.24	-.03	1,00													
X39	.72***	-.34	-.10	-.12	-.31	-.26	-.08	-.22	1,00												
X40	.19	-.09	-.01	.40*	.52**	-.02	.60*	-.16	.23	1,00											
X41	.36	-.03	.40*	.25	.47**	-.20	.44	-.22	-.02	.40*	1,00										
X42	.27	-.42	-.48*	-.42	-.40	-.39	.93***	-.37	.48*	.08	-.18	1,00									
X43	-.63**	.30	.25	.28	.64**	.35	.73	.29	.85***	-.03	.44	.76***	1,00								
X44	-.20	.25	.33	.50*	.39	.51	.92***	.33	-.35	-.12	.08	.76***	.58**	1,00							
X45	.40	-.21	.15	.22	-.06	.17	.55*	.23	.25	-.11	-.16	-.45*	-.07	.36	1,00						
X46	.67***	.29	-.02	.08	.17	.45	-.04	.32	.68***	-.34	-.28	-.66**	.77***	.71***	.00	1,00					
X47	-.47	.29	.20	-.10	.09	-.08	-.09	.12	-.50**	-.14	.31	-.05	.37	-.19	-.43*	.08	1,00				
X48	.47**	-.12	-.19	-.25	-.41*	-.40	-.56	-.17	.82***	.22	-.19	.51*	.80***	-.34	.02	-.48**	-.46	1,00			
X49	.08	.27	-.15	-.07	-.28	-.61*	-.44	-.36	.56**	.08	-.10	.60**	-.64**	-.42	-.36*	-.45*	-.07	.70***	1,00		
X50	-.06	-.45*	-.09	-.33	-.07	.82***	-.18	.47**	-.33	-.11	-.08	-.39	.46	0,25	.28	.43*	-.03	-.36*	.81***	1,00	
X51	.01	.18	.48**	.45**	.33	-.02	.81***	-.07	-.43*	-.27	.21	-.59**	.52*	.48*	.29	.11	.13	.63***	-.45**	-.11	1,00
X52	-.41	.47*	.21	.29	.43	-.12	.58	.06	-.52*	.04	.51*	-.45*	.60**	.25	-.16	.48*	.35	-.49*	-.31	.13	.25
X53	-.60**	.37	.30	.35	.70***	.33	.74	.18	.86***	-.02	.63**	-.63**	.86***	.46*	-.08	.81***	.44	.80***	-.66**	.45*	.53*
X54	.02	.22	.10	-.00	.11	-.43	.28	-.14	-.06	-.12	.10	-.20	.22	.01	-.11	.08	.03	-.11	-.04	-.14	.10
X55	-.65**	.43	.25	.33	.66**	.12	.71	.26	.75***	-.01	.58**	-.57**	.80***	.34	-.19	.70***	.59**	.72***	-.52*	.29	.40
X56	-.18	-.11	-.37	-.00	.11	-.44	-.78	-.16	.29	.14	-.01	.52*	-.38	-.32	-.33	-.11	.18	.30	.46*	-.34	.60**
X57	.69***	.16	.18	.17	.38	-.54	-.57	-.18	-.22	.11	.33	.07	.25	-.01	-.59**	.35	.52*	-.18	.18	-.20	-.29
X58	-.01	-.21	-.45	-.04	.02	-.33	-.85*	-.15	.37	.13	-.07	.58**	-.48*	-.44	-.24	-.24	.08	.35	.45*	-.31	-.60**
X59	-.45*	.22	.35	.31	.50*	.50	.77	.40	-.82*	-.07	.43	.72***	.85***	.57**	.40	.70***	.33	.80***	.78***	.63**	.65**
X60	.47*	-.08	.08	-.08	-.16	.20	.65	.10	.08	.00	-.41	-.34	.11	.25	.48*	-.14	-.59**	.11	-.21	.19	.28
X61	-.54*	.25	.17	.40	.61**	.51	.46	.16	.81***	.05	.49*	-.62**	.80***	.51*	.05	.70***	.25	.73***	.70***	.52*	.57**
X62	.28	-.17	-.28	-.49	-.55	-.06	-	.14	-.76*	-.16	-.36	-.24	.75*	-.11	-.05	-.39	.05	-.44	-.29	.31	.22

COOKED OATMEAL (OM)

	X52	X53	X54	X55	X56	X57	X58	X59	X60	X61	X62
X52	1,00										
X53	.78***	1,00									
X54	.61**	.33	1,00								
X55	.84***	.92***	.46*	1,00							
X56	-.12	-.23	-.07	-.08	1,00						
X57	.24	.24	.10	.40	.66**	1,00					
X58	-.14	-.31	.05	-.15	.95***	.50*	1,00				
X59	.54*	.80**	.11	.71***	-.63**	-.06	.71***	1,00			
X60	-.11	-.06	-.03	-.22	.83***	-.80**	.76***	.30	1,00		
X61	.44	.79***	-.02	.65**	-.44	.05	-.54*	.84***	.23	1,00	
X62	.43	.33	.35	.47	-.88**	-.46	-.78**	.73*	.91***	.40	1,00

(GR) and β-glucan (RO) content were higher than in 1993 or 1995. The protein content of grains (GR) only showed a year effect, whereas the amount of extraneous material (GR) and dark and damaged grains (GR, GBK) showed a cultivar effect (Table II).

Lindner and Tönnerfors (1991) reported that flake strength (amount of damaged flake particles) of rolled oats was cultivar dependent, which is contrary to our results. Data from our study showed a year effect; the amount of damaged flake particles was significantly lower in 1995 than in 1994 ($P < 0.05$).

Significant interactions between crop year and cultivar were found for GBK, RO, and oatmeal (OM) properties (Table II) suggesting that the cultivars did not respond in a similar manner to year effects. Figure 1 shows the interaction between crop year and cultivar for dietary fiber and maximum viscosity (RO). The interaction can be seen as a divergence of dietary fiber level pattern of C2 from that of C1 and C3 (Fig. 1A) in consecutive crop years. The resulting interaction for maximum viscosity can at least partly be explained by the high value obtained for C3 in 1994 (Fig. 1B). Other variables showing significant interactions between crop year and cultivar were moisture (GBK, RO), falling number (GBK, GAK), maltose value (GBK, RO), amount of other grains (GBK), protein content (RO), water binding capacity (RO), color value L (RO), fatty acids (RO), toasted odor and flavor (OM), adherence to spoon (OM), uniformity of mass (OM), and size of swollen flake particles (OM).

Based on the results of the Tukey's test, the means of C1 and C7 in several cases represented the extremes among the cultivars, C1 was the most superior in kernel size and weight and C7 was the most superior in water binding capacity, maximum viscosity, and β-glucan content (data not presented).

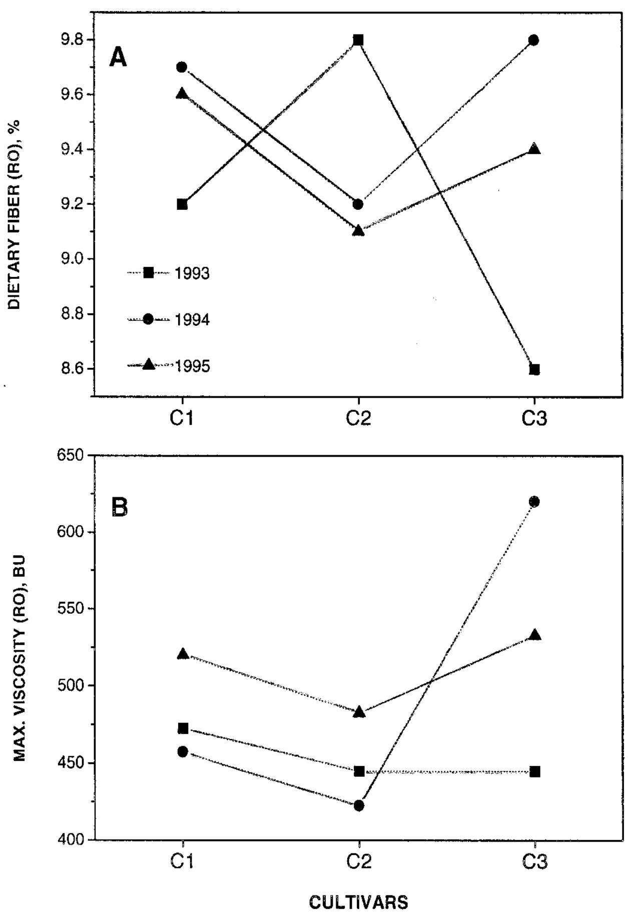

Fig 1. Dietary fiber **(A)** and maximum viscosity **(B)** levels recorded for rolled oats manufactured from sample cultivars C1, C2, and C3 in crop years 1993, 1994, and 1995.

Relationship Between Parameters in Oat Grain and Groats

Grain variables such as 1,000 grain weight, kernel size, 1,000 groat weight, and yield were interrelated ($r > 0.69$, $P < 0.05$) (Table III). Kernel size value was positively correlated with GBK variables such as groat weight ($r = 0.84$, $P < 0.001$) and the proportions of sieved GBK groats (% groats >2.5 mm, and % groats >2.2 mm), and negatively correlated with the water binding capacity (GBK) ($r = -0.80$, $P < 0.01$) and % groats <2.0 mm ($r = -0.79$, $P < 0.001$). Strong correlations between the grain (GR) and rolled oats (RO) variables were found only twice: between the grain moisture and crude fat content of rolled oats ($r = -0.77$, $P < 0.001$) and between the amount of dark and damaged grains and the maximum viscosity of rolled oats ($r = 0.76$, $P < 0.001$). Some weaker but interesting correlations were also found. Kernel size value, for instance, was negatively correlated with rolled oat parameters including β-glucan ($r = -0.50$, $P < 0.01$), water binding capacity ($r = -0.64$, $P < 0.001$), and color value a ($r = -0.66$, $P < 0.01$), and with oatmeal parameters such as total intensity of odor ($r = -0.64$, $P < 0.01$), toasted odor ($r = -0.61$, $P < 0.01$) and toasted flavor ($r = -0.62$, $P < 0.01$) (Table II). This suggests that selection of raw material according to large kernel size may not necessarily ensure positive parameters such as high β-glucan content or strong toasted aromatics in the final rolled oat product.

The protein content in grain or rolled oats did not correlate strongly ($r > 0.7$) with any of the other grain, groat (GBK, GAK), rolled oats, or oatmeal properties, which is not surprising given earlier findings. According to Welch (1995), no consistent relationship between protein and fat content has been found. A tendency toward a negative relationship between protein concentration and yield is generally expected (Burrows 1986), although various genotypes may respond differently (Ohm 1976). Peltonen-Sainio and Peltonen (1993) did not find an association between yield and protein content in a two-year study of 29 Northern oat cultivars and breeding lines. Earlier reports on an association between protein and β-glucan are somewhat controversial. Saastamoinen et al (1992a) found a negative correlation for 14 Northern genotypes in a two-year study, while Peterson et al (1995) reported a tendency to positive correlations, whereas Welch and Lloyd (1989) found no relationship between the traits. Genotypes differ in their responses (Welch 1995), which may offer one explanation for the inconsistent findings. Moreover, growing conditions also exert an influence. The data of Saastamoinen et al (1992b) showed a strong negative correlation between protein and β-glucan content when calculated using relative means of cultivars; when the environmental effects were taken into account, the correlation was positive but not significant.

Groat Variables

Most relationships between groat and other variables were associated with the falling number and water binding capacity of GBK. The falling number of GBK correlated positively with damaged starch of GBK ($r = 0.76$, $P < 0.01$), moisture and crude fat contents of RO ($r = 0.74$, $P < 0.001$ and $r = 0.73$, $P < 0.001$, respectively), and color value a of RO ($r = 0.83$, $P < 0.001$), and negatively with weight/volume of RO ($r = -0.71$, $P < 0.001$) and with oatmeal properties of toasted odor and toasted flavor ($r = -0.85$, $P < 0.001$, and $r = -0.70$, $P < 0.001$, respectively), size of swollen flake particles ($r = -0.814$, $P < 0.001$), and coarseness ($r = -0.837$, $P < 0.001$). The water binding capacity of GBK, which was negatively correlated to kernel size value (GR), was inversely related to the falling number of GBK ($r = -0.64$, $P < 0.01$), but positively related to the β-glucan content of rolled oats ($r = 0.64$, $P < 0.01$) and to the intensity of toasted odor and flavor of oatmeal ($r = 0.72$, $P < 0.001$ and $r = 0.74$, $P < 0.001$, respectively).

Relationships at Different Processing Stages

Most of the variables analyzed at different processing stages (GBK, GAK, RO) correlated strongly, indicating that the groat properties keep well during kiln drying. For instance, the correlation coefficient for maximum viscosity between GBK and GAK was $r = 0.78$ ($P < 0.001$), that between GBK and RO was $r = 0.84$ ($P < 0.001$), and that between GAK and RO was $r = 0.92$ ($P < 0.001$). Correspondingly, maltose value of GBK was correlated to that of RO with $r = 0.88$ ($P < 0.001$) and water binding capacity of GBK to that of RO with $r = 0.65$ ($P < 0.05$).

The color value *a* measured for GBK and RO correlated with $r = 0.66$ ($P < 0.01$). This was also associated also with the darkness of color perceived in oatmeal, as shown for GBK and in RO at $r = 0.84$ ($P < 0.01$) and $r = 0.75$ ($P < 0.05$), respectively. As expected, the grain size value correlated strongly with the corresponding groat size proportions in GBK with % groats > 2.5 mm ($r = 0.78$, $P < 0.001$), % groats > 2.2 mm ($r = 0.93$, $P < 0.001$), and % groats < 2.0 mm ($r = -0.79$, $P < 0.001$). These were not, however, associated with the particle size of cooked oatmeal perceived by the sensory panel.

PCA of Rolled Oat Variables

The relationships among rolled oat variables were also examined using PCA. Figure 2 displays the projection where the loadings of factor 1 (F1) and factor 2 (F2) for both rolled oat variables and cultivars are plotted on the same coordinates. The first axis (F1) accounts for 31.4% of the variance and mainly represents the fat content which is related to the amount of monounsaturated fatty acids (MUFA), and the falling number, and inversely correlated properties such as weight/volume, starch content, and damaged starch, together with the amount of polyunsaturated fatty acids (PUFA). The second orthogonal axis (F2) explains 25.8% of the data variation and is mostly associated with viscosity and structure parameters such as water binding capacity, maximum viscosity, dietary fiber, flake thickness, and the amount of damaged flake particles.

Rolled oats of cultivar C7 were the thinnest, bound the greatest amount of water, had the highest maximum viscosity, and the largest amount of β-glucan, and was therefore projected near the axis F2. Cultivar C8 had the highest fat content and falling number, and the lowest weight/volume and starch content, and was projected near the axis F1. The C1 rolled oats were the thickest and had the highest amount of starch, damaged starch, and polyunsaturated fatty acids, but had a low maximum viscosity, water binding capacity, and dietary fiber and protein content. C1 was, therefore, projected opposite C8 on the axis F1 and opposite C7 on the axis F2. Cultivar C2 differed from C1 particularly in the flake thickness and content of protein, fat, starch, and polyunsaturated and monoenic fatty acids. The rolled oats of C6, C4, and C3 were fairly similar and were located between C1 and C2 and, according to their weight/volume, starch content, fat, and polyunsaturated fatty acids, were closer to C1 than to the rolled oats of C2 or C8.

Relationships between rolled oat parameters displayed in Fig. 2 suggest that the thinner the flake, the larger the amount of water it binds, which is also associated with the higher viscosity. Rolled oats with a high falling number are also likely to have a high fat content which is associated with a large amount of monounsaturated fatty acids. The amount of fat and starch in rolled oats are inversely related, as was also reported by Peterson and Wood (1997) using high-oil oat cultivars. Our results show relationships between the fat contents and the most abundant individual fatty acids that are in agreement with those of Welch (1995). In our study, the crude fat content correlated negatively with palmitic acid ($r = -0.63$, $P < 0.01$), positively with the monounsaturated fatty acid C18:1 (oleic acid, $r = 0.71$, $P < 0.01$), and negatively with the major polyunsaturated fatty acid C18:2 (linoleic acid, $r = -0.314$, not significant).

Relationship of Rolled Oats and Oatmeal Properties

PCA was also applied to rolled oat properties and sensory properties of cooked oatmeal. The two-dimensional projection of F1 and F2 is displayed in Fig. 3 representing 66.7% of the variance of the data.

Rolled oat fat content and falling number, together with the color value *L*, were inversely related to the intensity of toasted odor and flavor, coarseness, and size of swollen flake particles perceived in the oatmeal mass, and to the color value *a* and weight/volume measured in rolled oats (Fig. 3). Similarly to Fig. 2, the properties pertaining to the structure and rolled oats interactions were pro-

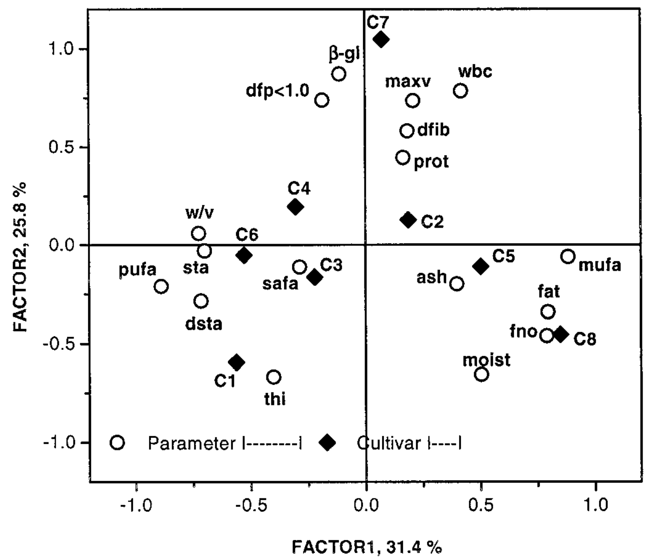

Fig. 2. Principal component analysis (PCA) projection of factor 1 and factor 2 of rolled oats (RO) properties of eight sample cultivars (C1–C8). Only parameters accounting for the largest loadings are presented. % of variance accounted by the factors. β-gl = β-glucan; dfb <1.0 = damaged flake particles; dfib= dietary fiber; dsta = damaged starch; fat = crude fat; fno = falling number; maxv = maximum viscosity; moist = moisture; mufa = monounsaturated fatty acids; prot = protein; pufa = polyunsaturated fatty acids; safa = saturated fatty acids; sta = starch; thi = thickness of flake; wbc = water binding capacity; w/v = weight/volume.

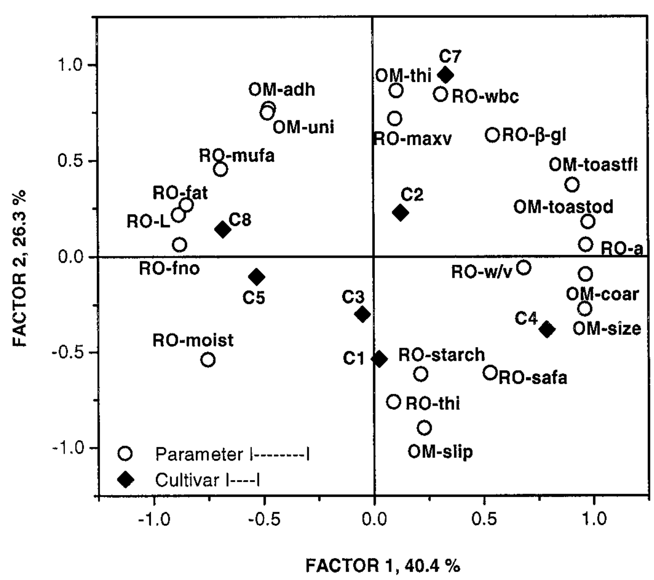

Fig. 3. Principal component analysis (PCA) projection of factor 1 and factor 2 of rolled oats (RO) and oatmeal (OM) properties of sample cultivars (C1–C5, C7–C8). Only parameters accounting for the largest loadings are presented. % of variance accounted by the factors. Sensory properties of oatmeal: OM-adh = adherence; OM-coar = coarseness; OM-size = size of swollen flake particles; OM-slip = slipperiness; OM-thi = thickness; OM-toastfl = toasted flavor; OM-toastod = toasted odor; OM-uni = uniformity of mass. Rolled oat properties: RO-a = color value a; RO-β-gl = β-glucan; RO-fat = crude fat; RO-fno = falling number; RO-L = color value L; RO-maxv = maximum viscosity; RO-moist = moisture; RO-mufa = monounsaturated fatty acids; RO-safa = saturated fatty acids; RO-thi = thickness of flake; RO-wbc = water binding capacity; RO-w/v = weight/volume.

jected on axis F2. Rolled oat starch content and flake thickness were associated with the slipperiness of the oatmeal and inversely correlated to the uniformity and adherence to spoon of the oatmeal mass. Oatmeal thickness and rolled oat maximum viscosity and water binding capacity projected close to each other.

Cultivars C8 and C5 with a high falling number and fat content were projected opposite C4 which had the strongest intensities of toasted odor and flavor, coarseness, the largest particle size perceived in the oatmeal mass, the highest color value *a*, and the greatest amount of saturated fatty acids (the cultivar differences for coarseness and particle size in the oatmeal mass were, however, not statistically significant). Differences in the other cultivars were mostly associated with the properties of axis F2; C7 had the thinnest flakes and thickest oatmeal mass and C1 had the greatest intensity of perceived slipperiness. The projection of F1 and F3 somewhat changed the mutual location of cultivars C7, C2, C3,

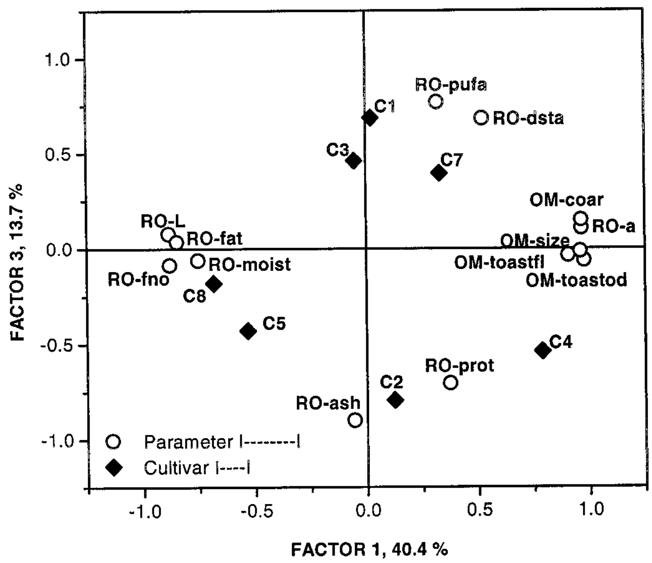

Fig 4. Principal component analysis projection of factor 1 and factor 3 of rolled oats (RO) and oatmeal (OM) properties of sample cultivars (C1–C5, C7–C8). Only parameters accounting for the largest loadings are presented. % of variance accounted by the factors. Sensory properties of oatmeal: OM-coar = coarseness; OM-size = size of swollen flake particles; OM-toastfl = toasted flavor; OM-toastod = toasted odor. Rolled oat properties: RO-a = color value a; RO-dsta = damaged starch; RO-prot = protein; RO-pufa = polyunsaturated fatty acids; RO-fat = crude fat; RO-fno = falling number; RO-L = color value L; RO-moist = moisture.

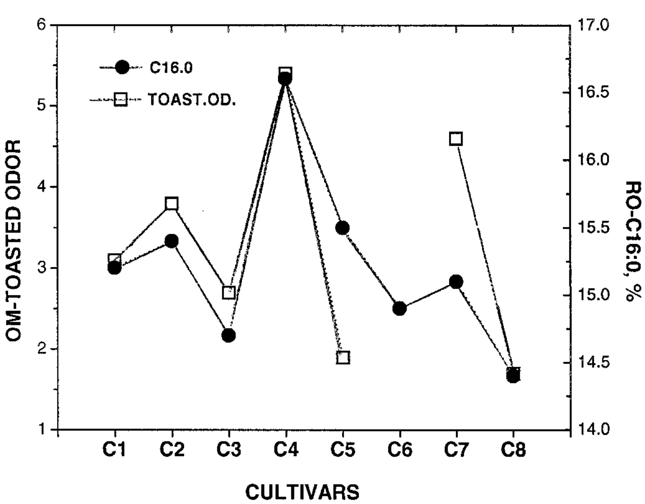

Fig 5. Association between intensity of toasted odor in oatmeal (OM) and palmitic acid (C16:0) content in rolled oats (RO).

and C1 (Fig. 4). F3 was associated particularly with protein and ash content, and with the amount of damaged starch and polyunsaturated fatty acids of rolled oats. When these properties are taken into account, C2 is projected opposite C3, C1, and C7 due to its high protein and ash content, whereas the projection of C8, C5, and C4 remains the same as in Fig. 3.

Toasted Odor

Toasted odor and flavor characteristics have been associated with nitrogen heterocycles formed from amino acids and reducing sugars by Maillard reactions (Mottram 1994). Haydanek and McGorrin (1986) suggested that Maillard intermediates react with lipid oxidation products (ketones and aldehydes possibly formed during the heat processing) leading to the formation of alkyl/alkenyl substituted pyrazines. The contribution of reducing sugars and lipids to toasted odor and flavor can also be seen with our data. Maltose value, representing reducing sugars, was positively correlated with the toasted odor ($r = 0.74$, $P = 0.09$) and toasted flavor ($r = 0.71$, $P = 0.11$) (Table III). As illustrated in Fig. 3, the intensity of the toasted odor and fat content were inversely correlated: the lower the fat content in rolled oats, the stronger the toasted odor in oatmeal ($r = -0.80$, $P < 0.001$). Low fat content was associated with relatively higher amounts of saturated fatty acids. When the intensity of toasted odor is plotted together with the content of the most abundant saturated fatty acid, C16:0 (palmitic acid), the levels of the two variables are parallel for all the cultivars (Fig. 5). Because oatmeal toasted odor and flavor were highly correlated ($r = 0.93$, $P < 0.001$), the palmitic acid content was also associated with the toasted flavor ($r = 0.63$, $P < 0.01$). As the oxidation rate of palmitic acid is fairly low, it may play only a minor role in the toasted odor formation. Nevertheless, the present data clearly shows that lipids and toasted odor/flavor characteristics are related. A low fat content in oats also tends to lead to a lowered oleic acid (C18:1) and elevated

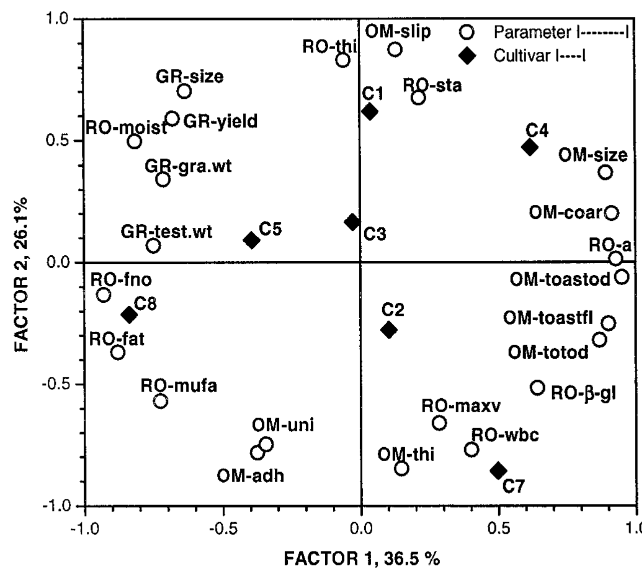

Fig 6. Principal component analysis (PCA) projection of factor 1 and factor 2 of grain (GR), rolled oats (RO) and oatmeal (OM) properties of sample cultivars (C1–C5, C7–C8). Only parameters accounting for the largest loadings are presented. % of variance accounted by the factors. Grain properties: GR-gra.wt = 1,000 grain weight; GR-size = kernel size value; GR-test.wt = test weight. Rolled oat properties: RO-a = color value a; RO-β-gl = β-glucan; RO-fat = crude fat; RO-fno = falling number; RO-maxv = maximum viscosity; RO-moist = moisture; RO-mufa = monounsaturated fatty acids; RO-sta = starch; RO-wbc = water binding capacity. Sensory properties of oatmeal: OM-adh = adherence; OM-coar = coarseness; OM-size = size of swollen flake particles; OM-slip = slipperiness; OM-thi = thickness; OM-toastfl = toasted flavor; OM-toastod = toasted odor; OM-totod = intensity of total odor; OM-uni = uniformity of mass.

linoleic acid (C18:2) content (Welch 1995). In this study, toasted odor was correlated with oleic acid at $r = –0.64$ ($P < 0.01$) and with linoleic acid at $r = 0.59$ ($P < 0.01$).

PCA of Grain, Rolled Oats, and Oatmeal Parameters

Selection of raw material for processing is based on a balance of the desired parameters that may vary according to the utilization of the final product. Figure 6 summarizes the selected properties of grain, rolled oats, and oatmeal. A good yield with balanced technological parameters can be gained with most of the cultivars studied. Rolled oat variables such as water binding capacity, β-glucan content, and maximum viscosity were projected opposite the grain yield and size. This suggests that if the rolled oats specifications require, for instance, good water binding properties, it may be advantageous to select the raw material from cultivars with the desired characteristics, such as C7, although this may need to be done at the expense of a lowered yield.

CONCLUSIONS

The present data shows cultivar differences in oat grain, groat, rolled oats, and oatmeal parameters. In many cases, crop year also profoundly influenced the parameters. In addition, many groat, rolled oats, and oatmeal variables such as crude fat (RO), maximum viscosity (GBK, GAK, RO), protein content (RO), water binding capacity (RO), color value *a* (RO), and all the fatty acids (RO), toasted odor and flavor (OM), adherence to spoon (OM), uniformity of mass (OM), and size of swollen flake particles (OM) showed a significant year by crop interaction. The grain variables were correlated with each other, though not particularly correlated with rolled oat or oatmeal variables. The protein content of grain or rolled oats did not correlate strongly with any other grain, groat, rolled oats, or oatmeal properties. In general, variables analyzed at different processing stages correlated strongly, indicating good retention of groat properties during processing.

The physicochemical parameters of rolled oats and sensory properties of oatmeal showed various associations. For instance, the crude fat content was negatively correlated to the intensity of toasted odor and flavor, indicating that oat lipids and toasted aromatics are associated. In PCA of RO and OM properties, F1 explained 40.4% of the variation and mostly represented parameters such as crude fat (RO), color values *L* and *a* (RO), toasted aromatics (OM), coarseness (OM), and size of swollen flake particles (OM). F2 accounted for 26.3% of the variance and was associated with water binding capacity (RO), viscosity (RO), flake thickness (RO), starch content (RO), thickness (OM), and slipperiness (OM) pertaining to the structure and rolled oats interactions. The cultivars were also grouped according to these properties. The results suggest that rolled oat processes deserve optimization on a cultivar basis, particularly when specific product properties such as good water binding properties are required.

Trained panelists perceived some sensory differences in oatmeal properties between the cultivars. Therefore, one future interest is to discover whether differences in the sensory properties of oatmeal made from selected cultivar can be detected by consumers.

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