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Aroma of wheat porridge and bread-crumb is influenced by the wheat variety

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ABSTRACT

Sensory evaluations were conducted on wheat-flour porridge and baked-bread samples, made from wheat varieties with known odour and flavour variations. The purpose was to determine if these odour and flavour variations were expressed in baked-bread. In all, 24 wheat varieties were used for porridge evaluation, from these eight were selected for bread evaluation. Porridge and bread results were compared. Variations were found in both evaluations. Five odour- and nine flavour descriptors were found to be common to both wheat porridge and bread. The results for two descriptors: "cocoa" and "oat porridge" were correlated between the wheat porridge and bread samples. Analysis of whole-meal and low-extraction samples revealed that the descriptors "malt", "oat-porridge", "øllebrød", "cocoa" and "grain" mostly characterized wheat bran, while descriptors for "maize", "bean-shoots", "chamomile", "umami", and "fresh grass" mostly characterized wheat endosperm. Low-extraction bread made from four different varieties also differentiated for five odour- and six flavour descriptors. These results indicate that variations in wheat flavour and odour directly affect bread flavour and odour even in low-extraction bread. This knowledge is important to the baking industry and to plant breeders as wheat aroma could possibly become a future quality parameter in breeding.

1. Introduction

Modern plant breeding methods, which became understood in the early 20th century, placed emphasis on improving yield capacity, however baking quality has also been regarded as an important parameter (Belderok, Mesdag, & Donner, 2000). Bread volume and texture are the two main baking quality parameters. These are important for consumer acceptance however bread aroma is increasingly receiving attention from consumers and producers. Therefore efforts to increase knowledge on wheat aroma variation could be of interest to the baking industry. Plant breeders may also find this knowledge useful in wheat breeding. The odours and flavours which are produced in bread result from complex interactions between several factors. These include the amount and type of ingredients used, yeast activity in the dough during fermentation, fermentation temperatures and times (Birch, Petersen, Arneborg, & Hansen, 2013; Birch, Petersen, & Hansen, 2012; Frasse, Lambert, Richard-Molard, & Chiron, 1993) and the bread baking process (Folkes & Gramshaw, 1977; Schieberle & Grosch, 1985, 1987, 1991). Sensory studies of bread crumb aroma have focussed on the impact of bread freshness contra staling (Heenan, Dufour, Hamid, Harvey, & Delahunty, 2009); (Jensen, Oestdal, Skibsted, Larsen, & Thybo, 2011; Jensen, Østdal, & Thybo, 2010) and consumer perception (Heenan, Dufour, Hamid, Harvey, & Delahunty, 2008; Hersleth, Berggren, Westad, & Martens, 2005).The contribution that wheat flour makes to bread flavour has not been so well described, although Czerny and Schieberle (2002) noted that components found in wheat flour are likely contributors to overall bread flavour. Chang and Chambers (1992) found odour and flavour differences between bread made from hard red winter wheat and hard white winter wheat. Løje, Møller, Laustsen, and Hansen (2003), made a sensory evaluation of cooked grains of cultivars of spelt, einkorn and emmer wheat and they could distinguish between the wheat species. Starr, Bredie, and Hansen (2013) found that a sensory panel could distinguish between different wheat varieties which were prepared as cooked grains, by sensory analysis. Differences in flavour between whole-meal flour and low-extraction flour may also impact on bread flavour. Heiniö, Liukkonen, Katina, Myllymäki, and Poutanen (2003) conducted a sensory evaluation of bread made from different

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milling fractions of rye, and they reported that bread made from the inner endosperm fraction of rye kernels had the mildest descriptors whereas bread made from the outer bran fraction contained the most intense flavours and aftertaste. Furthermore the same descriptors which were differentiated in the rye-flour fractions were also found to be differentiated in bread which was made from these samples. Wheat flour is the basic ingredient in bread, therefore variations in the odour and flavour of different varieties, species and landraces of wheat should be discerned in the odour and flavour of bread crumb. The aim of this paper is to investigate if it is possible to distinguish whole-meal bread made from different wheat varieties by sensory analyses. The wheat varieties used for the bread making will be selected based on sensory testing of whole-meal porridge made from 24 varieties, species and landraces as it is easier to make a porridge compared to bread. Additionally, it will also be tested if it is possible to distinguish bread made from low-extraction flour from different wheat varieties by sensory analyses.

2. Materials and methods

2.1. Wheat samples

Based on the results of sensory testing of cooked wheat grain (Starr et al., 2013) twenty four wheat samples were selected for the sensory test of whole-meal porridge and they were: spelt wheat (Oberkulmer Rotkorn), Emmer, Einkorn and Kamut (Aurion milling and baking company, Denmark); Solstice (Ian Foot, – Limagrain UK Ltd); Dragon (Per Kølster, Fuglebjerggård, Denmark); Complet (Saarzucht Firlbeck GmbH & Co., Germany); Extra Squarehead, Goldblume, Halland, Kolben, Purple Justin, Konini and Øland Wheat (Per Grupe, Mørdrupgård A/S, Denmark). Kossack, Kuban, Magnifik and Stava (Tina Henriksson, SW Seeds, Sweden); Kraka (Erik Tybirk, Nordic Seeds, Denmark); Ure (Peer Hummeluhr and descendants, Denmark); Heroldo, Hereward, Tuareg and Vinjett (Lars B. Eriksen, Sejet Plant Breeding, Denmark).

The samples were from the same batch that was used for sensory testing of cooked grain. Based on the results from the sensory evaluation of porridge eight varieties were selected for evaluation as whole-meal bread: Dragon Goldblume, Heroldo Konini, Kraka, Magnifik, Oberkulmer Rotkorn and Øland Wheat. Four of these varieties were selected for sensory evaluation of low-extraction bread: Goldblume, Konini, Magnifik and Oberkulmer Rotkorn. All grain samples were cleaned by visual assessment against a white paper background and removal of impurities. The pure grain samples were subsequently milled as whole-meal on a Quadrumat Junior Mill (Brabender OHG, Duisberg, Germany). The wheat samples which were prepared as low-extraction samples were refined through a 250 μm particle size mesh on a JEL 2000 test sieve (J.Engelsmann AG, Ludwigshafen am Rhein, Germany).

2.2. Porridge sample preparation

480 ml ordinary tap water was then added to 120 g of whole-meal or low-extraction samples in a 600 ml glass beaker and stirred until a homogeneous consistency was achieved throughout the sample. A Conmatic line Combi-steamer (Hounö A/S, Randers, Denmark), was set to full steam in order to mitigate crust formation on the top of the porridge sample. The temperature was selected to 135 °C. At this temperature, the samples, which were briefly re-stirred and then covered with aluminium foil, were placed in the oven for 23 min. After cooking the porridge samples were re-stirred to ensure a homogeneous consistency. Then the porridge was portioned out into approximately 35 g samples in FIX PACK, clear, round, 110 ml plastic beakers with lids made from a plastic material which was approved for foodstuffs. The plastic beakers were labelled with a three digit code. The sample beakers were tempered in a cooled incubator cabinet series KB8000, (Termaks A/S, Bergen, Norway) at 40 °C for 1 ½ hours before serving.

2.3. Bread sample preparation

The moisture content of the milled wheat samples was measured on the day of baking on a HOH-express He 90 moisture meter (Pfeuffer GmbH, Kitzingen, Germany). The amount of flour used for bread making was adjusted according to the water content so all the milled samples had 14 g/100 g moisture content. Bread dough was prepared thus: For whole-meal bread 300 g freshly milled whole-meal from the wheat variety being tested and 100 g commercial wheat flour “Bagerens Hvedemel” (Magdeburger Mühlenwerke GmbH, Magdeburg, Germany) were mixed. For low-extraction bread: 400 g freshly milled and sifted low-extraction flour from the variety being tested was used without adulteration. To all doughs were added: 272 ml tap water (30 °C) with the required adjustments for each sample to ensure 14 g/100 g moisture content moisture content of flour, 4 g “Malteserkors” yeast (De Danske Gærfabrikker A/S, Grenå, Denmark), 5.6.g salt, 5.6 g sugar were added. The ingredients were mixed in XBM 5 bread-mixing machines (Fovea A/S, Randers, Denmark) and the program was set to knead for 19 min. Kneading was staggered by a 2 min interval between samples to ensure that there was uniformity of sample treatment during dough kneading and placement of dough for fermentation. The kneaded doughs were transferred to baking trays, one per dough, and these were fermented at 10 °C for 18 h in a Termaks series 6000 cooling incubator (Termaks A/S, Bergen, Norway). Dough samples were then baked in a Conmatic line Combi-steamer (Hounö A/S, Randers, Denmark) for 40 min at 200 °C with full steam setting in order to minimise browning of the crust. The bread samples for sensory analysis were sliced on a Universal Metal Type 372 electric-slicer (Krups GmbH, Offenbach am Main, Germany) into one cm thick slices (Fig. 1). The crust was removed to a depth of 1 cm and discarded. The slices were cut into samples approximately 2 cm in width and portioned out into 30 g samples in 200 ml square plastic salad boxes with lids. The plastic material was approved for foodstuffs. Item number: 5181 and 5185. The plastic boxes were labelled with a three digit code. The bread samples were tempered in an incubator cabinet series KB8000, (Termaks A/S, Bergen, Norway) at 21 °C for 1 ½ hours before serving.

2.4. Sensory evaluation method

Both sensory evaluations were conducted within a two month interval, first the porridge evaluation then the bread evaluation. Evaluations took place in a sensory evaluation laboratory, which was equipped after guidelines laid down in ISO 85589:2007. One box was assigned to each assessor. The panels for this study were recruited from the external sensory panel at the University. This panel is selected based on olfaction and taste tests, their interest and motivation as well as ability to describe sensory impressions verbally (ISO 3972:1991). The external panel has experience in descriptive analysis of a range of food products.

The panellists evaluated the intensity experienced for each sensory descriptor on a continuous unstructured 15.0 cm scale line which was verbally anchored at each end with indentations. The left side of the scale corresponded to the lowest intensity of the descriptor and the right side corresponded to the highest intensity. Evaluations were registered electronically the data was collected in FIZZ Network Acquisition (Version 2.4 OE). The evaluation method used in both evaluations followed the same procedure and was

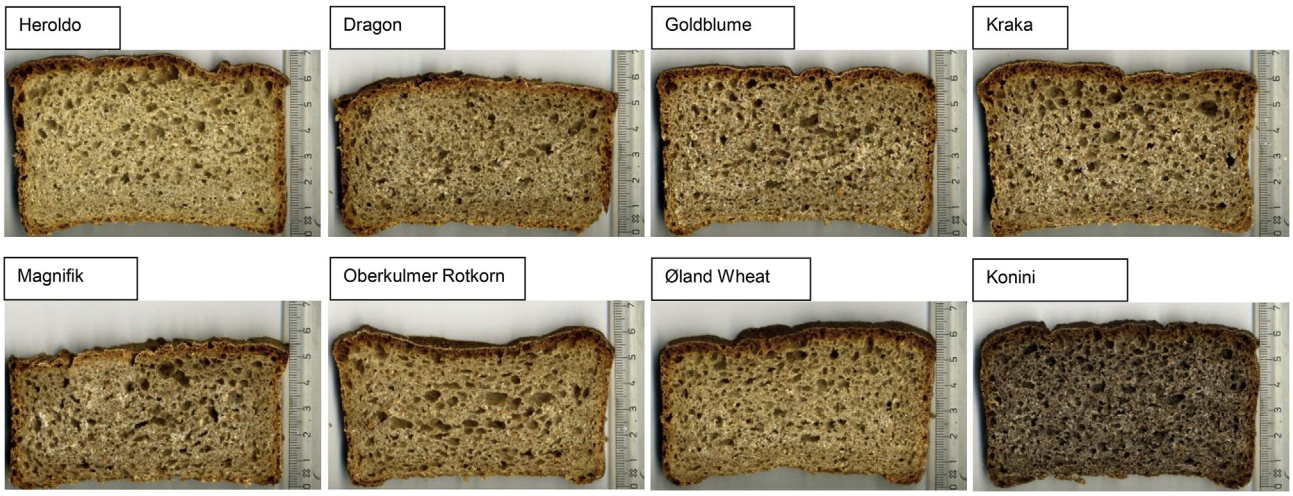

Fig. 1. Slice cross-sections of bread, which was made using eight selected varieties of wheat whole-meal and was subjected to sensory evaluation.

based on descriptive sensory analysis. Experienced panels were trained for this particular project. Panel training was conducted during the first week according to ISO guidelines (ISO 13299:2003). During four training sessions, which occurred over four days prior to evaluations, the panels suggested, discussed and finally established a set of sensory descriptors which they later used during the evaluation of the particular product. The first three days of training were used to develop the vocabulary for describing the sensory attributes and introducing ranking and scaling of intensities, the fourth day was used to train ranking and scaling. Panellists received feedback on their performance after each session in order to improve and standardize their discriminatory ability as a panel. The feedback was aimed at reaching consensus in defining each descriptor and in the span of intensities between the samples. The panellists established, by consensus, descriptors for attributes in the wheat flour porridge and the baked bread samples. The categories of attributes were odour (olfactory perception) and flavour (oral and retro-nasal perception). The descriptors and their references are listed in Table 1. During the evaluations the panellists were provided with Tap water, carbonated water and cucumber (peeled and cut in thin slices) to cleanse and refresh the mouth between each sample evaluation. As no green notes were reported in training sessions for either product cucumber was used as a palate cleanser to minimise any carry over effect. Peeled cucumber had no effect on the samples. Panellists had a minimum of 2 min between samples to cleanse their palates.

2.5. Sensory evaluation of wheat porridge

The panel consisted of 11 assessors (6 men and 5 women) with an age range between 21 and 38 years of age. An evaluation was made of 32 samples including a warm-up sample of porridge made from the variety Magnifik. This was served in three repetitions over each of the four evaluation days. The panel was thus served a reference sample and a series of 24–25 different samples following an incomplete block design. Within a session, samples were presented randomly to the assessors. Each evaluation lasted 2 h with a 10 min break.

Table 1
Sensory descriptors with references for odours and flavours found in wheat porridge and wheat bread (References which were tasted are in bold script).

Descriptors			References
Porridge	Bread	Odour/Flavour	
Maize	Maize	O/F	Fresh baby maize, 1.5 cm i each beaker **(avoid eating the stalk in the middle)**
Oat porridge	Oat porridge	O/F	Thick rolled oats "Irma økologisk balance", 2 dl oats boiled in 4.5 dl water 2–3 minutes, **(1 dl porridge oats added to 500 ml water for 5 miniutes then oats are strained off)**
Øllebrød[a]	Øllebrød[a]	O/F	1 dl Øllebrød powder "Beauvais" boiled in 3 dl boiled water for 2 min
Cocoa	Cocoa	O/F	Cocoa powder "Kend varen". 2 tsp full in each beaker
Chamomile	Chamomile	O/F	Chamomile flower, 1 tsp in each beaker **(Camomile flower water, 2 tsp camomile flowers in 200 ml boiled water for 5 min, 30 ml in each beaker)**
Malt		O/F	WEY MUNICH type 1 "Malzbazaren", 1 dl malt boiled in 5 dl water for 30 min
Beansprouts		O/F	Baby shoots from Føtex, 1tsp full in each beaker
Grain	Grain	O/F	Wholewheat flour "Finax", 1 tsp in each beaker
	Yeasty/fermented	O	Yeast
	Bulgur	O/F	Rough bulgur "Delicata". 2 dl bulgur boiled in 4 dl water for 10–12 min. One dessert spoonful per beaker
	Hazel nut	O/F	Hazelnuts roughly chopped. Approx. 4 nuts in a beaker.
	Honey	O/F	Clear Danish forest honey "Aulumgård".
	Fresh grass	O	Iceberg lettuce chopped together with lucerne shoots
Sweet	Sweet	F	**48 g/l sucrose stock solution. 12 g/l (D1 ISO:3972:1991) 250 ml stock + 750 ml water**
Sour	Sour	F	**2.4 g/l citric acid monohydrate stock solution. 0.6 g/l (D1 ISO:3972:1991) 250 ml stock + 750 ml water**
Salt	Salt	F	**8 g/l sodiumchloride stock solution. 1.4 g/l (D2 ISO:3972:1991) 175 ml stock + 825 ml water**
Bitter	Bitter	F	**0.04 g/l quinine stock solution. 0.006 g/l (D1/D2 ISO:3972:1991) = 150 ml stock + 850 ml water**
Umami		F	**4 g/l monosodium glutamate stock solution. 0.7 g/l (D2 ISO:3972:1991) 175 ml stock + 825 ml water**
Caramel		F	**Werthers original classic cream toffees, 1 caramel disolved in 100 ml boiled water. 30 ml in each beaker**

[a] A Danish porridge made from dark rye bread, malt beer, sugar, lemon peel, salt and double cream.

2.6. Sensory evaluation of wheat bread

The panel consisted of 10 assessors (3 men and 7 women) with an age range between 21 and 39 years of age. The average age of the panellists was 30. Two panellists were from the same panel that evaluated wheat porridge. An evaluation was made on 12 samples on each evaluation day including a warm-up sample which was commercial spelt bread. Six samples were served before a break of 10 min and six samples were served again after the break. Within each session samples were served in a random order. The general performance for both groups of panellists was checked using the computer program (Panelcheck v.1.3.2, Matforsk, Norway). The final statistical model for each evaluation was based on the results of the whole panel.

2.7. Statistical data analysis

A Generalized Linear Model (GLM) analysis, performed using SPSS (IBM SPSS Statistics, v.22) was used to make 2 models: an analysis of the porridge data and an analysis of the bread data. Each of the sensory attributes were analysed for their significance in discriminating the samples. Significant descriptors were selected at $P < 0, 05$ using the following model:

$\text{Attribute}_l = \alpha(\text{variety}_i) + \beta(\text{assessor}_i) + d(\text{variety}_i, \text{assessor}_i)$.

Post-hoc testing using Bonferroni-tests were performed using SPSS (IBM SPSS Statistics, v.22). The criteria for significant difference was $p > 0.05$. The results of the post-hoc tests were used to generate tables illustrating the significant differences between samples for each descriptor. Principal components analysis (PCA) was performed for 2 PCA figures using the Latentix software (LatentiX 2.0, Latent 5, Copenhagen, Denmark, www.latentix.com). The data was auto-scaled and cross-validated.

3. Results and discussion

The sensory descriptors for porridge and bread samples showing P-values, indicating the significant difference for each descriptor, by variety, are shown in Table 2. Eight odour descriptors and 13 flavour descriptors were used to describe wheat porridge. There were significant differences between the varieties for all descriptors of the whole-meal samples, and for most of the low-extraction samples, except for maize and cocoa odour, grain and beansprout flavour. Bread was described by 11 odour and 13 flavour descriptors. Many of the descriptors used to describe the whole-meal samples were significantly differentiated between the samples with the exception of chamomile, hazelnut and fresh grass odours and for the flavours of maize, chamomile, sour, salt, bitter, hazelnut and honey. The bread samples made from low-extraction flour had five odour descriptors and six flavour descriptors which were significantly differentiated between samples. A comparison of porridge and bread samples revealed five common odour descriptors and nine common flavour descriptors.

3.1. Sensory profile of whole-meal porridge

The distribution of wheat samples, based on the sensory descriptors for porridge made from whole-meal is presented in the PCA bi-plot in Fig. 2. It shows that the samples separate into those mostly described by the milder descriptors like camomile, beanshoots maize and oat porridge toward the lower middle part of the bi-plot and those samples mostly described by stronger descriptors like cocoa, malt, caramel and the descriptor for øllebrød (a Danish speciality) towards the upper-left of the bi-plot. Orthogonally positioned to these descriptors are the basic flavour descriptors for sweet, in the lower-left of the bi-plot and bitter, salt, sour and umami, towards the upper-right. The samples which are mostly described by strong descriptors are Complet, Emmer, Hereward, Konini, Kraka and Purple Justin. While milder descriptors are mostly found in Heroldo, Kolben, Kossack, Oberkulmer rotkorn, Solstice, and Øland Wheat, with other samples distributed more evenly between the two descriptor types The Einkorn sample has high values for bitterness and umami and a low value for sweetness. The sample Kamut is distinct from the rest of the samples and is placed to the right in PC2 where the influence of umami and camomile are dominant and sweetness is low. The distribution of the samples among these descriptors is similar to the order of distribution of these same samples when they were evaluated as cooked grain (Starr et al., 2013). The samples with descriptors for strong odour and flavour are more pronounced in the darker grains and the milder descriptors have higher values in the lighter grains. There are a few differences however. In the evaluation of cooked grain, Emmer and Einkorn were evaluated as being better described by mild odours and flavours but as wheat porridge they were considered by the panel to have higher values for the stronger descriptors. Another difference between the results from the evaluations of whole-meal porridge and cooked grain (Starr et al., 2013) is in the perception of sweetness contra bitterness for Kamut. When served as cooked grain Kamut was ranked very highly for sweetness. This discrepancy may be accounted for by the texture difference between porridge and cooked grain altering flavour perception or that odours and flavours released in porridge are more pronounced than in cooked grain. The eight samples which are marked in bold grey script (Fig. 2) indicate the samples which were also evaluated as bread. Mean evaluation values for these samples are shown in Table 3.

From these results it is possible to differentiate samples of whole-meal porridge made from different varieties and species by sensory evaluation. Furthermore that differentiation is largely consistant with that seen in cooked wheat grain (Starr et al., 2013).

3.2. Sensory profile of whole-meal bread

A PCA model (Fig. 3) was constructed based on the bread samples showing a bi-plot with wheat varieties as scores and significant sensory descriptors as loadings. The first principal component (PC1) explained 52.7% of the variation in the data and the second principle component (PC2) explained 20.1% of the variation giving a total explained variance of 72.8% for a two component model. The samples are separated along PC1 into two groups of whole-meal and low-extraction samples, which accounts for the high amount of variation being explained by PC1. However PC1 also accounts for variation in odour and flavour differences in the bread samples. The bread samples made from whole-meal marked (-W) are mostly described by stronger flavours and odours of grain, hazelnut, øllebrød, cocoa, bitter, sour and salt. The separation of the bread samples along PC2 is mostly explained by the odour of yeasty/fermented and honey odour and flavour. Bread made from Heroldo-W is associated with descriptors for grain, fermented/yeasty, oat porridge and bulgur, while Goldblume-W and Konini-W are associated with descriptors for honey, cocoa, øllebrød, sour and bitter. This distribution of whole-meal bread samples in relation to the descriptors follows the same pattern of distribution for these samples as was seen in the porridge samples and in the grain samples in Starr Bredie, & Hansen (2013). It is therefore possible to differentiate samples of whole-meal bread made from different varieties and species by sensory evaluation. The bread samples made from low-extraction wheat flour are marked (-S) and they are found on the right of the bi-plot (indicated with an oval), where they are mostly associated with descriptors for the odour and flavour of maize, bulgur, oat porridge and sweet. These samples will be discussed further in Section 3.5.

Table 2
Descriptors for porridge and bread samples indicating significant variation in values between wheat variety samples. Non-sigificant descriptors are marked NS.

Porridge	Whole-meal	Low-ext. flour	Bread	Whole-meal	Low-ext. flour
Odour	p-value[b]	p-value[b]	Odour	p-value[b]	p-value[b]
Maize	<0.0001	NS	Maize	0.026	0.025
Oat porridge	<0.0001	<0.0001	Oat porridge	<0.0001	0.001
Øllebrød[a]	<0.0001	<0.0001	Øllebrød[a]	<0.0001	<0.0001
Cocoa	<0.0001	NS	Cocoa	<0.0001	<0.0001
Chamomile	<0.0001	<0.0001	Chamomile	NS	NS
Malt	<0.0001	0.005			
Beansprouts	0.007	<0.0001			
Grain	<0.0001	<0.0001	Grain	<0.0001	0.029
			Yeasty fermented	0.008	NS
			Bulgur	<0.0001	NS
			Hazelnut	NS	NS
			Honey	0.011	NS
			Fresh grass	NS	NS
Porridge	whole-meal	low-ext. flour	Bread	whole-meal	Low-ext. flour
Flavour	p-value[b]	p-value[b]	Flavour	p-value[b]	p-value[b]
Maize	<0.0001	0.001	Maize	NS	0.05
Oat porridge	<0.0001	0.011	Oat porridge	<0.0001	NS
Øllebrød[a]	<0.0001	<0.0001	Øllebrød[a]	<0.0001	0.009
Chamomile	<0.0001	<0.0001	Chamomile	NS	NS
Grain	<0.0001	NS	Grain	<0.0001	NS
Sweet	<0.0001	<0.0001	Sweet	0.031	<0.0001
Sour	<0.0001	<0.0001	Sour	NS	0.015
Salt	<0.0001	<0.0001	Salt	NS	NS
Bitter	<0.0001	<0.0001	Bitter	NS	NS
Beansprouts	<0.0001	NS			
Umami	<0.0001	<0.0001			
Malt	<0.0001	<0.0001			
Caramel	<0.0001	<0.0001			
			Bulgur	<0.0001	NS
			Hazelnut	NS	NS
			Honey	NS	<0.0001
			Cocoa	<0.0001	<0.0001

[a] A Danish porridge made from dark rye bread, malt beer, sugar, lemon peel, salt and double cream.
[b] p-Values lower than 0.05 indicate that there are significant differences between samples for that descriptor.

3.3. Comparison of whole-meal porridge and corresponding bread samples

Mean values of the odour and flavour descriptors of the eight whole-meal samples of porridge corresponding by variety to the eight whole-meal bread samples are compared in Table 3. The odour descriptors which are common to porridge and bread show that maize odour was evaluated higher in porridge than bread as were most samples for chamomile odour with the exception of Kraka. The odour descriptors for oat porridge, øllebrød, cocoa and

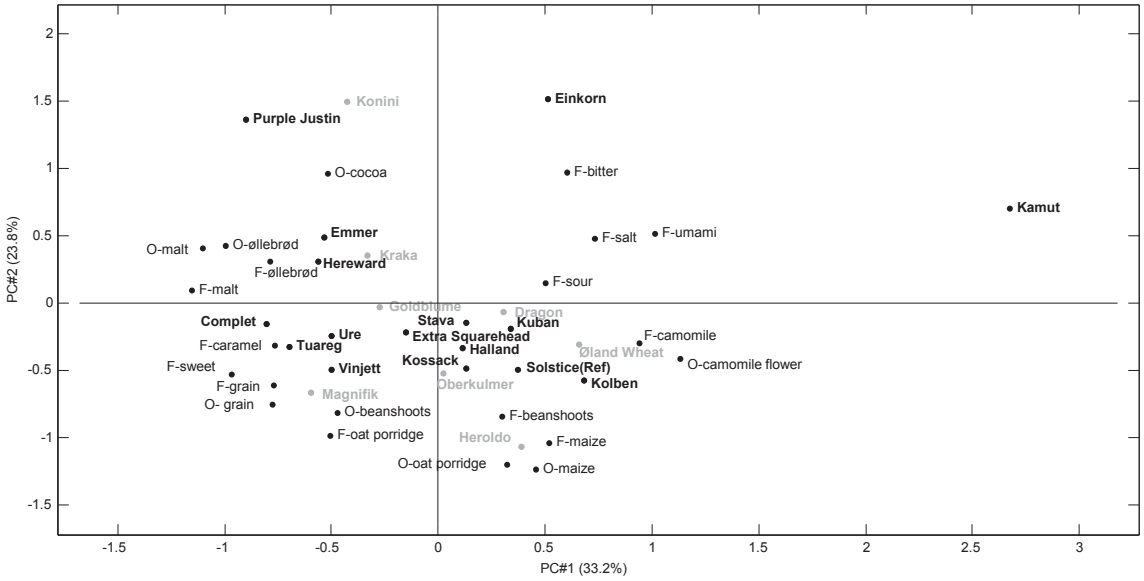

Fig. 2. Differentiation of wheat samples based on sensory evaluation of wheat porridge presented as a PCA bi-plot. Descriptors for odour (O) and flavour (F) are shown as loadings. Wheat samples (bold script) are shown as scores. Wheat samples which were selected for further evaluation as bread are indicated in bold grey script.

Table 3
Mean values of evaluations for each odour and flavour descriptor in samples of eight wheat varieties served as wheat whole-meal porridge and bread.

Odour	Drag	Gold	Hero	Koni	Krak	Magn	Ober	Ølan	P-value	Flavour	Drag	Gold	Hero	Koni	Krak	Magn	Ober	Ølan	P-value
Porridge samples																			
maize	5.5	5.7	7.3	4.1	5.5	6.3	6.5	7.1	<0.0001	maize	6.2	5.3	6.9	4.3	4.5	5.8	6.4	6.1	<0.0001
beanshoots	5.3	5.8	6.2	5.1	5.2	5.2	5.2	5.6	NS	beanshoot	6.1	5.5	5.7	4.5	5.0	4.8	5.4	6.3	<0.0001
oat porridge	4.6	4.6	5.4	3.4	4.9	5.4	5.0	5.6	<0.0001	oat porridge	6.1	5.1	5.8	4.9	5.4	5.9	6.1	5.1	0.026
øllebrod	5.2	5.7	3.8	5.5	6.1	5.1	5.3	4.7	<0.0001	øllebrod	5.3	4.8	3.6	4.3	5.4	4.3	4.5	4.8	0.003
malt	5.9	6.2	4.5	6.7	6.8	5.9	6.3	6.4	<0.0001	malt	5.4	5.8	5.3	5.5	5.0	5.4	5.4	4.7	NS
cocoa	3.4	3.4	2.6	5.6	3.1	2.7	2.5	3.1	<0.0001	caramel	3.7	5.0	4.8	3.8	3.6	6.3	5.5	3.5	<0.0001
chamomile	5.2	4.5	4.9	3.5	3.9	4.1	5.0	5.2	0.001	chamomile	6.2	5.8	5.5	4.7	4.1	4.8	5.7	5.4	<0.0001
grain	6.2	5.3	6.2	5.1	6.0	6.7	6.4	6.1	NS	grain	8.1	8.3	7.8	7.9	7.8	8.0	6.6	8.7	0.001
										umami	5.5	3.7	4.5	5.3	5.0	3.2	4.8	7.5	<0.0001
										sour	3.5	3.1	3.1	2.9	2.8	2.4	3.2	4.1	<0.0001
										salt	3.7	2.8	3.4	2.7	3.3	2.5	3.0	3.3	<0.0001
										sweet	8.9	9.6	10.0	6.6	8.0	12.4	11.5	6.8	<0.0001
										bitter	3.7	3.1	3.0	3.7	2.9	2.7	3.2	4.0	0.002
Bread sample																			
maize	4.5	3.0	3.9	3.7	3.9	4.1	3.6	4.7	0.007	maize	3.7	3.9	4.5	5.3	4.5	4.0	3.2	3.8	0.041
bulgur	4.9	4.0	7.2	4.6	6.2	6.2	6.1	5.9	<0.0001	bulgur	6.7	4.1	7.8	5.3	6.1	6.6	5.9	6.6	<0.0001
oat porridge	5.2	5.3	6.8	3.6	6.4	6.4	6,3.	6.8	<0.0001	oat porridge	6.1	5.8	7.6	4.5	6.6	7.0	6.0	6.7	<0.0001
øllebrod	8.7	8.9	6.1	9.1	7.3	7.3	6.9	6.9	<0.0001	øllebrod	7.4	7.4	5.0	8.0	6.1	5.5	6.7	6.4	<0.0001
hazelnut	4.9	5.0	4.8	5.1	5.1	4.9	4.7	4.9	NS	hazelnut	4.8	4.2	4.8	5.3	4.9	4.3	3.8	5.1	0.024
cocoa	5.9	6.5	6.1	10.2	5.6	6.0	5.5	6.0	<0.0001	cocoa	5.1	4.1	3.6	8.5	4.2	4.3	4.9	3.7	<0.0001
chamomile	3.9	3.9	4.0	3.4	4.2	3.5	4.1	4.1	NS	chamomile	3.6	3.5	5.2	4.0	3.7	3.9	4.1	4.2	NS
grain	7.8	7.9	9.6	6.5	9.4	8.6	8.7	7.6	<0.0001	grain	8.7	10.0	8.5	7.0	8.0	8.3	7.0	7.8	0.02
honey	4.9	5.3	4.8	7.2	5.3	4.4	5.4	5.7	NS	honey	3.5	5.1	4.3	5.0	4.1	4.4	4.0	4.2	0.002
yeasty/fermented	6.9	6.3	7.9	5.3	7.5	7.0	8.4	7.2	0.022	sour	6.9	7.3	5.7	6.9	6.2	5.9	7.4	6.5	0.043
fresh grass	4.8	4.8	4.4	2.9	4.2	4.0	4.1	4.5	0.004	salt	6.9	6.7	6.6	6.7	6.5	7.2	7.3	7.0	NS
										sweet	5.2	7.1	6.0	5.8	5.9	6.6	5.8	5.1	<0.0001
										bitter	7.1	7.0	6.9	8.1	6.6	6.6	6.0	7.4	0.024

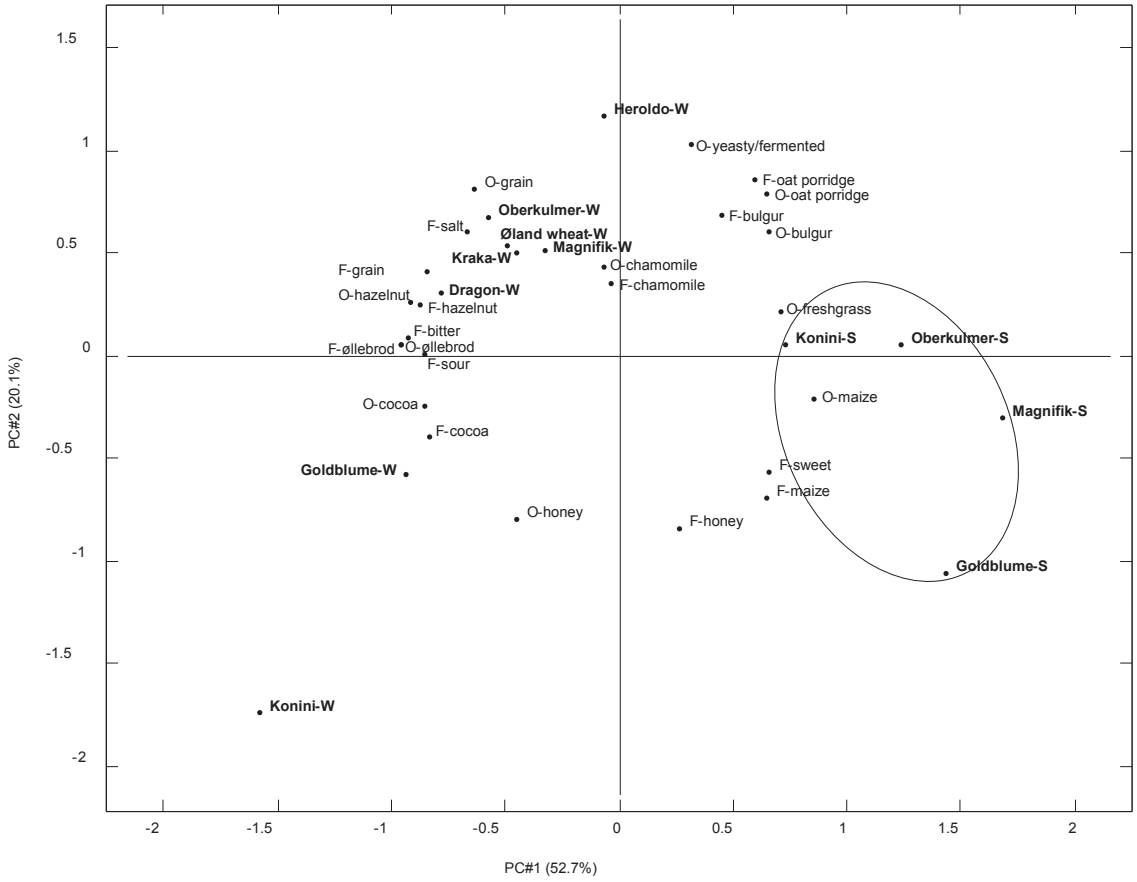

Fig. 3. Bread samples of whole-meal flour (-W) and low-extraction wheat flour(-S) and their descriptors shown in a PCA bi-plot with wheat bread samples as scores (Bold script) and odour (O-) and flavour (F-) descriptors as loadings. Low-extraction samples are disributed within a smaller area indicated by an oval.

grain are all evaluated as being higher in bread. In particular the odour descriptors for "oat porridge" and "cocoa" were found to have correlation coefficients of 0.97 and 0.95 respectively between porridge and bread (data not shown) indicating that these two distinguishing odour descriptors from wheat porridge made from the same wheat samples were directly repeated in the same order in bread samples. For the common flavour descriptors the same tendency is repeated with maize and chamomile flavour having mostly higher mean values in porridge samples. Chamomile variation in bread samples was also found to be non-significant while it was significantly differentiated in porridge. This may be attributed to the baking process causing an evaporation of the volatile compounds responsible for this descriptor. Oat porridge, øllebrød and grain still having mostly higher mean values in bread. Cocoa flavour was generally lower than cocoa odour in the bread samples, and it was not described in porridge samples. Sweet flavour is very high in the porridge samples compared to bread, and conversely sour, salt and bitter flavours are much higher in bread than in porridge. This is to be expected as fermentation reduces sweetness and increases sourness. A reduction in sweetness may increase any perception of bitterness and of salt, which is present in bread dough. The differentiation which can be seen between samples evaluated as whole-meal porridge can also be seen in whole-meal bread. This means that porridge can be used as a medium to screen sensory differences between wheat varieties.

3.4. Whole-meal and low-extraction flour used in porridge and bread

A comparison of the mean values of the descriptors for all wheat samples used for both low-extraction- and whole-meal porridge and bread (Table 4), shows that there is a significant difference between low-extraction flour and whole-meal samples for most of the sensory descriptors in both porridge and bread. However, there are non-significant exceptions: bitter and caramel flavour in porridge and yeasty/fermented odour, chamomile odour and flavour and honey flavour in bread. The significantly differentiated descriptors which are common to porridge and bread samples: maize, øllebrød, cocoa, sour and grain odours and flavours display a similarity of difference between samples of low-extraction flour and whole-meal in both bread and porridge (Table 4). Therefore these descriptors must be directly contributed to bread by the wheat flour. The descriptors for oat-porridge, øllebrød, malt, cocoa and grain, have significantly higher mean values in whole-meal mean samples than in low-extraction wheat samples when served as wheat flour porridge. This suggests that the elements which are contributing to these descriptors are mostly in the bran. However in bread samples; the mean values of oat porridge odour and flavour are higher in the samples made from low-extraction flour than from whole-meal. This discrepancy might be accounted for by the fermentation/baking processes which are involved in making bread. The descriptor for sweet flavour in porridge shows that the whole-meal samples are significantly sweeter, than low-extraction wheat samples while bitterness is unaffected by the removal of bran (Table 4). In bread samples however the removal of bran seems to account for an enhanced perception of sweetness in low-extraction bread as well as a significant reduction in bitterness which was also observed by Chang and Chambers (1992). Some descriptor mean values like maize, bean-shoots, chamomile, umami and fresh grass are higher for low-extraction flour samples than for whole-meal samples which indicate that they are present mostly in the endosperm. These findings are similar to those found in rye (Heiniö et al., 2003), and indicate that just as for rye, wheat-bran contains more intense flavours, while the endosperm has generally milder flavours. Descriptors which occur in bread but not in porridge and were significantly affected by bran removal include: bulgur, hazelnut and fresh grass. The descriptors for bulgur were previously identified in a sensory study of cooked wheat grains (Starr et al., 2013). They are significantly enhanced by bran removal. The descriptor for hazelnut flavour is significantly higher in whole-meal. Fresh grass odour in bread is significantly higher in low-extraction samples.

3.5. Differentiation between bread made from low-extraction flour

In the sensory evaluation of bread made from low-extraction flour, 11 odour and flavour descriptors differentiated the samples (Table 5). Among the wheat samples which were evaluated as low-extraction flour bread it was observed that Konini was significantly different to the other samples for odour of øllebrød and flavour of cocoa it was also significantly higher for odour of cocoa and flavour of øllebrød than Magnifik as well as odour of grain. Goldblume had a significantly higher value than the other samples for flavour of honey and significantly higher flavours of sweetness and sourness than did Konini and Oberkulmer Rotkorn. It ranked significantly lowest among all samples for odour of oat porridge. Oberkulmer Rotkorn was significantly lower than Magnifik for flavour of maize and significantly higher than Konini for odour of maize. Bread baked with low-extraction Konini flour could be characterized as having darker, richer characteristics while bread made from low-extraction Goldblume flour had a sweeter, more honeyed character. Low-extraction bread from both Magnifik and Oberkulmer Rotkorn had milder characters and they were more similar to each other except for Magnifik having a more maize-like character. In conclusion the diversity in odour and flavour, between the wheat varieties could be detected in bread baked with low-extraction flour by a trained sensory panel.

3.6. General comments

In porridge, water and heat cause the starch present in the wheat flour matrix to gelatinise. This facilitates greater molecular mobility, thus releasing more flavours and odours from the flour/water matrix (Goesaert et al., 2005). Porridge is therefore a good standard for comparing odour/flavour differentiation in bread made from the same flour. Furthermore porridge is a cheaper, easier alternative to bread especially when testing with small quantities. These findings indicate that there is a potential for using wheat porridge as a surrogate for bread when testing flavour differences between wheat varieties. Supplementing the whole-meal flour in all of the whole-meal bread samples with the same commercial low-extraction flour improved the baking quality of the whole-meal dough by mitigating the detrimental effect of bran to bread volume (Lai, Hoseney, & Davis, 1989). This also ensured a similarity of bread texture. During baking, the steam function was applied in order to minimize crust formation and to reduce the formation of Maillard aroma compounds which could migrate into the crumb and influence odour and flavour.

The large variation among sensory descriptors in low-extraction bread indicates that there is an exploitable potential for odour and flavour variation in commercially produced white breads. Further studies should investigate bread volatile profiles and compare with sensory results, more wheat varieties for flavour/odour variation and consumer preference testing made on them. It should be pointed out that the panels selected a mixture of broad and narrow descriptors to describe both porridge and bread some of which, caramel and hazelnut, are corroborated in a lexicon of French bread descriptors (Hayakawa, Ukai, Nishida, Kazami, & Kohyama, 2010). However some of the descriptors which are used in this paper, although they too were identified by the panellists used by

Table 4
A comparison of the means of evaluation values between all whole-meal & Low-extraction samples in poridge and bread. P-values indicate the significant difference between sample groups. NS denotes non-significance.

Odour	Whole-meal	Low-ext. lour	P-value	Flavour	Whole-meal	Low-ext. lour	P-value
Porridge							
O-maize	6.0	7.4	<0.0001	F-maize	5.7	7.5	<0.0001
O-beanshoots	5.4	7.6	<0.0001	F-beanshoot	5.4	6.8	<0.0001
O-oat porridge	4.8	3.8	<0.0001	F-oat porridge	5.6	3.8	<0.0001
O-øllebrod	5.2	1.4	<0.0001	F-øllebrod	4.6	1.1	<0.0001
O-malt	6.1	2.9	<0.0001	F-malt	5.3	2.6	<0.0001
O-cocoa	3.3	1.8	<0.0001	F-caramel	4.5	4.3	ns
O-chamomile	4.5	5.9	<0.0001	F-chamomile	5.3	6.7	<0.0001
O-grain	6.0	4.3	<0.0001	F-grain	7.9	4.3	<0.0001
				F umami	4.9	5.5	0.004
				F-sour	3.1	2.7	0.028
				F-salt	3.1	2.8	0.003
				F-sweet	9.2	8.1	<0.0001
				F-bitter	3.3	3.2	ns
Bread							
O-maize	3.9	6.0	<0.0001	F-maize	4.1	5.6	<0.0001
O-bulgur	5.6	6.6	<0.0001	F-bulgur	6.1	6.6	<0.0001
O-oat porridge	5.9	6.9	<0.0001	F-oat porridge	6.3	6.9	<0.0001
O-øllebrod	7.6	2.7	<0.0001	F-øllebrod	6.6	1.9	<0.0001
O-hazelnut	4.9	3.6	<0.0001	F-hazelnut	4.6	2.8	<0.0001
O-cocoa	6.5	3.8	<0.0001	F-cocoa	4.8	2.6	<0.0001
O-chamomile	3.9	3.6	ns	F-chamomile	4.0	3.8	ns
O-grain	8.3	5.5	<0.0001	F-grain	8.2	3.5	<0.0001
O-honey	5.4	5.0	0.037	F-honey	4.3	4.8	ns
O-yeasty/fermented	7.1	7.1	ns	F-sour	6.6	4.8	<0.0001
O-fresh grass	4.2	5.0	<0.0001	F-salt	6.9	6.1	0.001
				F-sweet	5.9	7.6	<0.0001
				F-bitter	7.0	4.6	<0.0001

Table 5
Differentiation found in odour (O-) and flavour (F-) descriptors for samples of low-extraction bread.[a]

O-oat porridge		O-cocoa		O-øllebrød		O-maize	
Wheat variety	Mean	Wheat variety	Mean	Wheat variety	Mean	Wheat variety	Mean
Magnifik	7.6 a	Konini	5.7 a	Konini	3.9 a	Oberkulmer	6.4 a
Konini	7.2 a	Oberkulmer	4.3 ab	Goldblume	2.6 b	Magnifik	6.3 ab
Oberkulmer	7.2 a	Goldblume	2.8 bc	Oberkulmer	2.3 b	Goldblume	6.2 ab
Goldblume	5.6 b	Magnifik	2.3 c	Magnifik	1.8 b	Konini	5.2 b
O-grain		**F-honey**		**F-cocoa**		**F-øllebrød**	
Wheat variety	Mean	Wheat variety	Mean	Wheat variety	Mean	Wheat variety	Mean
Konini	6.4 a	Goldblume	6.3 a	Konini	3.9 a	Konini	2.5 a
Oberkulmer	5.4 ab	Magnifik	4.5 b	Goldblume	2.4 b	Goldblume	1.9 ab
Goldblume	5.3 ab	Oberkulmer	4.3 b	Oberkulmer	2.4 b	Oberkulmer	1.8 ab
Magnifik	5.1 b	Konini	4.2 b	Magnifik	1.6 b	Magnifik	1.3 b
F-sweet		**F-sour**		**F-maize**			
Wheat variety	Mean	Wheat variety	Mean	Wheat variety	Mean		
Goldblume	9.5 a	Goldblume	5.1 a	Magnifik	6.3 a		
Magnifik	8.3 ab	Magnifik	5.1 a	Goldblume	6.2 ab		
Oberkulmer	6.8 bc	Konini	4.9 ab	Konini	5.1 ab		
Konini	5.9 c	Oberkulmer	4.0 b	Oberkulmer	5.0 b		

[a] Tukey b post-hoc test used: unshared letters indicate significant difference between samples.

Hayakawa et al., (2010) during initial sampling, are quite broad and could be further discriminated by a trained panel. These broader descriptors however were adequate for the purpose of these evaluations although any future sensory evaluations ought to be conducted with a focus on narrowing these descriptors further. Furthermore future sensory evaluations of bread baked with different varieties ought to be conducted using ordinary bread recipes in order to determine if any differences between varieties are directly commercially exploitable. The finding of differentiation between bread baked with low-extraction wheat from different varieties, reported in this paper, would suggest that this outcome may be likely. Therefore these findings should be of interest and importance to the baking industry, and plant breeders.

4. Conclusion

Porridge and bread made from different wheat varieties are significantly differentiated for odour and flavour descriptors. Five odour- and nine flavour descriptors are common to wheat porridge and bread. Furthermore variations in descriptors for “cocoa” and “oat porridge” correlate between wheat porridge and bread samples. These odours and flavours must be directly contributed to

bread from the wheat flour. This indicates that wheat variety influences bread aroma and that wheat porridge can be used as a surrogate for investigating the sensory contribution of wheat flour to bread. The descriptors for “malt”, “oat porridge”, “øllebrød”, “cocoa” and “grain” are highest in whole-meal samples and so mostly characterize bran. While descriptors for “maize”, “bean-shoots”, “chamomile”, “umami” and “fresh grass” are higher in low-extraction flour and must be more characteristic of wheat endosperm. Bread made from low-extraction flour was found to be significantly differentiated for five odour and six flavour descriptors between bread samples made from 4 different wheat varieties. This shows that odour/flavour variation also occurs in plain white bread depending on the variety of wheat used as flour.

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