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Sensory profiles of cooked grains from wheat species and varieties

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ABSTRACT

To assess differentiation in the flavour and odour properties of cooked wheat grain by sensory evaluation, 24 wheat samples representing different species, landraces and cultivars of wheat were served to a trained sensory panel. Descriptors were established by trained panellists to describe odour, flavour, appearance and texture attributes. Analysis of variance revealed significant differences in 7 out of 11 odour descriptors, in 7 out of 10 flavour descriptors, in 3 out of 3 appearance descriptors and in 4 out of 4 texture descriptors. A *post-hoc*, Bonferroni *t*-test revealed that many wheat varieties are significantly different from each other in odour and flavour profiles. Using Principal Component analysis, a distribution trend of the wheat samples was observed with ancient wheat species, landraces and older cultivars of bread wheat where dominated by descriptors of oat porridge and bulgur, while more recent cultivars were described by descriptors of wild rice, cooked malt, bitter, cocoa, vanilla, sweet and the Danish speciality "øllebrød". Correlations between sensory descriptors showed that grain darkness and hardness were positively correlated with descriptors for cocoa, cooked malt and øllebrød; meanwhile, bulgur correlated negatively. Bitter flavour positively correlated to dark appearance. These results may be useful to future plant breeding efforts.

1. Introduction

In recent years, flavour parameters of wheat (*Triticum* spp.) have become more important as criteria in consumer selection, as the quality of locally grown cereals have received more attention through modern culinary developments such as in the "New Nordic Cuisine" but also the "New Nordic Diet" (Mithril et al., 2011), in which wheat, in the form of cooked grains, is often used as the staple component of a meal. Cooked durum is widely used for bulgur as a staple food in the Mediterranean area. Up to now, wheat sensory properties have not been systematically included as quality parameters in the selection of new wheat varieties. Wheat is a temperate staple crop of global importance with 684.6 million metric tons produced in 2008–9 (FAO, 2011). As one of the founder crops of the agricultural revolution, wheat has evolved from its wild origins in the Middle East, to domestication over the last 11,000 years (Diamond, 1997). Wheat has evolved during its cultivation history (Reif et al., 2005), undergoing two significant hybridisation events, which ultimately led to the emergence of modern bread wheat (Haudry et al., 2007). Wheat domestication led to a diversity bottleneck (Haudry et al., 2007) which resulted in the evolution of landrace cultivars which were adapted to specific local conditions (Reif et al., 2005). Until the late nineteenth century, most cultivated wheat varieties in northern Europe were landraces (Belderok, 2000). From these landraces the first early selections were made, often by crossing local landraces with a landrace from another area (Lupton, 1987). After the rediscovery of Mendelian laws, in the early 20th century, an increased understanding of genetics resulted in modernized breeding programs across Europe. Wheat breeding focussed on improving yield capacity, disease resistance, stress tolerance and also milling and baking qualities (Belderok, 2000).

Concerns have been expressed that modern selection programs have exasperated the narrowing of the genetic base of newer wheat varieties, as the tendency in wheat breeding has been to propagate further on successful varieties which are genetically related (Tanksley, and McCouch, 1997). Reif et al. (2005) confirmed that this had indeed been the case between the years 1950 and 1989. However, they also reported that there had been a reversal of this tendency, at least for spring wheat, between 1990 and 1997, though only after deliberate intervention by breeders at the International Maize and Wheat Improvement Centre CIMMYT to introduce novel wheat material. The introduction of aroma/flavour quality as a new breeding criterion could possibly contribute towards broadening

Abbreviations: ANOVA, analysis of variance; PCA, Principal Components Analysis.

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genetic diversity of modern bread wheat, by causing future plant breeders to re-evaluate and incorporate novel genetic material. Although little attention has been paid to the importance of wheat flavour, the following steps have already been taken which have laid the foundation of this current work. Czerny and Schieberle (2002) showed significantly higher concentrations of some aroma compounds in whole-meal flour when compared to milled white flour. They isolated several odour-active compounds from the two flour types, and compared them. They then cross-referenced this data with published results of aroma compounds which had previously been isolated in bread crumb. They found that compounds which they had isolated in the wheat flour had also previously been identified as important contributors to the aroma of wheat bread crumb (Grosch and Schieberle, 1997; Schieberle, 1996). This led to their conclusion that wheat flour was an important source of bread odorants and that the type of flour used to make bread should be an influencing factor in the aroma quality of wheat bread. Løje et al. (2003) carried out a sensory test of cooked wheat grains from cultivars of the ancient wheats Einkorn, Emmer, and Spelt wheat as well as a bread wheat cultivar. A difference was reported between the Einkorn samples for the assigned descriptors of maize aroma and maize taste, which characterized these samples. The descriptor “hot oatmeal porridge” was found to be more intense in the Einkorn samples than in the bread wheat variety. The Einkorn samples were also reported as being generally sweeter than the other samples. The results of these previous studies (Czerny and Schieberle, 2002; Løje et al., 2003) suggest that there is a potential for aroma and flavour diversity in wheat. If this is the case, then it could be worth re-evaluating the qualities of older and obsolete varieties and landraces which are currently stored in gene-banks, and compare their flavour characteristics with bread wheat varieties. Up to now, no work has been conducted on the flavour differences among wheat varieties. It would therefore be of great value to systematically investigate wheat species as well as cultivars for their flavour attributes, as a tool to establish any differentiation between varieties, but also in order to understand the potential for production of aromatic, high quality bread wheat in both modern wheat varieties and older landraces. This could provide future breeding programs with the knowledge needed to improve or specialise new varieties or to select or deselect for specific aroma traits.

The objective of this work was to make an assessment of the sensory properties of different wheat varieties with an emphasis on flavour and aroma and to establish methodologies for future work in this area. The results of this study are intended to supplement future instrumental analysis of wheat and bread flavour. Cooked grains were used for the sensory evaluation as they provide the panellists with a wheat sample which has not received any other additions or undergone any other process than cooking.

2. Materials and methods

Cooked whole wheat grains from 24 different wheat samples were served to a trained panel of assessors for sensory evaluation. The samples that were tested were from the ancient wheat species: Einkorn, Emmer, Khorasan and Spelt wheats, as well as from landraces and modern bread wheat varieties.

2.1. Wheat samples

The wheat samples were all cultivated in the same harvest year (2009). The samples were obtained from different sources in northern Europe and were cultivated at different locations in Denmark, Sweden, Germany and the UK. Two of the Danish locations provided multiple samples: 7 samples were grown in the same field from one source in northern Zealand and 4 samples were grown in the same field from the source in northern Jutland. The Swedish source provided 4 samples but it was not possible to confirm that they had been grown in the same field.

The following wheat samples were used for sensory profiling: 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). Upon receipt, all grain samples were measured for moisture content on an HOH-Express HE90 (Pfeuffer GmbH, Kitzinger, Germany) to ensure that moisture content was less than 14%. This was done to minimise the risk of samples developing mould. The wheat grains were then stored at 5 °C. Information on taxonomy, pedigree and release dates of the tested wheat varieties are presented in Table 1.

2.2. Sample preparation

The grain samples were visually assessed against a white paper background and all visible impurities were removed, 80 g grains were then rinsed three times in cold water to remove any residual impurities before being placed in a 600 ml glass beaker. To the 80 g grain samples, 320 ml ordinary tap water was then added, a ratio of 4:1 for all samples except for Emmer, Spelt and Einkorn wheat to which only 240 ml water was added to 80 g grains, a ratio of 3:1, in accordance with the protocol established by Løje et al. (2003). A Combi-steamer (manufacturer: Conmatic line, Houno, Brønnum) was set to full steam and the temperature was selected to 135 °C. When the selected temperature was reached, the glass beakers containing the samples were placed in the oven.

Optimal cooking times for de-hulled whole wheat kernels were established by Løje et al. (2003). Einkorn and Emmer were cooked for 45 min, whereas Spelt wheat was cooked for 55 min and the remaining bread wheat samples were cooked for one hour and 10 min. The variance in cooking times is due to the variance in grain sizes between varieties. Larger grains needed more cooking than smaller grains to reach an acceptable sensory consistency (*al dente*) at which the cooked grains were firm yet with no hard particles present. These cooking times ensured that the samples all reached this basic texture. After cooking, the excess water was drained from the cooked grain sample and the samples were then placed on ice prior to sensory evaluation.

2.3. Sensory analysis

The cooked whole wheat grain samples were delivered for sensory evaluation in foil-covered 600 ml glass beakers. The cooked grains were portioned out into approx. 35 g samples in FIX PACK, clear round, plastic beakers of 11 cL volume, 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 20 °C for 1½ h before serving. All evaluations took place in a sensory evaluation laboratory, which was equipped after ISO guidelines (ISO 8589:2007). One booth was assigned to each assessor, there was air extraction in each booth, each booth had an independent light source and the ambient temperature in each booth was 22 °C. The panel consisted of 10 experienced assessors (three men and seven women between the ages of 21 and 39 years). The assessors were subjected to a screening

Table 1
Wheat species and varieties used for sensory evaluation.

Wheat species	Variety	Release date	Vernal	Country of origin	Pedigree
Triticum monococcum ssp.aegilopoides	Einkorn	Landrace	Winter		Landrace
T. turgidum ssp.dicoccon	Emmer	Landrace	Spring		Landrace
T. turgidum ssp.turanicum	Kamut	Landrace	Winter		Landrace
T. aestivum ssp.spelta	Oberkulmer Rotkorn	Landrace	Spring	Germany	Landrace
T. aestivum ssp.aestivum	Complet	1996	Winter	Germany	(Boxer) × (Maris-Huntsman × Monopol)
T. aestivum ssp.aestivum	Dragon	1988	Spring	Sweden	(Sicco × WW-12502) × (Sappo × 5 × Kadett)
T. aestivum ssp.aestivum	Extra Squarehead	1908	Winter	Sweden	Bred from Leuternritzer Squarehead (1892)
T. aestivum ssp.aestivum	Goldblume	1992	Winter	Germany	Selection in German Landrace
T. aestivum ssp.aestivum	Halland	Landrace	Spring	Sweden	Landrace
T. aestivum ssp.aestivum	Heroldo	2004	Winter	Germany	(Tambor × Greif) × Kris
T. aestivum ssp.aestivum	Hereward	1989	Winter	United Kingdom	Norman × Disponet
T. aestivum ssp.aestivum	Kolben	1892	Spring	Sweden	Repeated selection from landrace with variation
T. aestivum ssp.aestivum	Konini	1981	Spring	New Zealand	Fortuna/Arawa/Kopara/Purple Hilgendorf
T. aestivum ssp.aestivum	Kosack	1984	Winter	Sweden	(Mironovskaja 808 × Starcke M) × Holme M
T. aestivum ssp.aestivum	Kraka	1980	Winter	Denmark	Kranich × Caribo
T. aestivum ssp.aestivum	Kuban	2008	Winter	Sweden	Tambor × HADM.91639-89
T. aestivum ssp.aestivum	Magnifik	2004	Winter	Sweden	Kosack/Tjelvar/Urban/Folke-MB1N/STA-MB4B24//Helge-M7N
T. aestivum ssp.aestivum	Purple Justin		Spring	Australasia	E450/3*Arawa//3*Hilgendorf/3/Justin
T. aestivum ssp.aestivum	Solstice	2001	Winter	United Kingdom	Vivant × Rialto
T. aestivum ssp.aestivum	Stava	1995	Winter	Sweden	Helge-M7D1/Helge-M7D2// (Mildew Resistent line) WW-31254
T. aestivum ssp.aestivum	Tuareg	2005	Winter	Germany	Kris × dekan
T. aestivum ssp.aestivum	Ure	1993	Winter	Denmark	Selection from Vuka
T. aestivum ssp.aestivum	Vinjett	1998	Spring	Sweden	Tjälve M14/Tjälve M15/Cannon
T. aestivum ssp.aestivum	Øland Wheat	Landrace	Spring	Sweden	Selected from local Landraces on Øland by Hans Larson

test based on the ISO guidelines (ISO 3972:1991) and their selection was based on this test as well as their interest, motivation and ability to verbally convey sensory impressions. During four training sessions, which occurred over four days prior to evaluation, the panel suggested, discussed and finally established a set of sensory descriptors which they later used during evaluation of cooked wheat grain samples. Panel training was conducted during the first week according to the ISO guidelines (ISO 13299:2003). The first three days were used to develop the vocabulary for describing the sensory attributes and introducing ranking and scaling of the intensities. The fourth training day was used to train ranking and scaling. Panellists received feedback on their performance after each session for the purpose of improving and standardising their discriminatory ability as a panel. The feedback was aimed at reaching consensus in defining each descriptor and in the span of intensities between samples. Reference materials were used to clarify the descriptors to the sensory panellists and to establish panel consensus. The panellists established four categories of attributes which were Odour (olfactory perception), Flavour (oral and retro-nasal perception), Appearance (visual perception) and Texture (mouth-feel). The list of descriptors in the final vocabulary together with their definitions and references are listed in Table 2. The evaluation encompassed 24 samples, including a reference sample which was served in three repetitions over eight evaluation days. The evaluation method used was based on descriptive sensory analysis. 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 and the data was collected in FIZZ Network Acquisition (Version 2.4 OE). The descriptive evaluations were conducted over two weeks each with four consecutive evaluation days. All assessments took place in the morning from 11:00 am. On each of the eight evaluation days, the panel was served a reference sample and a series of seven to nine different samples following an incomplete block design (Cochran, and Cox, 1957). Within a session, samples were presented randomly to the assessors. Each evaluation lasted one hour without breaks. Tap water, carbonated water and cucumber (peeled and cut in thin slices) were provided to cleanse and refresh the mouth between each sample evaluation. Panellists had a minimum of 2 min between each sample to cleanse their palates. No green notes were reported in the samples during initial tasting sessions, therefore cucumber was used as a palate cleanser in order to minimise any carry-over effect. Peeled cucumber had no effect on the samples. The general performance of the panellists was checked using the computer program (Panelcheck v1.3.2, Matforsk, Norway). The final statistical model was based on the results from the whole panel.

2.4. Statistical data analysis

An analysis of variance (ANOVA) of the sensory data was performed using SPSS (IBM, version 19 Aug. 2010). 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 ANOVA model: $\text{Attribute}_l = \alpha(\text{Product}_i) + \beta(\text{Assessor}_i) + d(\text{Product}_{i,}\ \text{Assessor}_i) + \varepsilon_i$.

Post-hoc testing of the ANOVA results was made using the Bonferroni *t*-test function in SPSS. The results of the *post-hoc t*-tests were used to generate tables highlighting the significant differences between samples for each descriptor. Principal Component Analysis (PCA) was performed by Matlab 7.6.0 (R2008a). A PCA model was conducted with the wheat varieties as samples and the significant descriptors as variables. The scores and corresponding loadings are shown in the bi-plot in Fig. 1.

Correlations were determined by using Pearson's correlation coefficient (r). Significances were determined using table values (http://www.psystat.at.ua/Articles/Table_Pearson.PDF, 2012) for a two-tailed test.

Table 2
Descriptors and references used to characterise cooked wheat grain.

Category	Descriptor	Reference	*F*-value	*p*-value[b]
Odour	Intensity		2785	<0.001
	Vanilla	1 cm Bourbon vanilla	3057	<0.001
	Dried Figs	2/4 pieces Dried soft figs	0.886	NS
	Sawdust	Sawdust from Beech wood	0.920	NS
	Øllebrød[a]	"Beauvais" Øllebrød 1 dl 3 dl boiled water	3783	<0.001
	Nutty	Chopped Brazil, Pecan, Hazel and Wallnuts	1227	NS
	Cooked malt	1 Tsp Wey Münich type 1 malt. boiled for 30 min	3624	<0.001
	Cocoa	1 Tsp "Kend Varen" Cocoa	4092	<0.001
	Honey	"Aulumgård" clear Danish honey	0.987	NS
	Oat Porridge	2 dl "Irma økolokisk balance" oatmeal, boiled in 4.5 dl water 2–3 min.	3238	<0.001
	Bulgur	2 dl "Delicata" coarse bulgur boiled in 4 dl water 10–12 min.	2857	<0.001
Flavour	Wild Rice	"Princip" wild rice simmered for 40 min	1825	<0.05
	Watery	1 dl oatmeal suspended in 500 ml water for 5 min water then used as reference	3346	<0.001
	Sweet	48 g/l sucrose stock solution. 7.2 g/l (D2 ISO:3972:1991) = 150 ml stock + 850 ml water	3067	<0.001
	Salt	8 g/l NaCl stock solution. 1.4 g/l (D2 ISO:3972:1991) = 175 ml stock + 825 ml water	1345	NS
	Øllebrød[a]	"Beauvais" Øllebrød 1 dl 3 dl boiled water	3101	<0.001
	Cooked Malt	1 Tsp Wey Münich type 1 malt. boiled for 30 min	3.01	<0.001
	Oat Porridge	2 dl "Irma økolokisk balance" oatmeal, boiled in 4.5 dl water 2–3 min.	2382	<0.001
	Leavened Dough	10 g yeast in 1 dl tepid water with rye and wheat flour added to form dough	1703	<0.05
	Bulgur	2 dl "Delicata" coarse bulgur boiled in 4 dl water 10–12 min.	1095	NS
	Bitter	0.04 g/l quinine stock solution. 0.006 g/l = 150 ml stock + 850 ml water	2495	<0.001
Appearance	Dark	"Beckers" colour chart	73,349	<0.001
Texture	Hardness		8997	<0.001

[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. Results and discussion

3.1. Sensory profile of cooked wheat grains

The panel established a set of sensory descriptors against which they were able to evaluate the cooked wheat grains (Table 2). Significant differences, ($p < 0.001$), were found to occur between the cooked wheat samples for all of the descriptors describing texture and appearance. Significant differences, ($p < 0.001$), were found for seven out of eleven descriptors describing odour: overall odour intensity, odour of øllebrød, odour of oat porridge, odour of bulgur, odour of cooked malt, odour of vanilla and odour of cocoa. Significant differences, ($p < 0.001$), were found for six out of eleven sensory descriptors describing flavour attributes: flavour of øllebrød, flavour of oat porridge, flavour of cooked malt, watery flavour, and sweet flavour. Significant differences, ($p < 0.05$), were

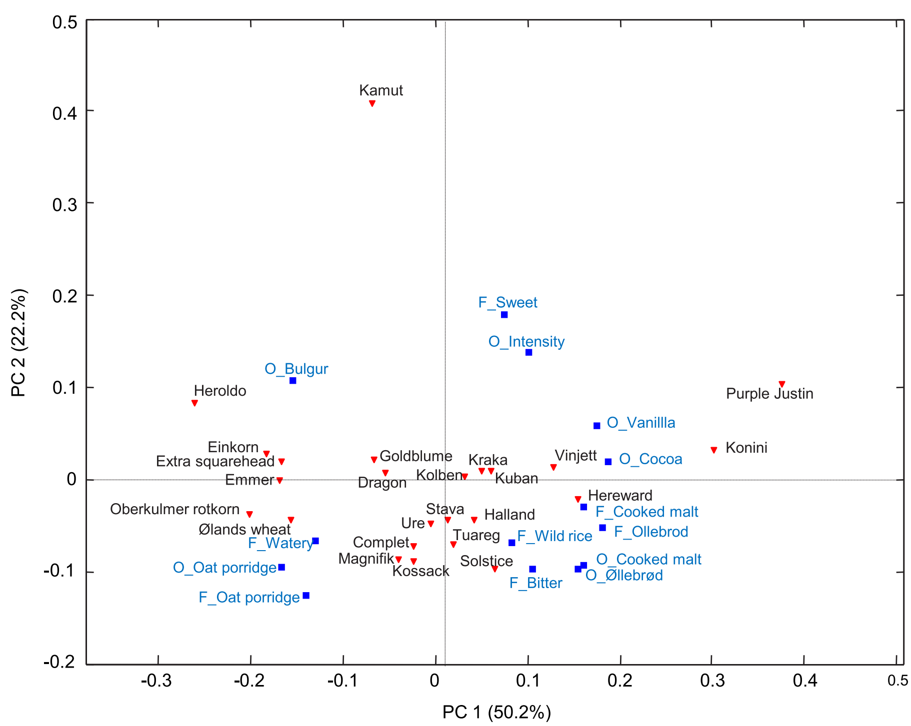

Fig. 1. PCA model (bi-plot) of the sensory evaluation values of different varieties of cooked wheat grains as scores and significant odour and flavour descriptors as loadings.

found for two out of eleven sensory descriptors describing flavour of wild rice and bitter flavour. The least mean square values for the evaluation scores of all the samples are presented for each descriptor of odour and flavour in Tables 3a and 3b. The descriptors for dark appearance and hard texture are presented in Table 4.

3.2. Principal Component Analysis (PCA)

The first Principal Component (PC1) explained 50% of the variation in the data, the second Principal Component (PC2) explained 22% of the variation, giving a total explained variance of 72% for a two component model. These first two components were used in Fig. 1 to give a sufficient visual overview of the relationship between samples and descriptors. The samples on the left of the PC1 axis (Fig. 1) are mainly influenced by descriptors for odour of bulgur, odour and flavour of oat porridge and the flavour descriptor watery. The samples on the right of PC1 are mostly described by descriptors for the odour and flavour of cooked malt, and øllebrød and the odours of vanilla and cocoa. In between, there are samples which are a mixture of both. On the left side of PC1 are the samples Einkorn, Emmer, Extra Squarehead, the spelt wheat Oberkulmer rotkorn, Øland wheat and the white wheat variety Heroldo. Apart from Heroldo, these are the oldest wheat samples in the sample set; Einkorn and Emmer are the earliest cultivated wheats. Spelt wheat is also an ancient, cultivated, bread wheat. Øland wheat is a bread wheat variety which was collected in Swedish landraces growing on the Swedish Island of Øland and Extra Squarehead is a very old Swedish variety, released in 1908, which was bred from an imported squarehead variety. The squarehead wheats have their origins in the United Kingdom where Squarehead was first officially propagated in 1870 although wheats of this type had been grown since the 1830s in eastern England (Percival, 1948; Vavilov, 1951). Squareheads are thought to originally have been the result of a hybridisation between club and soft wheats (Vavilov, 1951).

In Tables 3a and 3b many significant differences in odour and flavour can be seen between these six samples and the two purple, Australasian samples Konini and Purple Justin, which are the furthest to the right on PC1 (Fig. 1).

Amongst these samples, Heroldo had a significantly lower value for the wild rice flavour descriptor than Einkorn (Table 3b). Meanwhile, Einkorn had a significantly lower value for watery flavour than Oberkulmer Rotkorn. The rest of these samples did not differ significantly from each other. There were no significant differences between Purple Justin and Konini for odour and flavour descriptors (Tables 3a and 3b). However when their values for odour were compared to the next closest samples on PC1: Hereward and Vinjett, then Purple Justin was shown to have a significantly higher value for vanilla odour than Vinjett and Hereward and a significantly higher value for cocoa odour than Vinjett. The samples which are in the middle of PC1 were characterised as having the middle values for most of the significantly differentiated descriptors. Among these samples were a single Swedish landrace Halland and the Swedish variety Kolben, which was released in 1892. The remaining samples in this group however are more modern varieties: Goldblume, Kossack, Magnifik, Solstice, Complet, Tuareg, Stava, Ure, Kraka, Dragon, Kolben, and Kuban. The release dates of these samples range from 1980 to 2005. As shown in Tables 3a and 3b, the Swedish spring wheat, Dragon, was assessed to have a significantly lower cocoa odour than Kolben and Halland. Goldblume had a significantly higher score for watery flavour than Kraka, Complet and Kossack. The samples Complet, Halland, Kossack, Kraka, Kolben, Kuban, Magnifik, Solstice, Stava, Tuareg, and Ure were found to have no significant differences between them for any of the odour or flavour descriptors.

PC2 is mostly described by sweet flavour and bitter flavour. The sample Kamut stands apart from the other samples along the PC2 axis. From the data in Tables 3a and 3b it can be seen that this Khorasan wheat was significantly different to many of the other samples for all seven odour descriptors and in six out of seven flavour descriptors, in particular for sweet flavour where it was significantly sweeter than all the other varieties with the exception of Purple Justin. When compared to the descriptor values for dark,

Table 3a
Mean square value tables of odour descriptors. Significant differences between samples were determined by Bonferroni *post hoc* data treatment, samples which do not share a letter are significantly different.

Sample	Odour intensity		Øllebrød odour		Oat Porridge odour		Bulgur odour		Cooked malt odour		Vanilla odour		Cocoa odour	
	L. sq. mean		L. sq. mean		L. sq. mean		L. sq. mean		L. sq. mean		L. sq. mean		L.sq. mean	
Complet	C	7.74	ABCD	4.33	AB	5.43	ABCD	4.83	ABCDE	4.47	CDE	3.99	CDEF	2.76
Dragon	BC	8.74	ABC	4.61	AB	4.66	ABCD	5.79	BCDEF	3.66	CDE	3.88	EF	1.99
E. Squarehead	ABC	9.68	ABCD	3.68	A	5.80	ABCD	5.72	DEF	3.35	E	2.33	DEF	2.15
Emmer	ABC	8.94	BCD	3.55	A	6.06	ABCD	5.92	ABCDEF	4.27	DE	2.75	F	1.62
Enkorrn	ABC	9.40	ABCD	3.76	A	5.99	ABCD	5.93	CDEF	3.47	CDE	3.40	F	1.62
Goldblume	ABC	9.07	ABCD	4.04	A	5.61	BCD	4.70	ABCDEF	4.18	CDE	3.96	CDEF	2.78
Halland	ABC	8.98	ABCD	4.19	AB	4.42	ABCD	5.58	ABCD	5.17	BCD	4.90	ABCD	3.96
Hereward	ABC	9.47	AB	5.88	AB	3.98	D	3.58	EF	2.74	CDE	4.04	DEF	2.10
Heroldo	C	7.68	D	2.04	AB	5.10	AB	6.71	ABCD	4.95	BC	5.15	ABC	4.43
Kamut	A	11.08	CD	2.43	B	3.26	A	7.36	F	2.25	BC	5.19	BCDEF	3.31
Kolben	ABC	9.37	ABC	4.77	AB	4.50	ABCD	5.27	ABCDE	4.78	BCDE	4.60	ABCD	4.03
Konini	AB	10.67	AB	5.83	B	3.24	CD	3.90	AB	5.63	AB	6.84	AB	5.19
Kossack	C	8.11	ABCD	4.19	AB	5.51	ABCD	4.95	ABCDEF	4.26	BCD	4.71	BCDEF	3.37
Kraka	ABC	8.79	ABC	4.64	AB	3.99	CD	3.76	ABCDEF	4.35	ABC	5.56	CDEF	2.95
Kuban	ABC	8.84	ABC	4.74	AB	4.31	BCD	4.20	ABCD	5.06	CDE	4.17	CDEF	2.97
Magnifik	C	7.95	AB	4.82	AB	5.04	BCD	4.25	ABCDEF	4.39	CDE	3.61	BCDEF	3.27
O. Rotkorn	ABC	8.83	ABCD	4.04	AB	5.40	ABC	6.35	BCDEF	3.68	DE	2.81	EF	1.97
P. Justin	AB	10.91	AB	5.83	B	3.25	CD	3.92	A	6.03	A	7.69	A	5.62
Solstice	ABC	9.31	A	5.99	AB	5.13	CD	4.11	ABC	5.53	BCD	4.83	BCDEF	3.41
Stava	ABC	9.08	AB	4.99	AB	4.63	CD	3.98	ABCDE	4.80	ABC	5.65	BCDEF	3.48
Tuareg	C	8.32	AB	5.41	AB	4.64	BCD	4.51	ABCD	5.47	CDE	3.83	BCDEF	3.56
Ure	ABC	8.77	AB	4.81	AB	5.11	BCD	4.69	ABCD	5.40	CDE	4.06	BCDEF	3.24
Vinjett	ABC	9.57	AB	4.89	AB	3.94	D	3.51	ABCDE	4.46	BC	5.19	BCDE	3.66
Øland Wheat	BC	8.77	BCD	3.54	A	5.85	BCD	4.64	BCDEF	3.61	CDE	3.72	CDEF	2.51

Table 3b
Mean square value tables of flavour descriptors. Significant differences between samples were determined by Bonferroni *post hoc* data treatment, samples which do not share a letter are significantly different.

Sample	Oat porridge flavour		Øllebrød flavour		Wild rice flavour		Cooked malt flavour		Bitter flavour		Watery flavour		Sweet flavour	
	L. sq. mean		L. sq. mean		L. sq. mean		L. sq. mean		L. sq. mean		L. sq. mean		L. sq. mean	
Complet	ABC	6.46	ABCDEFG	3.42	ABC	4.11	ABCDE	4.17	AB	6.20	CDEFG	4.94	DE	5.06
Dragon	ABC	6.52	BCDEFG	3.31	ABC	4.39	ABC	4.86	ABC	5.06	ABCD	6.20	BCD	6.42
E. Squarehead	AB	6.84	CDEFG	2.57	ABC	3.83	DE	2.72	ABC	5.89	ABCDE	5.89	CDE	5.43
Einkorn	ABC	6.44	FG	1.89	A	5.23	DE	2.76	CD	4.01	DEFG	4.70	CDE	5.44
Emmer	ABC	6.65	CDEFG	2.99	ABC	4.53	BCDE	3.45	BCD	4.02	BCDEF	5.72	CDE	5.59
Goldblume	ABC	5.98	ABCDEFG	3.48	C	2.80	ABCD	4.51	ABC	5.71	A	7.52	BC	6.81
Halland	ABC	6.35	ABCDEFG	3.33	ABC	4.55	ABCD	4.47	A	6.78	BCDEF	5.71	CDE	5.39
Hereward	ABCD	5.69	ABCD	4.19	ABC	4.60	ABCDE	4.16	AB	5.93	CDEFG	4.98	CD	6.06
Heroldo	AB	7.19	G	1.69	BC	2.98	CDE	2.90	ABCD	4.70	ABCD	6.20	CD	6.19
Kamut	BCD	4.73	DEFG	2.44	ABC	3.20	E	2.57	D	3.82	FG	4.02	A	8.62
Kolben	ABC	6.48	ABCDEF	3.63	ABC	3.67	ABCDE	4.06	AB	6.20	BCDEF	5.60	CD	6.06
Konini	ABCD	5.37	A	5.23	AB	5.07	AB	5.17	AB	6.20	EFG	4.25	BCD	6.48
Kossack	AB	7.18	ABCDEF	3.62	ABC	4.62	ABCDE	3.77	A	6.65	DEFG	4.80	DE	5.28
Kraka	ABCD	5.84	ABCDE	3.81	ABC	4.36	ABCDE	3.90	ABC	5.49	CDEFG	5.03	CDE	5.99
Kuban	ABCD	5.67	ABCDEFG	3.58	ABC	3.76	AB	4.91	ABCD	5.03	BCDEFG	5.08	CD	6.21
Magnifik	AB	7.02	ABCD	4.21	ABC	4.28	ABCDE	4.03	ABCD	4.94	ABCDE	5.93	CD	6.12
O. Rotkorn	AB	6.84	EFG	2.26	ABC	4.21	DE	2.64	ABC	5.08	ABC	6.65	E	4.60
P. Justin	CD	4.20	AB	4.94	ABC	4.46	A	5.75	A	7.52	FG	4.01	AB	7.71
Solstice	A	7.31	ABC	4.41	ABC	4.80	BCDE	3.73	ABCD	4.98	BCDEFG	5.06	CDE	5.61
Stava	AB	7.01	ABCDEF	3.67	ABC	4.21	BCDE	3.49	ABCD	4.25	ABCD	6.20	CDE	5.58
Tuareg	ABC	6.54	ABCD	4.29	ABC	4.10	BCDE	3.57	ABCD	4.80	BCDEFG	5.49	CDE	5.53
Ure	ABC	6.32	ABCDEFG	3.50	ABC	4.02	ABCDE	3.80	ABC	5.72	BCDEF	5.68	CDE	5.64
Vinjett	ABCD	5.88	ABCDE	3.97	AB	5.11	ABCDE	4.32	ABC	5.60	G	3.82	CDE	5.99
Øland Wheat	A	7.35	CDEFG	2.89	ABC	3.48	BCDE	3.35	ABC	5.68	AB	6.78	CDE	5.45

shown in Table 4, it was observed that the samples in the PCA model spread along the PC1 axis from left to right in order of increasing darkness.

3.3. Descriptor correlations

All significant descriptors were compared to key descriptors from each sensory modality in order to reveal any intra-modal or cross-modal interactions. The key descriptors used for comparison were odour intensity, sweet flavour, bitter flavour, dark appearance and the texture descriptor hardness. The remaining odour and flavour descriptors were also compared to each other. The r critical values in the two-tailed test, with df $(n-2)$ for 24 samples, were, for $(p < 0.05) \pm 0.404$, for $(p < 0.01) \pm 0.515$ and for $(p < 0.001) \pm 0.629$.

There were 60 significant correlations found in total (Table 5) including some for the texture descriptors, sticky and effort required and the appearance descriptors: yellow and brown which have not been discussed in this paper. Table 5 shows that 23 correlations contain information on the relationship between interacting descriptors within the same sensory modality, and 37 correlations contain information on the relationship between descriptors from different sensory modalities. An interesting finding amongst the correlation results in Table 5 was the positive correlation between the descriptors for dark appearance and the descriptor for hard texture and that together, hardness and darkness correlated to other descriptors: cocoa odour, cooked malt odour, øllebrød flavour and odour all correlate positively, while bulgur odour correlated negatively. Bitter flavour was also found to have a positive correlation to dark appearance. The intra-modal correlations for odour (Table 5) show a positive correlation between bulgur and øllebrød, cooked malt and cocoa, cooked malt and øllebrød, oat porridge and vanilla, cocoa and vanilla and øllebrød and cocoa. The odours of bulgur and cooked malt were negatively correlated as were cocoa and oat porridge odours.

There was a positive flavour to flavour correlation between cooked malt and bitter and between cooked malt and øllebrød. There was also a negative correlation between sweet flavour and oat porridge flavour.

The aim of the study was to make a comparative study of the sensory attributes of different varieties of cooked wheat grain with emphasis on flavour and odour. These results show that there are differences among wheat species and varieties for odour and flavour attributes. Whether or not the sensory variability seen in whole wheat cooked grains continues to have an impact beyond processing, and thereby can be found in products such as flour and

Table 4
The mean square value tables for the appearance descriptors for dark and the texture descriptor for hard. Significant differences were determined by Bonferroni *post hoc* data treatment, samples which do not share a letter are significantly different.

Dark appearance			Hard texture		
Sample		L. sq. mean	Sample		L. sq. mean
Kamut	A	0.95	Enkorn	A	4.78
Heroldo	A	1.44	Goldblume	AB	4.94
Enkorn	B	3.66	Dragon	ABC	5.19
O.Rotkorn	BC	3.88	Heroldo	ABC	5.26
Emmer	BCD	4.37	Øland wheat	ABCD	5.79
E. Squarehead	BCD	4.67	E. Squarehead	ABCDE	6.26
Øland wheat	CDE	4.92	O.Rotkorn	ABCDE	6.42
Goldblume	DEF	5.54	Magnifik	ABCDEF	6.44
Dragon	EF	6.16	Kamut	ABCDEFG	6.55
Kolben	EF	6.16	Kossack	ABCDEFG	6.67
Halland	FG	6.75	Stava	ABCDEFGH	7.00
Complet	GH	7.86	Kolben	BCDEFGH	7.12
Magnifik	GHI	7.92	Emmer	CDEFGH	7.27
Ure	GHI	8.22	Halland	DEFGHI	7.92
Kossack	HIJ	8.44	Ure	DEFGHI	7.92
Kuban	HIJK	8.72	Complet	DEFGHI	8.02
Stava	HIJKL	8.74	Hereward	EFGHI	8.47
Vinjett	HIJKL	9.20	Kraka	EFGHI	8.48
Solstice	IJKL	9.40	Solstice	FGHI	8.72
Kraka	JKL	9.85	Tuareg	GHI	8.75
Tuareg	KL	9.97	P.Justin	HI	9.16
Hereward	L	10.46	Konini	I	9.69
Konini	M	13.96	Vinjett	I	9.89
P.Justin	M	14.03	Kuban	I	10.17

Table 5
Correlations found between significant sensory descriptors for cooked wheat grain. Correlation coefficients marked (−) denote negative correlation. $P < 0.001$ is strongly correlated, $p < 0.01$ is moderately correlated and $p < 0.05$ is weakly correlated.

Intra-modal descriptor correlations

Descriptors	Corr. coef.	*P*-value
Odour intensity >< Bulgur odour	(−) 0.59	$p < 0.01$
Odour intensity >< Oat porridge odour	(−) 0.59	$p < 0.01$
Odour intensity >< Vanilla odour	0.56	$p < 0.01$
odour intensity >< cocoa odour	0.49	$p < 0.05$
Bitter >< Cooked malt flavour	0.65	$p < 0.001$
Bitter >< Øllebrød flavour	0.52	$p < 0.01$
Sweet >< Oat porridge flavour	(−) 0.75	$p < 0.001$
Bulgur odour >< Cooked malt odour	(−) 0.74	$p < 0.001$
Bulgur odour >< Øllebrød odour	0.81	$p < 0.001$
Cooked malt odour >< Cocoa odour	0.68	$p < 0.001$
Cooked malt odour >< Øllebrød odour	0.87	$p < 0.001$
Oat porridge odour >< Cocoa odour	(−) 0.78	$p < 0.001$
Oat porridge odour >< Vanilla odour	0.84	$p < 0.001$
Vanilla odour >< Cocoa odour	0.87	$p < 0.001$
Øllebrød odour >< Cocoa odour	0.66	$p < 0.001$
Bulgur odour >< Cocoa odour	(−) 0.58	$p < 0.01$
Bulgur odour >< Vanilla odour	0.51	$p < 0.05$
Cooked malt odour >< Vanilla odour	0.47	$p < 0.05$
Øllebrød flavour >< Cooked malt flavour	0.76	$p < 0.001$
Oat porridge flavour >< Watery flavour	0.60	$p < 0.01$
Wild rice flavour >< Watery flavour	(−) 0.55	$p < 0.01$
Oat porridge flavour >< Cooked malt flavour	(−) 0.47	$p < 0.05$
Øllebrød flavour >< Wild rice flavour	0.42	$p < 0.05$

Cross-modal descriptor correlations

Descriptors	Corr. coef.	*P*-value
Odour int >< Oat porridge flavour	(−) 0.73	$p < 0.001$
Odour int >< Stickiness	(−) 0.42	$p < 0.05$
Odour int >< Watery flavour	(−) 0.50	$p < 0.05$
Bitter >< Cocoa odour	0.56	$p < 0.01$
Bitter >< Cooked malt odour	0.56	$p < 0.01$
Bitter >< Bulgur odour	(−) 0.47	$p < 0.05$
Bitter >< Crispiness	0.48	$p < 0.05$
Bitter >< Effort required	0.46	$p < 0.05$
Bitter >< Vanilla odour	0.45	$p < 0.05$
Bitter >< Øllebrød odour	0.50	$p < 0.05$
Sweet >< Odour intensity	0.64	$p < 0.001$
Sweet >< Oat porridge odour	(−) 0.65	$p < 0.001$
Sweet >< Vanilla odour	0.54	$p < 0.01$
Dark >< Bulgur odour	(−) 0.86	$p < 0.001$
Dark >< Cocoa odour	0.78	$p < 0.001$
Dark >< Cooked malt flavour	0.75	$p < 0.001$
Dark >< Cooked malt odour	0.86	$p < 0.001$
Dark >< Effort required	0.79	$p < 0.001$
Dark >< Hard	0.75	$p < 0.001$
Dark >< Vanilla odour	0.69	$p < 0.001$
Dark >< Øllebrød flavour	0.93	$p < 0.001$
Dark >< Øllebrød odour	0.90	$p < 0.001$
Dark >< Bitter flavour	0.60	$p < 0.01$
Dark >< Oat porridge odour	(−) 0.53	$p < 0.01$
Dark >< Wild rice flavour	0.55	$p < 0.01$
Dark >< Watery flavour	(−) 0.43	$p < 0.05$
Hard >< Bulgur odour	(−) 0.64	$p < 0.001$
Hard >< Cocoa odour	0.65	$p < 0.001$
Hard >< Cooked malt odour	0.66	$p < 0.001$
Hard >< Ølleberød flavour	0.71	$p < 0.001$
Hard >< Øllebrød odour	0.67	$p < 0.001$
Hard >< Cooked malt flavour	0.53	$p < 0.01$
Hard >< Oat porridge odour	(−) 0.62	$p < 0.01$
Hard >< Vanilla odour	0.58	$p < 0.01$
Hard >< watery flavour	(−) 0.62	$p < 0.01$
Hard >< Oat porr flavour	(−) 0.44	$p < 0.05$
Hard >< Wild rice flavour	0.44	$p < 0.05$

in baked bread, still needs investigation. These results however do provide a reference point for sensory studies of these products. Indeed, comparisons with findings on both of these topics are planned for discussion in future publications. These results describe the sensory attributes found in cooked wheat grain but these alone do not explain which chemical compounds are responsible for them nor do they indicate which genetic or environmental factors may be causing the sensory differences. They will however be able to supplement future planned instrumental studies of aroma compounds in different wheat species and varieties. It is still possible however to comment generally on factors which may be active in contributing to wheat flavour and odour. The free phenolic compounds which are available to contribute to flavour and aroma in wheat grains can vary between 0.5 and 1% of the total phenolic content depending on the variety, (Li et al., 2008). Phenolic compounds are mostly found in wheat grains in the form of ferulic- and vanillic acid (Li et al., 2008). Relatively higher contents of vanillic acid and ferulic acid have previously been detected in purple wheats compared to other varieties (Liu et al., 2010). The two purple wheat varieties evaluated in this study had significantly higher scores for vanilla odour in relation to the sample group, which suggests a possible link between vanillic acid and vanillin content in wheat grains. According to Liu et al. (2010), darker coloured wheat might signify higher flavonoid content than in lighter coloured wheat. The results in this study indicate that increasing wheat darkness might also be linked to an up- and/or down-regulation of the specific odour and flavour descriptors associated with wheat. One implication of this finding is that grain colour itself may potentially serve as a predictive indicator of stronger grain flavour and grain odour properties. The two purple varieties in this study, Konini and Purple Justin owe their purple colour to a tetraploid purple accession, E450 (Zeven, 1991). This accession came from a collection of Ethiopian wheat plants which was introduced to New Zealand and the wheat accession E450 became the basis for establishing grain yielding purple varieties in Australasia. The purple colour is the result of a maternally inherited pigmentation, caused by anthocyanins stored in the pericarp (Mc Intosh and Baker, 1967; Zeven, 1991), and in the testa (Guo et al., 2011). Anthocyanins contribute to plant protection and can increase under various stress conditions such as increased heat (Hosseinein et al., 2008). Raised anthocyanin rates have also been observed in plants which have had to adapt to higher Ultra Violet irradiation (Tsormpatsidis et al., 2008). The high occurrence of anthocyanin in wheat from the Ethiopian highlands may be a result of their adaptation to cultivation at high elevations (over 2400 m above sea level) at low latitudes (Zeven, 1991). Anthocyanins are known to affect mouth-feel by increasing astringency (Brossaud et al., 2001). Anthocyanins were found to interact with food volatiles in a co-pigmentation reaction (Dufour and Sauvaitre, 2000). However it is not understood whether this can significantly impact the product flavour. Bitterness and astringency are often linked (Lesschaeve and Noble, 2005) and, in this study, we observed a correlation between the descriptors for dark and bitter (see Table 5). The odour descriptors for dried figs, sawdust, nutty, and honey and the flavour descriptors for salt and bulgur used by the panel to describe cooked wheat grain did not show any significant differences between wheat varieties. These descriptors are still important to the overall flavour of cooked wheat. Having a common set of odour and flavour attributes contributes to give wheat its stable and recognisable underlying character, despite any variations to which the more variable descriptors may contribute. The omnibus *F*-value for leavened dough flavour was significant ($p < 0.05$) which indicates that there is at least one significant difference between the samples, yet none of the sample comparisons were significant in the Bonferroni *t*-test. This is a possible outcome when using the conservative Bonferroni *t*-test (Sheskin, 2011). These 24 samples have been cultivated on at least 8 different locations in northern Europe. It would have been optimal, if all the wheat samples had been grown at the same location so that the environmental influences were negligible, however the aim was to compare as many different wheat species and cultivars as was possible and to establish methodologies, and it was not possible to acquire all the samples from one location as cultivation of the samples was not included in this project. Despite this inherent limitation it ought to be pointed out that within the sample set, seven samples, from Mørdrupgård, Denmark, were all grown in the same field. Results from the bi-plot (Fig. 1), show that they are distributed right across the PC1 axis, from left to right. The same broad differentiation can also be seen (Fig. 1) for the four samples grown in the field at Sejet Plant Breeding, Denmark. The significant differences in odour and flavour descriptors, which the data shows between some of the samples grown at the same location in our sample set, suggest that genetic factors are also responsible for odour and flavour differentiation. However, further studies are needed in order to determine how the influence of genetic variation compares with environmental influence.

These results show that a complex range of odours and flavours do exist between different varieties of cooked wheat grains and that while the differences between varieties also seem to vary depending on which varieties are being compared, the causality of these differences may be due to a complex interplay of environmental and genetic factors. If genetic factors alone can be shown to be a determinant in flavour and odour differentiation, then the odour and flavour of wheat could come to be regarded as a potential resource for quality improvement in future breeding programs and in the commercial production and application of wheat based products.

Future consumer studies of wheat varieties are also recommended in order to determine potential preferences for different wheat cultivars. This could be useful information for plant breeders and for the selection of wheat varieties for wheat based products.

4. Conclusions

Significant differences in odour and flavour have been observed among 24 varieties of wheat during sensory evaluation of cooked wheat grain. A set of sensory descriptors of cooked wheat grains which included 11 descriptors for odour, 10 descriptors for flavour, three descriptors for appearance and four descriptors for texture, have been established by a trained panel. Significant differences are reported between samples for three appearance descriptors, four texture descriptors, seven odour descriptors and seven flavour descriptors. The ancient species Emmer, Einkorn and Spelt as well as some land races and the oldest bred varieties in the sample group had a mild aroma and were mostly described by the descriptors for oat porridge odour and flavour, watery flavour and odour of bulgur. The purple varieties and some of the modern varieties had a much stronger aroma and were better described by wild rice, bitter, cooked malt, cocoa, vanilla, sweet and the Danish speciality "Øllebrød". The Khorasan wheat Kamut stood apart from the main sample group and was characterised as having high aroma intensity and sweet flavour. Sensory descriptors for cocoa odour, cooked malt odour, øllebrød flavour and odour were found to be positively correlated with levels of grain darkness and hardness while bulgur odour correlated negatively to these descriptors.

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