Campden BRI
food and drink innovation

Members only

The effect of added bran on water addition and bread quality

2015

R&D report no. 392

R&D report no. 392

The effect of added bran on water addition and bread quality

N Maher, T Mörsky and F Gates

2015

Station Road, Chipping Campden, Gloucestershire, GL55 6LD. UK
Tel: +44(0)1386 842000

www.campdenbri.co.uk

The effect of added bran on water addition and bread quality

Nicole Maher, Tiia Mörsky and Fred Gates
Campden BRI, Chipping Campden, Glos, GL55 6LD

R&D Report 392 (2015)
Project Number: 128876

Summary

Fibre addition affects bread quality, which results in a number of problems such as reduced bread volume, decreased dough strength, high water absorption, sticky dough, dark crumb colour and an unpleasant taste. The aim of this study was to understand these problems and develop strategies to solve them. Key to this is a clear understanding of the impact of bran components on dough water absorption and gas cell stability.

As expected, the addition of wheat or oat bran decreased bread specific volume. There was a greater reduction in volume at the higher (20%) substitution level compared to lower (10%). However, surprisingly it was also found that over the range of water addition rates studied (optimum ±2%) no effect on specific volume was found, suggesting that water addition level does not play an important role in the final product but is more important during processing.

It was found that bread made with 20% wheat bran had similar crumb firmness to the control; in comparison 20% oat bran bread had a softer crumb, which was not as expected. Both 10% wheat and oat bran breads showed decreased firmness when compared to the control. Bread firmness was determined on day after production (DOP +1). Both wheat and oat bran substitution decreased the number of cells in the crumb, which was as expected. This may be due to reduced gas cell stability that leads to coalescence.

There was no increase in bread specific volume with added gluten or yeast at either level. However, added gluten or yeast seemed to give softer crumb structure at 10 and 20% wheat bran and 20% oat bran, although this was not significant. There was no clear trend with 10% oat bran although with extra gluten it seemed to reduce bread crumb firmness.

Contents

1. Introduction

1.1 The role of water in bread making

Water is an essential ingredient in dough making (Mastromatteo et al., 2013). It allows proteins form a gluten matrix and contributes to dough consistency. Water has four main functions: to dissolve soluble molecules, activate enzymes, promote the formation of bonds between the macromolecules, and change the rheological properties.

Mixing is an important stage of bread making in that it disperses the ingredients, dissolves and hydrates dry ingredients, develops the gluten structure and incorporates air bubbles within the dough (Cauvain and Young, 2008). Water addition has an impact on all these aspects and must be added at an optimal level. The optimal addition of water is usually measured by a Brabender Farinograph, and it depends on flour moisture, protein content and quality, damaged starch levels and fibre content of the flour. Components of the full dough recipe such as salt, sugars and enzymes also change the optimal water content. The type of mixer used and the bread making process also affects the amount of the water needed.

The rheological properties of dough (Cauvain and Young, 2008) are critical for processing a baked product with desired qualities. It is well known that a higher water level leads to softer dough that will flow more during processing. If the water level is too low to hydrate all dough ingredients, the gluten might not get fully hydrated and develop to its full potential (Mastromatteo et al., 2013). Too little water can lead to a tight dough that can tear at the surface during moulding (Cauvain and Young, 2008). Tightness also has an effect on the dough matrix itself and can negatively affect stabilisation of gas bubbles. Insufficient softness or elasticity within dough restricts gas bubble expansion and can result in the coalescence of two or more bubbles giving rise to larger bubbles. Large bubbles have lower internal pressure than smaller bubbles, and this allows them to grow at a faster rate. If a large bubble grows fast enough and coalesces with other large bubbles it can become a large cell in the crumb.

Conversely, too much water leads to soft and sticky dough with the damaging effect of dough sticking to processing surfaces such as the moulder (Mastromatteo et al., 2013). The terms softness and stickiness are often confused because they are difficult to measure independently. Dough can be sticky, soft or both at the same time (Cauvain and Young, 2008).

Water is also important in yeast fermentation. The carbon dioxide gas which is evolved from yeast initially goes into solution. Once the solution becomes saturated, it causes carbon dioxide to come out of the solution and into gas cells. This gas is then released during baking as the gas bubbles interconnect.

1.2 The role of gluten in bread making

The variation of protein content is wide in wheat flour, but most commercial wheat flour contains around 8-16% protein (Hoseney, 1998). Around 80-90% of the proteins are gluten proteins (Sivam et al., 2010); these are storage proteins that are insoluble in water (Hoseney, 1998). The remaining proteins are water-soluble albumins and globulins, that are soluble in salt solutions. The gluten complex contains two main groups of proteins: gliadins (prolamins) and glutenins (glutelins). It is well known that gluten properties are largely responsible for the quality of bread, with much of the focus being on gliadin and glutenin. During dough development the gluten proteins generate a continuous viscoelastic network and increase the ability of dough to retain gas. Gliadins are soluble in alcohol and contribute towards the viscosity of dough. Glutenins are insoluble and contribute towards its strength and elasticity (Sivam et al., 2010).

1.3 Definition and consumption of dietary fibre

The definition of dietary fibre is not clear cut. The Food and Agricultural Organisation (FAO, 2008) defines dietary fibre as ‘carbohydrate polymers with ten or more monomeric units, which are not hydrolysed by endogenous enzymes in the small intestine’. Additionally they should be edible carbohydrate polymers naturally occurring in the food or obtained from food raw material by physical, enzymatic or chemical means and shown to have a physiological effect of benefit to health as demonstrated by generally accepted scientific evidence. Alternatively they can be synthetic carbohydrate polymers.

From the chemical position, dietary fibre consists of a wide variety of different compounds, as shown in Figure 1. The FAO does not specify whether carbohydrates containing 3 to 9 monomeric units should be included as dietary fibre or not. This is left to the national authorities to decide. In the EU these oligosaccharides are counted as dietary fibre (EC, 2008).

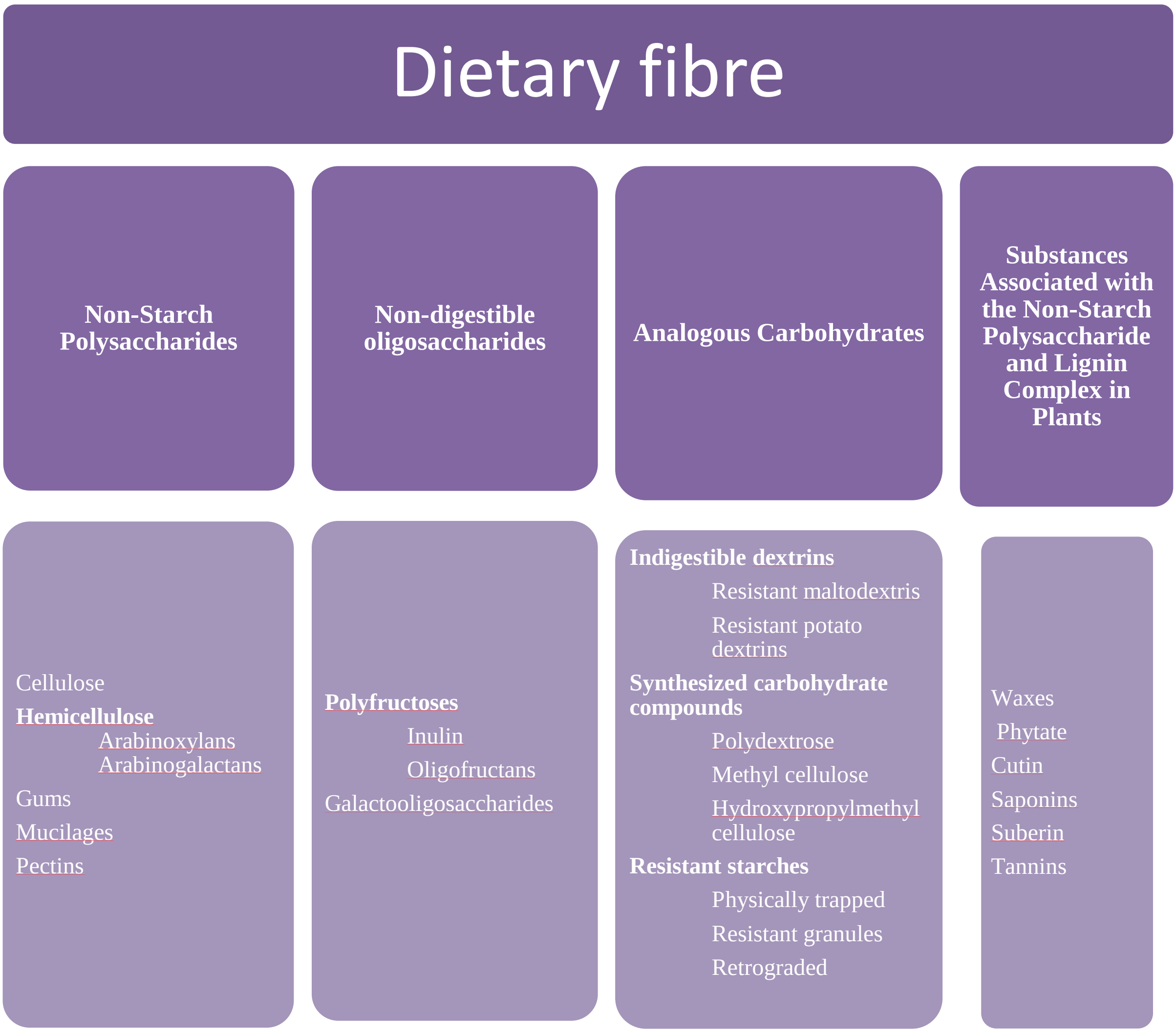

Figure 1. Constituents of dietary fibre (AACC, 2001)

The EU has permitted two nutrition claims for dietary fibre (EC, 2013):

- A food is a source of fibre if a product contains at least 3 g of fibre per 100 g or at least 1.5 g of fibre per 100 kcal.
- A product is high in fibre if the product contains at least 6 g of fibre per 100 g or at least 3 g of fibre per 100 kcal.

The EU has not authorized any health claims for generic dietary fibre. Table 1 gives health claims for specific dietary fibres including arabinoxylan, β-glucan, pectin, guar gum and resistant starches.

Table 1. EU authorised health claims for dietary fibres (EC, 2014)

Type of fibre	Authorised EU health claims
Arabinoxylan	Consumption of arabinoxylan as part of a meal contributes to a reduction of the blood glucose rise after that meal
β-glucan	Beta-glucans contribute to the maintenance of normal blood cholesterol levels Consumption of beta-glucans from oats or barley as part of a meal contributes to the reduction of the blood glucose rise after that meal Barley and oat beta-glucans have been shown to lower/reduce blood cholesterol High cholesterol is a risk factor in the development of coronary heart disease
Pectin	Consumption of pectins with a meal contributes to the reduction of the blood glucose rise after that meal Pectins contribute to the maintenance of normal blood cholesterol levels
Guar gum	Guar gum contributes to the maintenance of normal blood cholesterol levels
Resistant starches	Replacing digestible starches with resistant starch in a meal contributes to a reduction in the blood glucose rise after that meal.

The recommended levels of dietary fibre vary with different countries. For example, in the UK the dietary reference value for non-starch polysaccharides is 18 g/day, but the mean daily intake for adults was only 14 g/day (FSA, 2010). In Finland it is 25 g/day for women and 35 g/day for men (VRN, 2014). Data for mean daily dietary fibre intake in 2013 for men was 22 g and for women 21 g (NIHW, 2013). However, the values from the UK and Finland are not comparable, because the Finnish survey included various types of dietary fibres and not only non-starch polysaccharides. However, in both countries the consumption is lower than the recommendation.

1.4 Wheat and oat brans

The wheat kernel can be divided into three main parts: endosperm, bran and germ. The outer layers of the wheat kernel are called the bran. Wheat bran itself consists of several layers: pericarp, seed coat, nucellar epidermis and endosperm. Pericarp makes up 5% of the kernel (Hoseney, 1998). The seed coat and nucellar epidermis are bound firmly to the other layers. Botanically the aleurone layer is part of the endosperm but is removed in miller's bran. The aleurone layer of wheat is only one cell layer thick and is composed mostly of arabinoxylan, β-glucan and phenolic acids (Antoine et al., 2003). The aleurone layer is also rich in vitamins, minerals, enzymes, lipids and phytic acids compared to other parts of the kernel. Reduction in the wheat bran particle size has been shown to increase the release and availability of phenolic acids, flavonoid, anthocyanin and carotenoids (Brewer et al., 2013).

One of the main differences between wheat and oat kernels is that oats are harvested with their hulls on, whereas wheat hulls are free threshing and so hulls are removed during harvesting (Hoseney, 1998). Both wheat and oats have aleurone layers only one cell thick compared with barley in which this layer is 2-3 cells. The definition of oat bran differs to that for wheat bran (Mälkki, 2001) because the sub-aleurone layer in oats, which consists of thick cell walls, is usually included in the bran. The definition of oat bran in the United States is that the bran fraction should not be more than 50% of the kernel, and should contain at least 5.5% (dwb) β-glucan and 16% (dwb) total dietary fibre. The composition and structural properties of wheat and oat brans are different (Purhagen et al., 2011). Wheat bran is richer in dietary fibre (55.1% dwb) than oat bran (18.0% dwb); however, oat bran contains much more soluble β-D-glucan. Oat bran also contains more proteins and lipids than wheat bran.

1.5 Effects of bran fractions on bread quality

Most wheat bran is used as livestock feed and only small amounts are used in human food products. The milling industry would like to find applications for bran that have higher value that for feed products and at the same time increase the utilization rate of the kernel. Bran enriched breads have three main advantages compared to white bread. First, there is evidence that high fibre diets reduce the risk of obesity, diabetes and cardiovascular disease (Jones, 2007). Second, because consumers associate dietary fibre with health benefits the high fibre content provides a positive publicity message for the product (Mialon 2002). The third advantage is in increasing the utilization rate of the wheat kernel. Wheat flour extraction is usually 73-77% (and up to 80-82% in the UK) for white flour, with the remaining by-product being composed mainly of bran (Prückler, 2014).

Even though bran enriched products have many advantages, both dietary and economical, there are disadvantages for the quality of bakery products (Figure 2). This is due to the negative effects bran has on white bread, such as; bread containing bran has a lower specific volume than bread made with 75% extraction rate white flour (Katina et al., 2006; Noort et al., 2010). One reason for this is the negative effect bran has on the gluten network. Wheat bran also increases the flour water absorption and makes the dough stickier because of the different hydration time for bran and flour (Steyer and Gelinas, 2009). Finally, crumb and crust colour are darker compared to white wheat bread (Zhang and Moore, 1999).

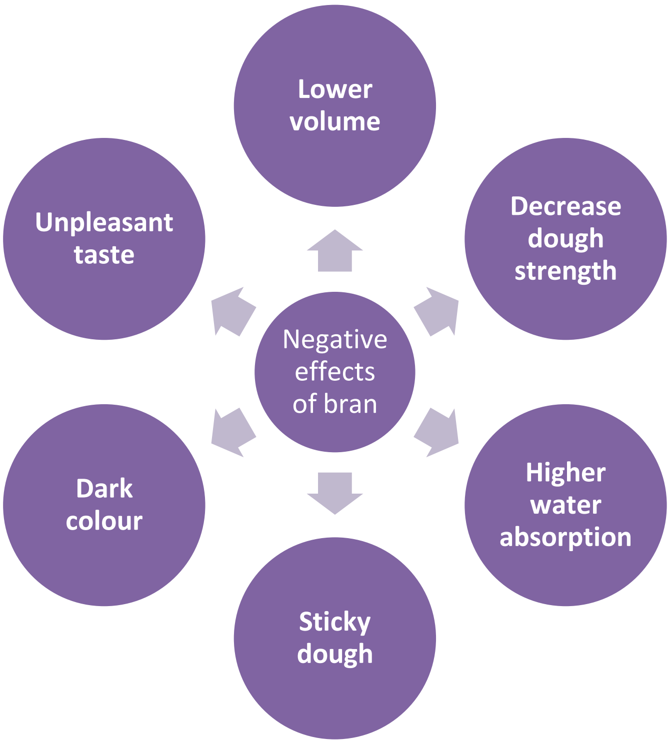

Figure 2. Negative effect of bran on wheat bread quality

Particle size of bran has an effect on dough rheological properties and bread quality. The particle size of wheat bran was shown to have a minimal effect on Farinograph water absorption, although finer bran required a shorter mixing time and gave a higher mixing tolerance index value (Zhang and Moore, 1997). It is worth stressing that Farinograph mixing is considerably longer than with high shear mixing and so the effects of bran on water absorption may not be the same. Contradictory results have been published concerning the effect of particle size on bread volume. Lai et al. (1989) found that finer particle size gave greater volume than coarser particle size, whereas Noort et al. (2010) reported opposite results. In comparison, Zhang and Moore (1999) found that bread containing medium particle size wheat bran had higher specific volume than breads with finer or coarse bran. All of the above work was on wheat bran.

It is known that wheat and oat bran have different effects on the quality aspects of bread. Oat bran has a lower water absorption capacity compared to wheat bran at 3% addition rate

(Maher and Gates, 2014; Purhagen et al., 2012). However, the development time and stability of dough are higher with oat bran than wheat bran. Purhagen et al. (2012) also noticed in their studies that when 3% of the wheat flour was replaced by oat bran the specific volume was increased compared with the same replacement by wheat bran. Also the weight loss during the baking was slightly smaller in oat bran breads than wheat bran breads.

There are subtle differences in taste of bread made with oat and wheat bran. The taste of oat bread is mild, nutty and pleasant (Flander et al., 2007), unlike wheat bran which is described as having a bitter taste. Wheat bran particle size has effects on sensory qualities of bread (Zhang and Moore, 1999) with bread containing finer bran having improved crust appearance and less gritty mouthfeel than bread contain medium or coarse bran. Consumers rated bread with finer or medium bran particle size more acceptable than samples with coarse bran. Also the flavour of bread containing fine particle size bran was rated better than bread with coarse bran.

1.6 Aims

The aim of this work was to understand problems associated with fibre addition and develop strategies to solve them. The effect of water addition and bran water absorption on bread quality was studied. Wheat and oat bran were used in measurements. Different gluten and yeast addition levels were studied.

2. Material and methods

Commercial ingredients were used in baking: wheat flour (protein: 11.7%, Hagberg falling number: 353, water absorption: 60.9, development time: 2.0 and stability: 5.5), wheat bran, oat bran, high activity yeast, salt, bread fat emulsion. Three minor ingredients were used: fungal alpha amylase, Panodan A2020 Datem, and ascorbic acid.

2.1 Bread making

Bread made with added bran used wheat flour substituted at 10% or 20% levels with wheat or oat bran. Water absorptions as measured by the Farinograph to the 500 line were taken as the optimal (Table 2). Other water levels used included -2%, -1%, +1% and +2%. The amount of added gluten was measured using the Glutomatic using levels of 0.9% and 1.8% for flour mixtures with 10% bran and 1.7% and 3.4% for flour mixtures with 20% bran.

Doughs were prepared in a PC-controlled Morton mixer set at 300 rpm and mixed to an energy input level of 11 Wh/kg. Dough pieces were scaled to 910±5g and rounded using a conical moulder. First or intermediate proof time was 5 minutes at bakery ambient temperature within a closed box. Before moulding, a small amount (less than 1g) of flour was added on the surface of the dough piece to prevent sticking to roller and moulder surfaces. Bread pan size was 250 x 122 mm, 125mm deep. Dough was proofed at 40ºC and 70% relative humidity to height (11 cm), typically taking 50-60 minutes. Baking temperature was 220ºC for 25 minutes. Bread was packed into plastic bags after 2 hours cooling at ambient temperature.

2.2 Bread evaluation

Bread was evaluated on the day after production. Specific Volume was measured using a TexVol BVM L370 (Perten, Sweden). Cell wall thickness, cell diameter and number of cells were measured using a C-Cell (Calibre Control, UK). Firmness was measured using a TA-XT2 Texture Analyser (SMS, USA). Moisture content was measured using a BS oven 250 (Gallenkamp, UK).

2.3 Statistical analysis

Bread evaluation was made from three replicate bread samples, with each test bake repeated twice. Significance between samples was analysed using one-way analysis of variance (ANOVA) and, if ANOVA was significant, Tukey's Honestly Significant Difference (HSD) test ($P < 0.05$). Minitab 17 software was used.

3. Results

3.1 Farinograph

The addition of wheat or oat bran changed the water absorption of wheat flour and increased dough development time (Table 2). Oat bran absorbed less water than wheat bran (Purhagen et al., 2012). The Farinograph was measured to the 500 line instead of 600 as it was found in the previous report to give a more representative indication of water absorption of wheat flour and added bran (Maher and Gates, 2014).

Table 2. Effect of bran on Farinograph parameters (500 line)

		Water absorption (%)	Development time (min)	Stability (min)
wheat flour		64.3	2	10+
wheat bran & flour	10%	67.1	7	10+
	20%	69.7	8	10+
oat bran & flour	10%	63	10	10+
	20%	66	11	10+

3.2 Effects of water content on the quality of wheat and oat bran enriched breads

Substitution of part of the wheat flour for wheat or oat bran decreased the specific volume of bread compared to the control bread (Table 3). There was a greater reduction in volume at a higher substitution level compared to lower. However, water content variation (-2% to +2%) had no effect on specific volume.

Table 3. The specific volume (ml/g) of breads supplemented with 10% and 20% wheat and oat bran and white wheat control bread.

	Control	Wheat bran		Oat bran	
		10%	20%	10%	20%
-2% water content	-	4.42[a]±0.17	3.73[a]±0.26	4.32[a]±0.05	4.05[a]±0.05
-1% water content	-	4.42[a]±0.11	3.93[a]±0.13	4.27[a]±0.04	4.09[a]±0.04
opt. water content*	4.64±0.23	4.41[a]±0.19	3.91[a]±0.14	4.32[a]±0.16	4.09[a]±0.04
+1% water content	-	4.41[a]±0.25	3.89[a]±0.22	4.36[a]±0.11	4.03[a]±0.05
+2% water content	-	4.27[a]±0.09	3.94[a]±0.10	4.32[a]±0.10	4.06[a]±0.12

Mean values ± standard errors of three replicates. Mean values followed by the same letter in the same column are not significantly different ($p<0.05$).
*Optimum water content of the control bread was 64.3%, 10% wheat bran bread 67.1%, 20% wheat bran bread 69.7%, 10% oat bran bread 63% and 20% oat bran bread 66%.

Lower wheat bran substitution level slightly decreased the firmness of the crumb compared to the wheat bread control; however, once the substitution level increased to 20% the crumb became firmer than the control apart from +2% water. The differences were not statistically significant. Water content of the wheat bran bread had little effect on firmness of the crumb (Figure 3). Once the substitution level increased to 20% the water content of the bread seemed to have a small effect on firmness, with increasing water level resulting in a slight decrease in firmness. However, the difference was not statistically significant as they were tested on the day after production (DOP +1).

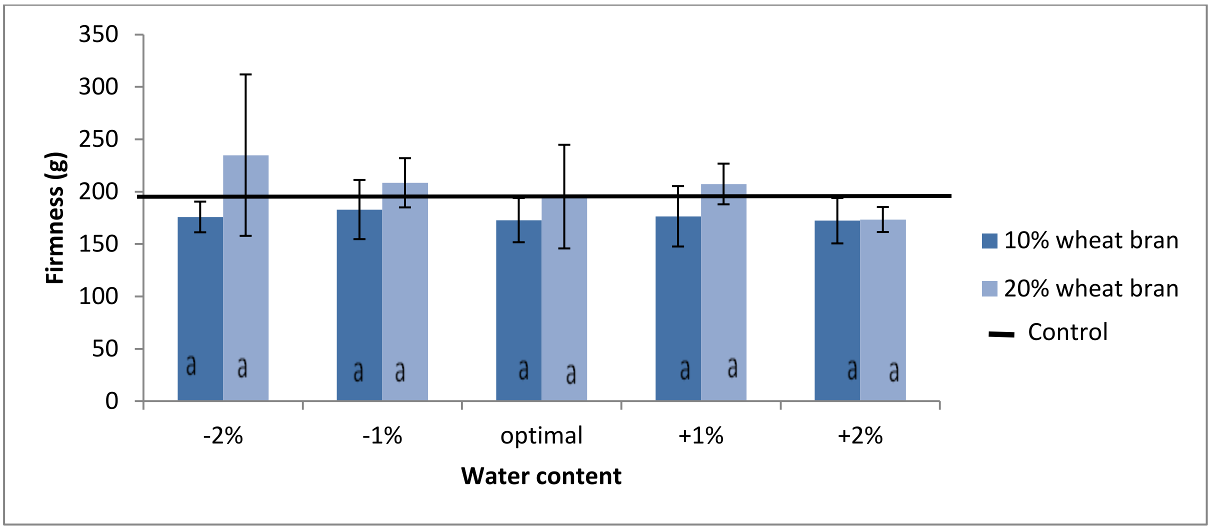

Figure 3. Firmness of the crumb of wheat bran bread with different water contents. Columns marked by the same letter are not statistically different at P<0.05%.

Similar to the wheat bran, 10% sub substitution with oat bran decreased the firmness of the crumb compared to the control; however, there was also a decrease in firmness at 20% substitution level. Water content of the bran bread had no significant effect on firmness of the crumb (Figure 4).

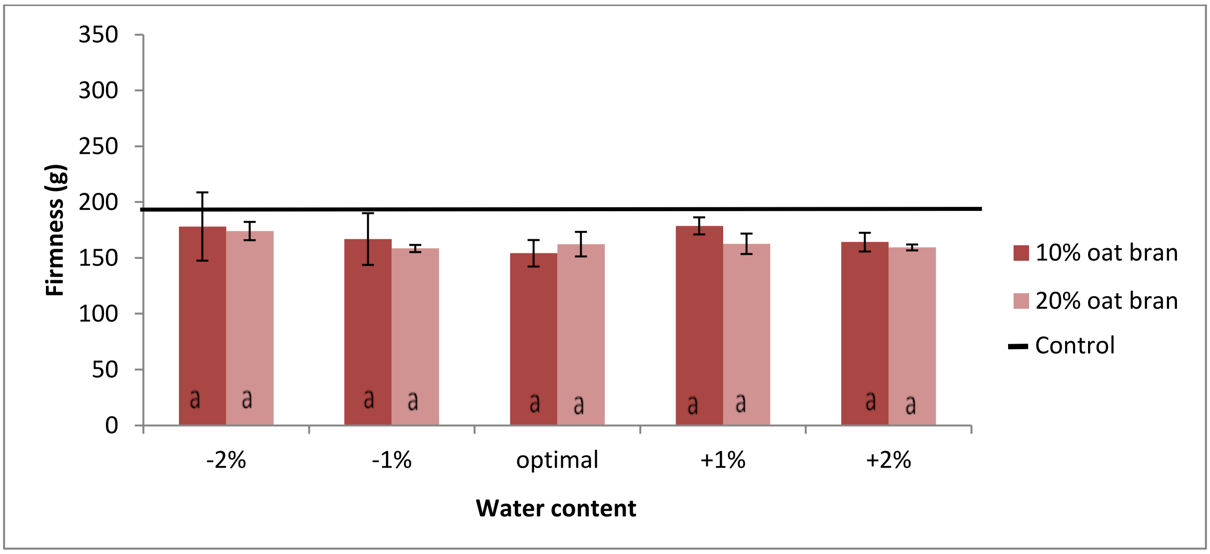

Figure 4. Firmness of the crumb for oat bran bread with different water contents. Columns marked by the same letter are not statistically different at P<0.05%.

Substituting 10% of flour with wheat or oat bran decreased the number of cells compared to the wheat bread control by around 20-25%. At 20% substitution, the cell number decreased by around 30-35%. Water content had no effect on the number of cells (Figures 5 and 6).

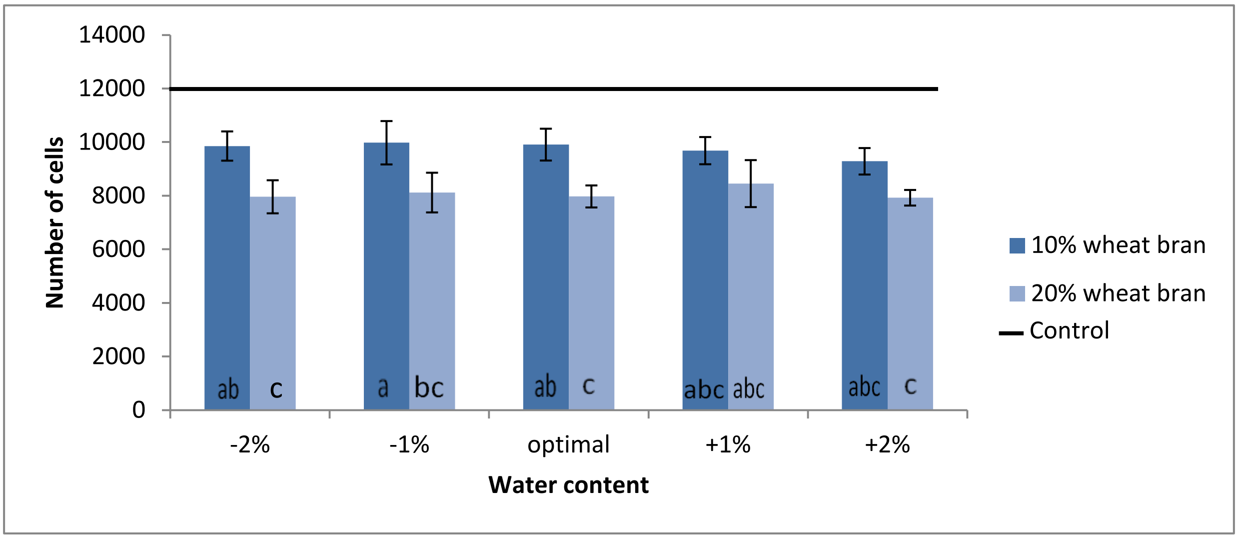

Figure 5. Number of cells of the crumb for wheat bran bread with different water contents. Columns marked by the same letter are not statistically different at P<0.05%.

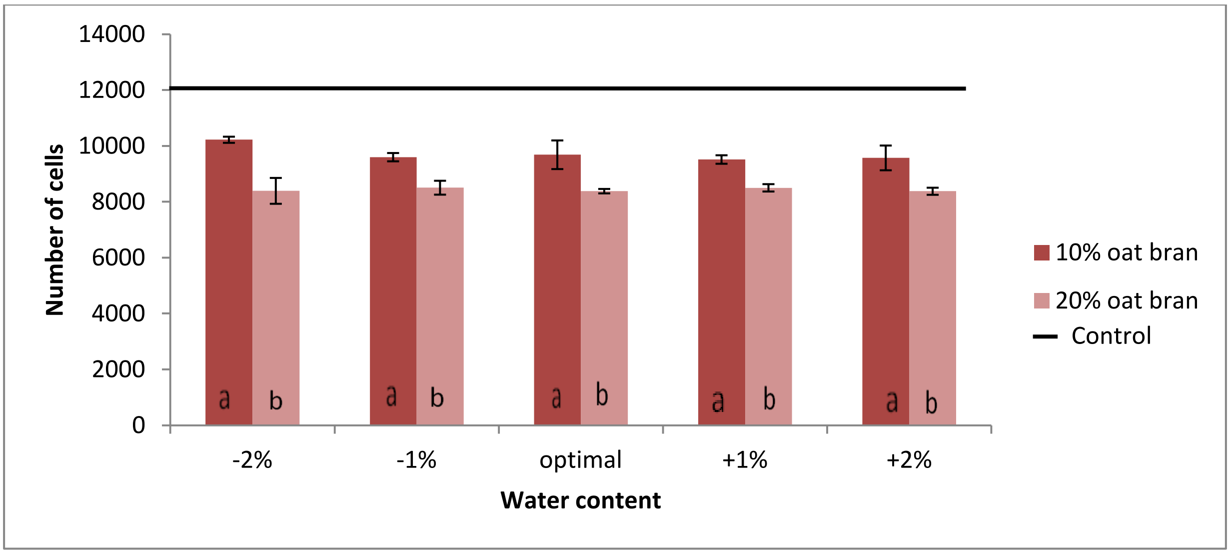

Figure 6. Number of cells of the crumb for oat bran bread with different water contents. Columns marked by the same letter are not statistically different at P<0.05%.

Water content had no effect on cell wall thickness at 10% and 20% substitution levels in either wheat bran or oat bran bread. Breads with 20% bran had thicker cell walls compared to breads with 10% bran, which in turn had thicker cell walls than the control bread (Figure 7).

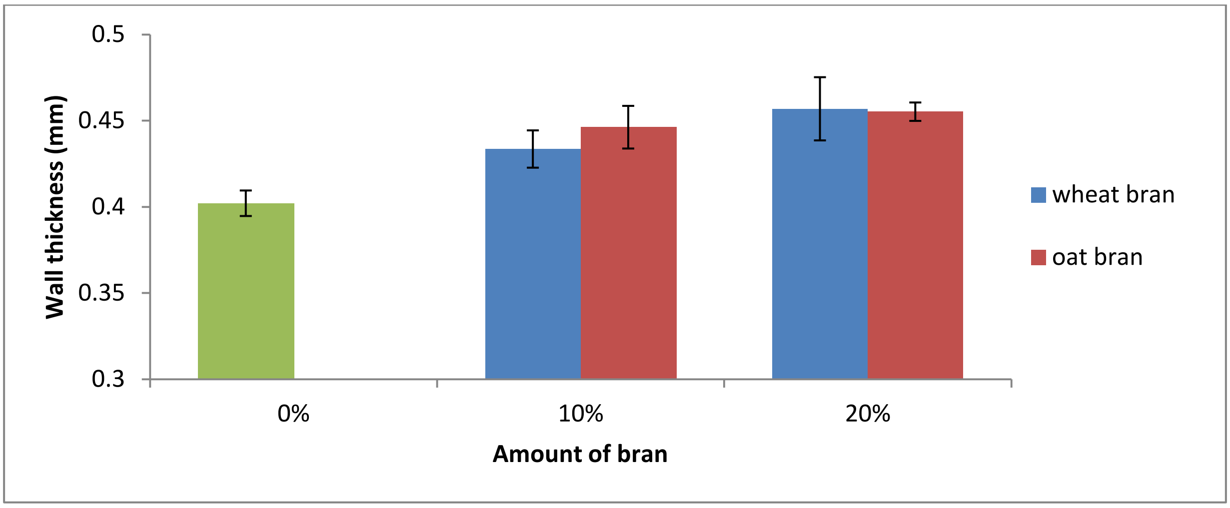

Figure 7. Wall thickness of 10 and 20% wheat and oat bran bread.

3.3 Effects of gluten content on the quality of wheat bran enriched breads

The level of added gluten had no effect on specific volume with 10% and 20% substitution level of wheat or oat bran (Table 4).

Table 4. Specific volume (ml/g) of breads supplemented with 10% and 20% wheat and oat bran, with different levels of added gluten.

	Wheat bran		Oat bran	
	10%	20%	10%	20%
without extra gluten	4.41[a]±0.21	3.91[a]±0.16	4.31[a]±0.16	4.09[a]±0.07
compensate to gluten dilution	4.25[a]±0.11	4.02[a]±0.09	4.46[a]±0.09	4.09[a]±0.08
addition of gluten	4.30[a]±0.07	4.08[a]±0.06	4.65[a]±0.22	4.18[a]±0.08

Mean values ± standard errors of three replicates. Mean values followed by the same letter in the same column are not significantly different ($p<0.05$)

The addition of gluten to bread containing wheat bran gave softer bread crumb compared to the breads without added gluten (Figures 8). However, the difference was not significant. The trend with oat bran was not clear (Figure 9).

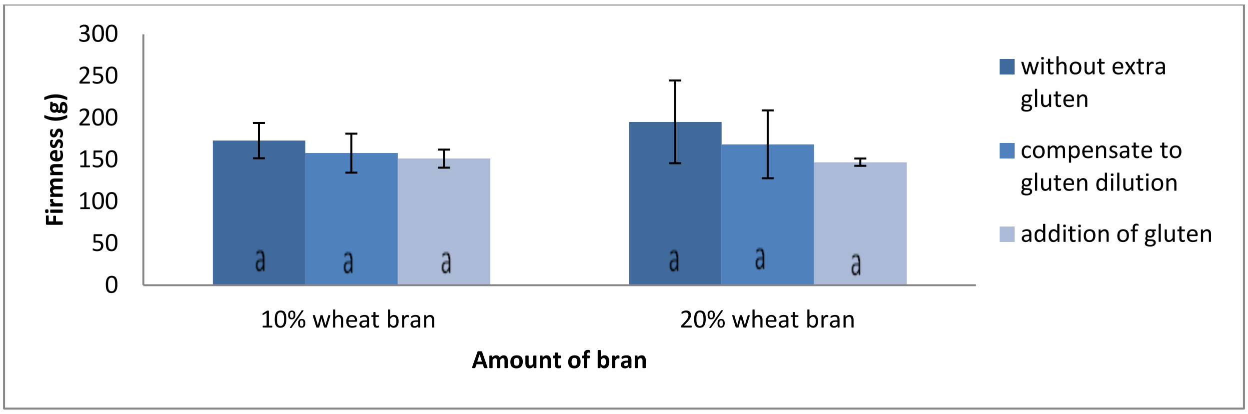

Figure 8. Firmness of breads supplemented with 10% and 20% wheat bran, with different levels of added gluten. Columns marked by the same letter are not statistically different at P<0.05%.

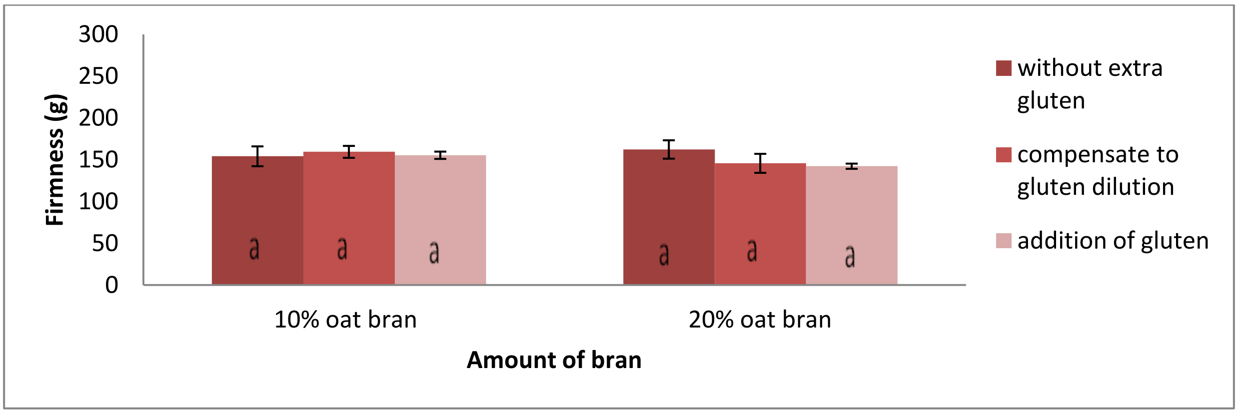

Figure 9. Firmness of breads supplemented with 10% and 20% oat bran, with different levels of added gluten. Columns marked by the same letter are not statistically different at P<0.05%.

3.4 Effects of yeast content on the quality of wheat bran enriched breads

The amount of yeast had no effect on the specific volume of wheat bran enriched bread. Higher amounts of yeast increased the specific volume slightly when the oat bran was used. The addition of yeast showed a trend towards decreased firmness at higher addition levels, giving softer bread crumb (Figure 10 and 11).

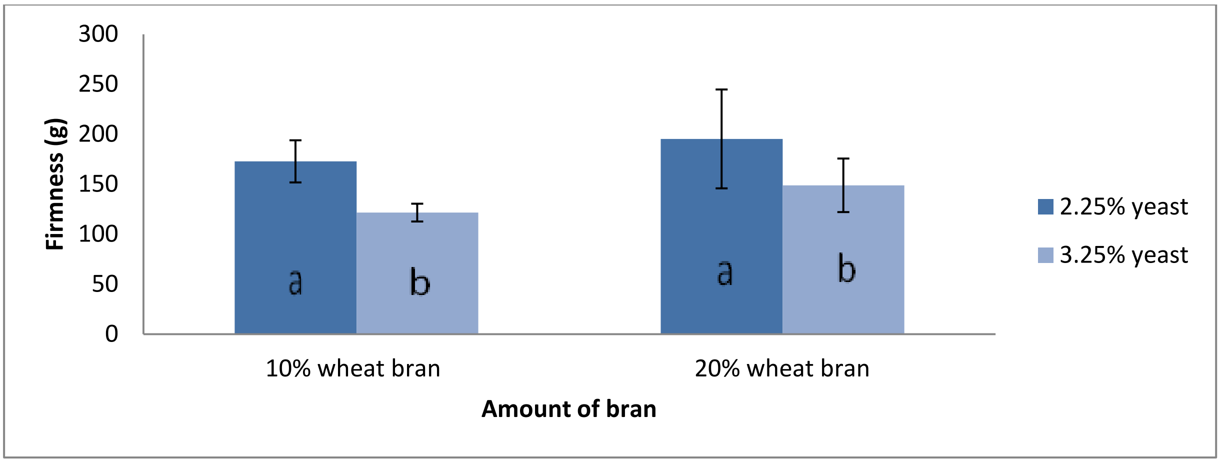

Figure 10. Firmness of breads supplemented with 10% and 20% wheat bran, with different levels of yeast. Columns marked by the same letter are not statistically different at P<0.05%.

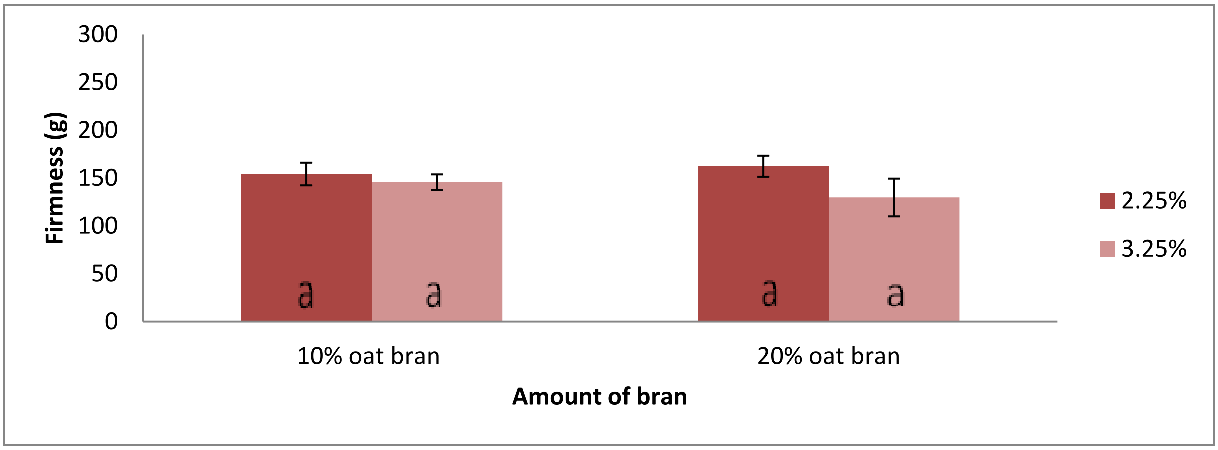

Figure 11. Firmness of breads supplemented with 10% and 20% oat bran, with different levels of yeast. Columns marked by the same letter are not statistically different at P<0.05%.

4. Discussion and conclusion

As expected the addition of wheat or oat bran decreased the bread specific volume. Katina et al. (2006) reported a decrease in specific volume in bread containing 20% wheat bran. However, not all studies resulted in the same conclusion. Curti et al. (2013) reported no significant difference between the volume of the control bread and bread containing 13% wheat bran, while Kaprelyants et al. (2013) noticed that small substitution levels (5 to 11%) increased the bread volume whereas higher levels (23%) decreased bread volume. It was also found that, over the range of water addition rates studied (-2% to +2%), no effect on specific volume was found. This may suggest that water addition is not as important for specific volume as previously thought.

Substitution of 10% flour with wheat or oat bran decreased bread crumb firmness. When the addition level was increased to 20% the firmness of the wheat bran bread was similar to the control bread. However, at 20% oat bran substitution level it was found that the bread was softer compared to the control. This may be due to the relationship between bread firmness and specific volume, with greater volume resulting in softer bread. The specific volume of the oat bran bread at 20% was greater than the wheat bran bread at the same level. Date of testing may also influence the results; bread from this trial was analysed DOP +1 and so the firmness of the bread may change over its shelf life.

Both wheat and oat bran substitution decreased the number of cells in the crumb, which was the expected effect. This may be caused by reduced gas cell stability that leads to coalescence. Van Dyck et al. (2014) noticed that bran substitution level had no effect on total porosity but instead affected closed porosity. Closed pores are cells that are not connected to neighbour cells by open breaks in the cells walls. They found that whole wheat bread contained significantly more closed pores compared to half wheat bread, which itself had more closed pores than white breads. This may be explained by an increase in cell wall thickness preventing them from rupturing during baking, which we plan to investigate further in the next stage of the project.

Water content had no effect on bread firmness with 10% substitution of flour with wheat or oat bran, and only a slight effect on firmness at the 20% level. Kaprelyants et al. (2013) reported that water content (±2% from optimum) or the amount of added gluten did not have an effect on specific volume. One possible explanation for their results might be that strong flour was used and contained sufficient gluten. Mastromatteo et al. (2013) reported that water content had an effect on crumb firmness with white bread when the water content ranged from 54 to 74%, with medium water addition levels giving the softest crumb. Understanding the effects of water addition levels on dough and bread parameters remains an area for further study.

Higher yeast content slightly increased the specific volume of oat bran breads, but not when wheat bran was used. Proof time (to height) was similar for all bread types, although higher yeast content shortened the proof time. This suggested that the dough was able to contain the carbon dioxide within intact gas cells but the oven step caused the cells to leak in different ways. This finding has been supported by other work and remains an area for further study (Auger, 2014).

Results presented in this report raise a number of questions about the effects of bran on gas cell stability in dough. There are a number of factors that influence the experiments and could lead to confusion with the results. Variation in bran composition and physical properties is key to understanding how a bran fraction will behave when mixed into dough. Bran of different particle size fraction is sometimes prepared by sifting the whole bran, which may lead to differences in chemical composition of bran fractions, but can also be prepared by grinding to a defined particle size. It is likely that the chemical make-up of bran prepared in these two ways will be different.

5. Further work

The next stage of the project will investigate the effect of bran on the gas holding capacity of dough. One factor to consider will be the water absorption effect of bran pre-heat treatment, pre-soaking and the particle size. It will aim to answer a number of questions:

- Why is the oven spring less significant in bran-enriched bread? Micro CT (a type of non-invasive X-ray scanning method) is available to visualise gas cells in bread and can show the bran particles relative to gas cell walls.
- How does competition for water between bran and other recipe components take place during dough mixing, proof and baking?
- How does the amount of starch in bran flour affect the gluten-starch network, and how much starch is needed to create the network?

6. References

[AACC] American Association of Cereal Chemists. 2001. The definition of dietary fiber. Cereal Foods World. 46:112-26.

[EC] European Commission. 2008. Commission Directive 2008/100/EC Annex II. Official Journal of the European Union.

[EC] European Commission. 2013. Nutrition claims and conditions applying to them as listed in the annex of regulation (EC) n°1924/2006 Available: http://ec.europa.eu/food/food/labellingnutrition/claims/community_register/nutrition_claims_en.htm. Read: 21.8.14.

[EC] European Commission. 2014. Health claims. Available: http://ec.europa.eu/nuhclaims/?event=search. Read: 21.8.14.

[FAO] The Food and Agricultural Organisation. 2008. Codex Alimentarius Commission CL 2008/35-NFSDU: Distribution of the report of the 30th session of the Codex Committee on nutrition and foods for special dietary uses (ALINORM 09/32/26).

[FSA] 2010. Food Standards Agency and Department of Health. National Diet and Nutrition Survey, Headline results from Year 1 of the Rolling Programme (2008/2009).

[NIHW] National Institute for Health and Welfare. 2012. The National FINDIET 2012 Survey. THL raportti 16/2013. Tampere.

[VRN] Valtion ravitsemusneuvottelukunta. 2014. Terveyttä ruoasta, suomalaiset ravitsemusuositukset 2014. 2nd edition. Tampere.

Antoine C, Peyron S, Mabille F, Lapierre C, Bouchet B, Abecassis J, Rouau X. 2003. Individual contribution of grain outer layers and their cell wall structure to mechanical properties of wheat bran. J Agric Food Chem 51:2026–33.

Auger, F. 2014. Bubble generation and stabilization in bread. Presentation at Campden BRI Bakery Technology conference, Campden BRI, 3-4 June 2014.

Brewer LR, Kubola J, Siriamornpun S, Herald TJ, Shi Y-C. 2013. Wheat bran particle size influence on phytochemical extractability and antioxidant properties, Food Chem. doi: http://dx.doi.org/10.1016/j.foodchem.2013.11.128

Cauvain S., Young L, 2008. Bakery food manufacture and quality: water control and effects. 2nd edition. Oxford, United Kingdom: Wiley-Blackwell. 289 pp.

Curti E, Carini E, Bonacini, Tribuzio G, Vittadini E. 2013. Effect of the addition of bran fractions on bread properties. J Cereal Sci 57:325-32

Flander L, Salmenkallio-Marttila M, Suortti T, Autio K. 2007. Optimization of ingredients and baking process for improved wholemeal oat quality. LWT 40:860-70.

Hoseney RC. 1998. Principles of cereal science and technology. 2nd edition. Minnesota: AACC International. p.378.

Jones JM. 2007. Dietary fibre or whole grain or both? Salovaara H, Gates F, Tenkanen M, editors. Dietary Fibre Components and Functions. 1 edition. Wageningen, Netherlands. Wageningen Academic. p. 13-30

Kaprelyants L, Fedosov S, Zhygunov D. 2013. Baking properties and biochemical composition of wheat flour with bran and shorts. J Sci Food Agric 93:3611-6

Katina K, Salmenkallio-Marttila M, Partanen R, Forcsell P, Autio K. 2006. Effects of sourdough and enzymes on staling of high-fibre wheat bread. Food Sci Tech 39:479-91.

Lai CS, Hoseney RC, Davis AB. 1989. Effects of wheat bran in breadmaking. Cereal Chem 66(3):217-9.

Mälkki Y. 2001. Oat fiber, Production, Composition, Physicochemical properties, Physiological effects, Safety and food applications. Dreher ML and Sung soo Cho S. Handbook of Dietary Fiber. CRC Press.

Maher N, Gates F. 2014. Determining water absorption for improved fibre enriched baked goods. Campden BRI, R&D report no. 373

Mastromatteo M, Guida M, Danza A, Laverse J, Frisullo P, Lampignano V, Del Nobile MA. 2013. Rheological, microstructural and sensorial properties of durum wheat bread as affected by dough water content, Food Research Int 51:458-66.

Mialon VS, Clark MR, Leppard PI, Cox DN. 2002. The effect of dietary fibre information on consumer responses to breads and ‘‘English’’ muffins: a cross-cultural study. Food Quality and Preference 13:1–12

Noort MWJ, van Haaster D. Hemery Y. Schols HA. Hamer RJ. 2010. The effect of particle size of wheat bran fractions on bread quality – evidence for fibre-protein interactions. J Cereal Sci. 52:59-64.

Prückler M, Siebenhandl-Ehn S, Apprich S, Höltinger S, Haas C, Schmid E, Kneifel W. 2014. Wheat bran-based biorefinery 1: Composition of wheat bran and strategies of functionalization. Food Sci Tech 56:211-2.

Purhagen JK, Sjöö ME, Eliasson A-C. 2012. Fibre-rich additives – the effect on staling and their function in free-standing and pan-baked bread. J Sci Food Agric 92:1201-13.

Seyer M-E, Gelinas P. 2009. Bran characteristics and wheat performance in whole wheat bread. Int J Food Sci Tech 44:688-93.

Sivam AS, Sun-Waterhouse D, Quek SY, Perera CO. 2010. Properties of bread dough with added fiber polysaccharides and phenolic antioxidants: a review. J. Food Sci: 75:R163-74.

Van Dyck T, Verboven P, Herremans E, Defraeye T, Van Campenhout L, Wevers M, Claes J, Nicolai B. 2014. Characterisation of structural patterns in bread as evaluated by X-ray computer tomography. J Food Eng 123:67-77

Zhang D, Moore WR. 1997. Effect of wheat bran particle size on dough rheological properties. J Sci Food Agric 74:490-6.

Zhang D, Moore WR. 1999. Wheat bran particle size effect on bread baking performance and quality. J Sci Food Agric 79:805-9.