Wheat bran arabinoxylans in breadmaking

– Their effect on staling and other quality aspects

Arabinoxylaner från vetekli i brödbakning – effekt på hållbarhet och andra kvalitetsaspekter

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Abstract

In the face of agriculture-related global challenges, there is a need to produce food more efficiently and effectively, reduce food waste and increase utilization of agricultural by-products such as wheat bran. Extracted arabinoxylans from wheat bran have previously been found to retard staling and thus extend shelf life of bread. The purpose of this study was therefore to investigate the effect of addition of 0.3, 1.0 and 1.7 % of three arabinoxylan fractions (extract, feruloylated and unferuloylated arabinoxylan) on dough and bread quality aspects and on staling, to evaluate the fractions in terms of their potential as bread improvers, and to determine whether arabinoxylan addition influences consumer acceptance of fresh and stored bread. Breads were made with each arabinoxylan fraction and addition level combination. Dough and bread quality aspects were determined on the baking day. Staling-related parameters were measured after 1, 7 and 14 days of storage. Bread quality aspects were largely unaffected by arabinoxylan addition. Some positive effect on textural parameters during storage were observed. The main difference between the fractions was their effect on baking absorption and crumb moisture content. In the consumer acceptance test, arabinoxylan addition did not significantly influence acceptance of fresh or stored breads. All three arabinoxylan fractions have potential as bread improvers to retard staling while maintaining quality. However, the overall lack of significant results in this study calls for further research to elucidate the future role of wheat bran arabinoxylans in industrial breadmaking.

Keywords: arabinoxylan, wheat bran, breadmaking, staling, bread quality

Sammanfattning

För att möta de jordbruksrelaterade utmaningar som världen står inför behövs en effektivare matproduktion, reducerat matsvinn och ökad användning av agrara biprodukter såsom vetekli. Extraherade arabinoxylaner från vetekli har tidigare visats kunna motverka föråldringsprocessen i bröd och därmed förlänga brödets hållbarhet. Syftet med denna studie var därför att undersöka effekten av att tillsätta 0,3, 1,0 och 1,7 % av tre olika arabinoxylanfraktioner (extrakt samt arabinoxylanfraktion med och utan ferulasyra) på kvalitetsegenskaper hos deg och bröd och på föråldringprocessen, att utvärdera fraktionernas potential som brödtillsats, samt att undersöka huruvida tillsats av arabinoxylan påverkar konsumenters acceptans av färskt och lagrat bröd. Bakning av bröd gjordes med alla kombinationer av arabinoxylanfraktion och tillsatsnivå. Deg- och brödegenskaper mättes på bakdagen. Lagringsrelaterade parametrar mättes efter 1, 7 och 14 dagars lagring. Brödkvaliteten påverkades inte nämnvärt av arabinoxylantillsats. Däremot observerades vissa positiva effekter på brödets textur under lagring. Den huvudsakliga skillnaden mellan fraktionerna var deras effekt på vattenabsorption vid bakning och vattenhalt i brödets inkråm. Vid det sensoriska konsumenttestet gav arabinoxylantillsats ingen effekt på acceptansen av färskt eller lagrat bröd. Alla tre arabinoxylanfraktionerna har potential att användas som brödtillsats för att bromsa åldrandeprocessen med bibehållen brödkvalitet. Det låga antalet signifikanta resultat i denna studie pekar dock på behovet av vidare forskning för att utreda vilken roll arabinoxylaner från vetekli har i framtidens industriella brödbakning.

Nyckelord: arabinoxylan, vetekli, brödbakning, föråldring av bröd, brödkvalitet

"All sorrows are less with bread."

Miguel de Cervantes Saavedra

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Abbreviations

Ara*f*	A-L-arabinofuranosyl
AX	Arabinoxylan
AXE	Arabinoxylan extract
AXOS	Arabinoxylan oligosaccharides
BU	Brabender units
CO_2	Carbon dioxide
CRD	Completely randomized design
DDT	Dough development time
FA	Ferulic acid
FAX	Feruloylated arabinoxylan
HMW	High-molecular-weight
LMW	Low-molecular-weight
MW	Molecular weight
NSP	Non-starch polysaccharides
RCBD	Randomized complete block design
RT	Room temperature
SLU	Swedish University of Agricultural Sciences
TA	Texture analyzer
TPA	Texture profile analysis
UFAX	Unferuloylated arabinoxylan
WB	Wheat bran
WEAX	Water-extractable arabinoxylan
WUAX	Water-unextractable arabinoxylan
Xyl*p*	β-D-xylopyranosyl

1. Introduction

The world is facing several challenges related to agricultural food production. While the global population continues to grow, the amount of arable land cannot increase much (Alexandratos & Bruinsma 2012). Agriculture is a major contributor to greenhouse gas emissions and other environmental impacts (Tilman *et al.* 2001). Yet, one third of all the food that is produced is lost or wasted (Food and Agriculture Organization of the United Nations 2011). More than 10 % of the world population is undernourished (United Nations 2019). At the same time, almost 25 % of people are overweight or obese (World Health Organization 2020) and the prevalence of diet-related non-communicable diseases is increasing (Habib & Saha 2010). In order to meet these challenges and reach sustainability targets such as the Sustainable Development Goals (United Nations n.d.), food production must become more efficient and effective. By increasing the utilization of agricultural by-products and reducing waste, more food can be produced with less resources and reduced environmental impact.

Bread has been a major staple food worldwide for thousands of years, and still is. Bread is usually made from wheat, one of the most extensively grown crops globally (Wrigley 2009). During milling of wheat into white flour, the bran is removed along with the germ (Wrigley 2009). This is a waste of agricultural resources as the bran constitutes about 14-25 % of the kernel weight (Maes & Delcour 2002; Prückler *et al.* 2014). It is also a waste of nutrients, since bran contains compounds with known health benefits (Prückler *et al.* 2014). In addition to this, fresh bread is among the most wasted food commodities on retail and consumer level (Østergaard & Hanssen 2018), due to its short shelf life and consumers' demand for high-quality fresh bread (Lebersorger & Schneider 2014; Silvennoinen *et al.* 2014). Reducing the staling rate of bread could thus help reduce food waste.

Due to its high carbohydrate content, bread is a calory dense foodstuff (Rosell 2019). Although cereal grains are generally a major source of dietary fiber (Dewettinck *et al.* 2008), the dietary fiber content is relatively low in white bread (Li *et al.* 2002). Dietary fiber is known to have health benefits and decrease the risk of several non-communicable diseases such as cardiovascular disease, hypertension and type-2 diabetes (Dewettinck *et al.* 2008). A high dietary fiber intake is recommended by the Nordic Nutrition Recommendations to promote the health of

the population (Nordic Council of Ministers 2014). One way to increase the dietary fiber content of bread is to add wheat bran (WB). Unfortunately, bran generally has detrimental effects on the quality of bread, making it unattractive for consumers (Coda *et al.* 2015).

The main dietary fiber in WB is arabinoxylan (AX) (Maes & Delcour 2002). AX has several functional properties and therefore has potential as a valuable co-product from wheat milling (Koegelenberg & Chimphango 2017). In bread, the addition of optimal levels of AX from WB has been shown to improve quality aspects like volume and to prolong shelf life by retarding staling (Biliaderis *et al.* 1995). Hence, AX holds potential to replace the additives and improvers that are used today in the bread industry to improve quality and extend shelf life, while also boosting the dietary fiber content. Consumers tend to be suspicious towards additives (Kaptan & Kayısoglu 2015), while an improved dietary fiber content is generally considered attractive (Collar 2008). Nevertheless, consumers often prefer the look and taste of white bread (Collar 2008; Hartikainen *et al.* 2014), which makes addition of dietary fiber a challenge. If AX could be used in breadmaking to retard staling while maintaining other quality aspects and consumer acceptance, it could help reduce food waste and improve the nutritional value of bread. This would contribute to a more ecologically, economically and socially sustainable food chain.

1.1. Purpose and objectives

The purpose of this study was to investigate the effect of WB arabinoxylans on staling of wheat bread during storage and on some other quality aspects of the bread and dough. The study aimed to provide insight in the potential to use AX fractions as bread improvers to prolong the shelf life of bread while maintaining quality. The objectives were the following:

- Study the effect of replacing wheat flour with AX fractions at different levels on dough and bread quality aspects and on staling during storage,
- Evaluate three types of AX fractions in terms of their potential as bread improvers,
- Determine whether addition of AX to bread influences consumer acceptance of freshly baked and stored bread.

2. Background

2.1. Bread

People have been eating bread for thousands of years and it is considered a staple food worldwide (Cauvain 2012). Bread is made from flour, water, salt and yeast (Delcour & Hoseney 2010c). Often, other ingredients like sugar, fat or improvers are added for flavouring, nutritional or functional reasons. Bread is usually made with wheat flour due to its unique ability to form a gluten network which gives a viscoelastic dough that entraps gas during fermentation (Delcour & Hoseney 2010b).

2.1.1. Breadmaking

Breadmaking is a complex and dynamic process which involves physiochemical changes and interactions between dough components (Rosell 2019). In Europe, bread is usually made using the straight-dough procedure: all ingredients are mixed into a dough which is fermented, molded into loaves and then proofed in pans before baking (Delcour & Hoseney 2010c).

During each step of the breadmaking process, important changes and interactions occur. During mixing, the flour particles are hydrated and the gluten forms a continuous protein network which gives the dough viscoelastic properties and enables incorporation of air bubbles (Rosell 2019). During fermentation, the dough increases in volume. This is due to anaerobic fermentation of sugars by yeast into ethanol and carbon dioxide (CO_2), which causes gas bubbles to grow in size (Delcour & Hoseney 2010c). Often, the dough is punched at least once during fermentation, in order to create new gas cells and redistribute ingredients to make more sugar available to the yeast (Delcour & Hoseney 2010c). After fermentation, the dough is divided, and each piece is sheeted and molded to into loaves. The loaves are proofed for about one hour, which further increases volume (Delcour & Hoseney 2010c).

During baking, the dough turns into bread through a series of processes. During the initial baking phase (below the yeast inactivation temperature), the yeast becomes increasingly active and produces more CO_2. Moreover, CO_2 becomes less

soluble and moves from the aqueous phase into the air bubbles, and gas entrapped in the dough expands with heat. These changes cause a volume increase known as ovenspring (Delcour & Hoseney 2010c). Next, the dough surface dries and forms a crust which undergoes browning as baking continues. Browning is caused by Maillard reactions between reducing sugars and proteins. When the crumb temperature increases, starch granules swell and gelatinize while the gluten network becomes stiffer due to protein denaturation and cross-linking (Gray & Bemiller 2003). Eventually, the gas cells rupture and expansion ceases. A sponge structure is formed with gas as its continuous phase – the dough has turned into bread.

2.1.2. What is bread quality?

The notion of bread quality is subjective and varies among persons, cultures and bread types (Rosell 2019). Even so, there are various methods to assess the quality of bread. According to Rosell (2019), the concept of bread quality can be defined in terms of instrumental measurements, sensory evaluation and nutritional aspects.

Instrumental quality

In the scientific literature, bread quality is often assessed based on objectively measurable attributes (Rosell 2019) related to the appearance and texture of the bread (Scanlon & Zghal 2001). Some instrumental parameters commonly used to assess bread quality are specific volume, crust colour, crumb texture (such as hardness, springiness and cohesiveness), crust properties, water activity, moisture content, width/height ratio, crumb cell structure and volatile compounds (Rosell 2019). In addition to properties of the final bread, rheological dough properties are often measured since they are important determinants for final product quality and for processing (Mondal & Datta 2008). Water absorption, dough development time (DDT) and dough stability time are commonly measured rheological dough properties (Tilley *et al.* 2012).

Sensory quality

The individual judgement of food quality is based on the sensory experience during eating. Bread quality can be decided by the sensory perception of the visual appearance, smell, texture and flavour of the bread (Rosell 2019). According to Rosell (2019), the quality of bread is strongly connected to freshness.

The sensory quality of bread is generally assessed either by descriptive or affective analysis (Marinopoulou *et al.* 2019). Descriptive analysis uses trained panellists to quantify the perceived intensity of bread attributes such as specific tastes, smells and texture. Affective analysis uses untrained consumer panels to quantify the degree of liking of a product and its attributes (Lawless & Heymann 2010).

Nutritional quality

As consumers become more conscious about nutrition and health, these aspects are increasingly important for the concept of bread quality (Rosell 2019). Some common parameters for nutritional quality assessment or bread are nutritional content, glycemic index and glycemic load, which are influenced by the dietary fiber content (Rosell 2019). Although excluded from the scope of this study, an improved dietary fiber content could thus improve the nutritional quality of bread.

2.1.3. Bread staling

As a major determinant of bread quality (Rosell 2019), freshness is of great importance for bread makers, retailers and consumers. During storage, bread gradually loses its freshness in a process called staling. Staling has a detrimental effect on bread quality and consumer acceptance (Cauvain 2015), and causes significant food waste worldwide (Fadda *et al.* 2014). Retarding staling of bread therefore has the potential to reduce waste and mitigate environmental and economic burdens related to food waste.

Staling of bread is the result of complex chemical and physical changes in the crust and crumb (Fadda *et al.* 2014) which begin immediately after baking (Cauvain 2015). These changes mainly lead to increased crumb firmness, but also to deterioration of important sensory parameters like flavour, aroma and texture of crumb and crust (Fadda *et al.* 2014; Cauvain 2015). Although staling affects both crumb and crust, crumb staling is generally the main concern for the consumer as well as for the researcher (Gray & Bemiller 2003; Cauvain 2015).

Despite the extensive research on the mechanisms behind bread staling (Fadda *et al.* 2014), the phenomenon is not yet fully understood (Gray & Bemiller 2003; Rayas-Duarte & Mulvaney 2012). Gray and Bemiller (2003) present an overview of proposed staling mechanisms and the role of different bread components in the staling process. They conclude that retrogradation of starch (mainly amylopectin) contributes to staling although there may not be a direct cause-and-effect relationship between starch retrogradation and crumb firming. Gluten may be involved in crumb firming through interactions with starch, but research is contradictory and the role of gluten remains unclear. Pentosans such as AX are generally believed to retard staling, either by increasing the moisture content of the crumb, interacting with gluten or reducing starch retrogradation (see also section 2.2.4). Native flour lipids and shortening reduce the firming rate of bread, possibly through lipid-protein or lipid-starch interactions (Gray & Bemiller 2003).

The rate of staling is influenced by factors like storage temperature, moisture migration within the bread (Gray & Bemiller 2003) and the presence of anti-staling agents (Cauvain 2015). The staling rate increases at lower storage temperatures (Colwell *et al.* 1969). This may be explained by an accelerated rate of starch retrogradation at low (but not freezing) temperatures (Aguirre *et al.* 2011).

Although staling is not caused by *loss* of moisture from the bread (Boussingault 1852; Cauvain 2015), moisture migration within the bread is important for the staling process (Gray & Bemiller 2003; Choi *et al.* 2008). During storage, water migrates from crumb to crust and is redistributed between bread components (Gray & Bemiller 2003). Different mechanisms involved in water redistribution during staling have been proposed, but the topic remains relatively unclear (Cauvain 2015). Generally, however, a higher moisture content of the bread leads to a slower rate of staling (Cauvain 2015). Staling can be retarded by the addition of anti-staling agents such as enzymes, emulsifiers and pentosans (Cauvain 2015).

In summary, staling of bread mainly manifests as crumb firming and general loss of quality. Although much remains unknown, starch retrogradation and moisture migration from crumb to crust are regarded as two main processes responsible for crumb firming (Cauvain 2015). Staling can be retarded by addition of anti-staling agents.

2.2. Wheat arabinoxylans

2.2.1. Wheat and wheat bran

Wheat (*Triticum* spp.*)* is one of the most important crops worldwide both in terms of production volume and human nutrition (Gooding 2009). The wheat kernel consists of three major parts: the germ, the endosperm and the bran (Posner 2009). The germ is the embryo of the new plant, the endosperm provides energy and nutrients for the germinating seed and the bran encapsulates and protects the seed. During milling of wheat, the endosperm is separated from the bran and germ, which are considered by-products (Posner 2009). The endosperm is rich in starch and proteins and is usually processed into white flour (Cornell 2012). The bran is not a botanical constituent of the wheat kernel, but a fraction that results from the milling process. It consists of the outer and inner pericarp, the seed coat (testa), the nucellar epidermis (hyaline layer) and the aleurone layer (Bechtel *et al.* 2009). In a botanical sense, the aleurone layer is part of the endosperm, but since it is removed with the bran during milling it is considered as part of the bran (Bechtel *et al.* 2009). The bran mainly consists of non-starch polysaccharides (NSP) (Maes & Delcour 2002) and is thus a good source of dietary fiber. Today, WB is primarily used as animal feed (Posner 2009).

2.2.2. Arabinoxylan structure and function

Arabinoxylans (AX) are the main non-cellulosic NSP, or hemicellulose, in the cell walls of cereals and other plants (Izydorczyk 2009). Wheat contains about 6-7 % arabinoxylan (Delcour & Hoseney 2010a), present in both the endosperm and the

bran (Izydorczyk 2009).WB, which makes up about 14-19 % of the wheat kernel weight, contains around 30 % AX (Maes & Delcour 2002). Thus, WB is a good source of AX.

AX consist of a linear 1→4 linked xylopyranosyl (Xyl*p*) backbone substituted with monomeric α-L-arabinofuranosyl (Ara*f*) residues at O2, O3 or both O2 and O3 positions (Rosicka-Kaczmarek *et al.* 2016). In secondary cell walls, the arabinoxylan structure can also contain attached glucuronic acid residues (Izydorczyk 2009), and is then referred to as glucuronoarabinoxylan (Delcour & Hoseney 2010a). The function of arabinoxylans in the wheat endosperm and aleurone layer is to maintain the cell wall integrity through matrix gel-formation. In the pericarp tissues of the bran, arabinoxylans provide rigidity to the cell walls through covalent crosslinks to other AX molecules and to other cell wall components (Izydorczyk 2009).

Arabinoxylan crosslinking occurs through ester linkages between Ara*f* and ferulic acid (FA, see Figure 1). FA constitutes up to 0.9 % of arabinoxylans (Rosicka-Kaczmarek *et al.* 2016). It is a phenolic acid which possesses antioxidant properties, radical scavenging activity and lipid peroxidation potential (Srinivasan *et al.* 2007).

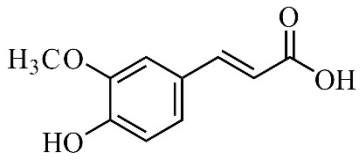

Figure 1. Ferulic acid.

Arabinoxylans are classified based on their extractability into water-extractable arabinoxylans (WEAX) and water-unextractable arabinoxylans (WUAX). WEAX are loosely bound to cell walls and can easily be extracted, while WUAX are linked to other cell-wall components and are therefore more difficult to extract (Rosicka-Kaczmarek *et al.* 2016). Crosslinking between AX molecules gives a high molecular weight and makes the AX less extractable (Delcour & Hoseney 2010a). In WB, only about 6 % of AX are water-extractable (Wang *et al.* 2020).

The solubility of AX is influenced by its structural features such as arabinose/xylose ratio (degree of substitution), degree of crosslinking and molecular weight (MW). A higher arabinose content makes the AX more soluble (Rosicka-Kaczmarek *et al.* 2016). The arabinose/xylose ratio varies among cell wall types (Izydorczyk 2009). Crosslinking via FA decreases solubility. The FA content and degree of crosslinking are also tissue dependent. Bran tissue cell walls generally contain more FA and have a higher degree of crosslinking than endosperm cell walls (Izydorczyk 2009).

Water-soluble AX can form highly viscous solutions depending on polymer concentration, molecular weight, degree of crosslinking and substitution pattern

and degree (Izydorczyk 2009; Delcour & Hoseney 2010a; Rosicka-Kaczmarek *et al.* 2016). WUAX have high water holding capacity (Delcour & Hoseney 2010a). Under oxidizing conditions, high-molecular weight (HMW) AX also have the ability to form weak gels at high concentrations, stabilized by hydrogen bonds and crosslinks with ferulic acid (Courtin & Delcour 2002; Izydorczyk 2009). This is called oxidative gelation.

AX can be partially degraded into arabino-oligosaccharides (AXOS). Degradation is usually carried out by enzymatic hydrolysis using endoxylanases (Izydorczyk 2009). Furthermore, FA can be removed from the AX backbone using the enzyme feruloyl esterase (Rosicka-Kaczmarek *et al.* 2016).

2.2.3. Extraction and isolation

AX are usually isolated using aqueous and alkaline extraction and/or enzymatic treatment (Döring *et al.* 2016). As explained above, WEAX can easily be extracted from the plant tissue using water. WUAX can be extracted with alkali or with the use of enzymes to partially degrade the polymer (Izydorczyk 2009). The selection of extraction method impacts the AX structure, and in turn its functionality. For example, enzymatic extraction yields AX with lower molecular weight, and alkaline extraction produces AX with a lower FA content (Wang *et al.* 2020). The type of enzyme used for extraction and/or degradation of AX into AXOS influences structural properties like substitution degree, substitution pattern and arabinose/xylose ratio (Courtin & Delcour 2002; Wang *et al.* 2020).

The AX fractions used in the present study were produced from WB using a patented method with combined enzymatic treatment, subcritical water extraction, ethanol precipitation and membrane ultrafiltration (Vilaplana & Ruthes 2017). The WB is first pretreated with enzymes to remove starch and β-glucans. Extraction of AX is carried out using subcritical water at a temperature which preserves a high molecular weight. The product is AX extract (AXE) containing WEAX and FA. The FA is removed through saponification. The AXE with and without FA is precipitated with ethanol and then filtrated to yield the purified feruloylated AX (FAX) and unferuloylated AX (UFAX).

2.2.4. Effect on dough and bread properties

AX are known to influence bread and dough properties in various ways, mainly due to their high water-binding capacity and gelling properties (Kaur *et al.* 2019). The effect depends on the molecular weight and structure as well as on the concentration. Too high concentration of AX can reverse the potentially beneficial effects of adding AX to the dough (Muralikrishna & Rao 2007).

WEAX have been found to increase water absorption of the dough, increase DDT and dough stability, and give larger bread volume, improved crumb structure

and retarded staling (Courtin & Delcour 2002; Döring *et al.* 2016; Rosicka-Kaczmarek *et al.* 2016; Kaur *et al.* 2019). WEAX is believed to improve gas retention in the dough by increasing viscosity and stabilizing the film around gas bubbles, which slows down the diffusion of CO_2 out of the dough (Courtin & Delcour 2002; Izydorczyk 2009; Delcour & Hoseney 2010c). The increased stability of the dough foam structure prolongs oven rise and prevents gas coalescence, which increases loaf volume and gives a fine, homogenous crumb (Gan *et al.* 1995; Courtin & Delcour 2002). Improved volume and crumb structure could also be attributed to WEAX gel-formation and reinforcement of the gluten network during baking (Izydorczyk 2009; Rosicka-Kaczmarek *et al.* 2016).

Addition of WUAX to dough also increases water absorption (more so with increasing molecular weight (Izydorczyk 2009)), but generally has a negative impact on loaf volume, crumb structure and texture (Courtin & Delcour 2002). WUAX are thought to destabilize the dough structure through physically interfering with the gluten network development during dough-making and perforating gas cells during fermentation (Courtin & Delcour 2002; Izydorczyk 2009). They also compete with gluten for the available water in the dough (Courtin & Delcour 2002).

Both WEAX and WUAX have been shown to retard staling during storage by decreasing crumb firmness. The staling retardation can be attributed to either reduced starch retrogradation by interference with starch structures, or by increased moisture content which plasticizes the starch-gluten matrix (Courtin & Delcour 2002). Generally, a higher moisture content increases the rate of starch retrogradation (Izydorczyk 2009). However, the plasticizing effect of the increased moisture has a larger impact on crumb firmness (Courtin & Delcour 2002) and a higher moisture content leads to slower staling rates (Cauvain 2015).

2.3. Analysis methods

2.3.1. Farinograph

The most common instrument to measure rheological dough properties is the farinograph (Mondal & Datta 2008) (see Appendix I, Figure I). The farinograph provides empirical measurements, which are useful when assessing quality and processing performance of flours and doughs. However, empirical rheological tests depend on the instrument type, samples and testing conditions (Dobraszczyk & Morgenstern 2003). This means that farinograph measurements are only valid for this instrument and cannot be compared with measurements made with other instruments (Delcour & Hoseney 2010b).

The farinograph essentially measures the resistance of a dough during mixing. It can be used to determine water absorption of flours and dough parameters such as DDT (AACC 2000). During mixing, the resistance of the dough (usually measured

in Brabender units (BU)) is recorded in a farinogram. During the initial mixing phase, the resistance increases until optimum dough development or maximum resistance (MacRitchie 2016). This is the point where the flour particles are fully hydrated (Delcour & Hoseney 2010c). Upon continued mixing, the resistance decreases due to breakdown of the gluten network in the dough (MacRitchie 2016).

2.3.2. Image analysis

The cellular crumb structure of a bread slice can be evaluated by visual examination or by digital image analysis. Traditionally, the crumb structure was evaluated and scored by trained assessors. Nowadays, development of image processing technologies has enabled objective analysis of crumb structure (Young 2012).

Image analysis techniques are based on segmentation of an image into distinct segments which correspond to objects in the image. Thresholding is a segmentation method that distinguishes objects from background (crumb cells from crumb walls in the case of bread) through selection of grey level values (Gonzales-Barron & Butler 2006). After segmentation of the image into objects and background, the crumb structure of the bread slice is quantitatively evaluated in terms of number of cells per area, total cell area, mean cell size etc. (Scheuer *et al.* 2015).

2.3.3. Texture analysis

Food texture is defined by the International Organization for Standardization (ISO) as “all the mechanical, geometrical and surface attributes of a product perceptible by means of mechanical, tactile, and where appropriate, visual and auditory receptors” (ISO 1994). The concept of food texture includes both physical and sensory aspects and the correlation between them (Liu *et al.* 2019). Texture can thus be measured by sensory assessment or instrumentally, but instrumental measurements are only valuable if they can accurately predict sensory perceptions (Bourne 2002b; Liu *et al.* 2019).

Instrumental texture measurements produce quantifiable and reproducible data while requiring little time, money and labour (Bourne 2002c; Liu *et al.* 2019). This enables efficient food quality evaluation and control. The selection of instrumental test principle is often based on the corresponding sensory evaluation principle. For example, if the texture of a sample is evaluated by biting through the product with the teeth, then a texture profile analysis (TPA) is a suitable test (Bourne 2002c).

A widely used instrument to measure food texture by imitating human behaviour like biting, chewing or squeezing, is the texture analyzer (TA). The TA contains a probe controlled by a force transducer. The probe moves down and up, deforming the sample and transmitting the changes of deformation to the force transducer

Texture profile analysis (TPA) is a well-established empirical method to assess textural features of food samples. It uses a TA two-cycle uniaxial compression

which simulates the movement of the upper jaw during biting of food (Liu *et al.* 2019). A force-time curve (see Figure 2) is obtained from which several textural parameters like hardness, cohesiveness and springiness can be derived. Springiness and cohesiveness are considered positive attributes in bread, and they diminish when the baked products go stale (Young 2012). The textural parameters obtained from a TPA have been shown to correlate well with sensory evaluation of the same parameters (Bourne 2002a), especially for hardness (Szczesniak 2002). Table 1 gives the physical definition, corresponding sensory description and calculation of hardness, cohesiveness and springiness from the TPA force-time curve.

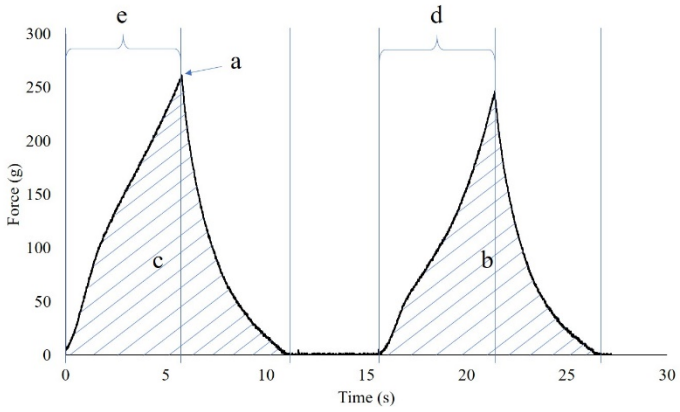

Figure 2. Typical force-time curve obtained from a TPA. a: peak force of first compression; b: area of second compression; c: area of first compression; d: distance of second compression; e: distance of first compression.

Table 1. Textural parameters obtained from a TPA

Textural parameter	**Physical definition (Szczesniak 2002)**	**Sensory definition (Szczesniak 2002)**	**TPA definition : (Bourne 2002a)**	**In Figure 2**
Hardness	Force needed to obtain a certain deformation	Force needed to compress food between molars	Peak force value of first compression	a
Cohesiveness	Degree of deformation before rupture of sample	Extent of compression of food between teeth before rupture	Ratio between force areas of second and first compression	b/c
Springiness	Rate of recovery after deformation of sample	Degree of recovery to original shape after compression between teeth	Recovered height of the sample between the two compressions	d/e

2.3.4. Sensory evaluation

The way people perceive food is the result of multiple sensory stimuli and the interpretation thereof. Food perception is thus a complex process which is difficult or impossible to predict using instrumental measurements only (Lawless &

Heymann 2010). The best way to predict how consumers will perceive food is therefore by using human sensory data (Lawless & Heymann 2010).

Sensory evaluation of food can serve different purposes, and the selection of test method should reflect the purpose of the study. Essentially, there are two types of sensory tests: analytic and hedonic tests. Analytic tests aim to reveal whether, how or how much products differ in specific sensory attributes. Hedonic, or affective, tests are performed when one wants to find out how well products are liked (Lawless & Heymann 2010). Hence, if the goal is to find out which product consumers will prefer, an affective test is suitable.

Affective tests use participants who are frequent users of the products and thus part of the target population. These consumer panellists are untrained and evaluate products in a non-analytical way. Contrary to trained panels, who generate very specific and precise sensory information, consumer panellists perceive products as a whole and should not be asked too to provide too specific or technical information. Instead, they are simply asked how much they like a product, or which alternative product they prefer (Lawless & Heymann 2010).

A widely used method to obtain quantitative affective data is the 9-point hedonic scale (see Figure 3). It uses a labeled and balanced scale with equal psychological intervals between scale steps. This allows for statistical analysis of the results. An affective test should use a large panel of about 75-150 consumers to compensate for the high variability between individual preferences.

9-point hedonic scale

☐ *Like extremely*

☐ *Like very much*

☐ *Like moderately*

☐ *Like slightly*

☐ *Neither like nor dislike*

☐ *Dislike slightly*

☐ *Dislike moderately*

☐ *Dislike very much*

☐ *Dislike extremely*

Figure 3. 9-point hedonic scale used to assess product liking in affective consumer tests

3. Materials and methods

3.1. Materials

Frozen arabinoxylan extract (AXE) in suspension, freeze dried feruloylated arabinoxylan (FAX) and freeze-dried unferuloylated arabinoxylan (UFAX) (see also section 2.2.3) were provided by Lantmännen. The MW distribution of UFAX and FAX were similar, with a peak at around 70 000 Da. The MW of AXE was unknown, but it likely contained some LMW AX which were lost during later purification steps into FAX and UFAX. The AX purity was 69 % for the AXE, 60 % for the FAX and 57 % for the UFAX. The AXE contained about 1.2 % FA, the FAX fraction contained 1.3 % FA and the UFAX contained only traces of FA. The fractions also contained 4-12 % β-glucans and 2-6 % starch as well as some protein and small amounts of other sugars. During the baking trials, the amount of each fraction was corrected so that a specified amount of *AX* was added to the dough. Therefore, the amount of AX *fraction* added at each level was different for each fraction.

Bread ingredients were purchased from the local supermarket: wheat flour (Kungsörnen Vetemjöl special, 12.73 % moisture content), sugar (Garant Strösocker), compressed yeast (Jästbolaget Kronjäst för matbröd), table salt (Jozo Fint salt utan jod) and rapeseed oil (Eldorado Rapsolja). Microencapsulated sorbic acid (MIRCAP® SB 85-G) was provided by Lantmännen. Tap water at the Swedish University of Agricultural Sciences (SLU), Uppsala, was used for all measurements and baking. All ingredients were used at room temperature (RT).

3.2. Preliminary baking trials

Before baking with all AX fractions, preliminary baking trials were conducted to test the bread recipe, optimize the baking method and determine which AX levels to use for further testing. The preliminary baking trials and their results are detailed in Appendix I.

3.3. Experimental design

This study used a completely randomized design (CRD) with two independent crossed factors at three levels: 1) AX fraction (AXE, FAX and UFAX) and 2) AX addition level (0.3, 1.0 and 1.7 %). Each fraction and level combination was baked in duplicates (i.e. two doughs were made for each combination). Four control doughs (no AX addition) were made. From each dough, four bread loaves were baked and tested for various parameters and after different storage times (further described below). Figure 4 shows an overview of the experimental design.

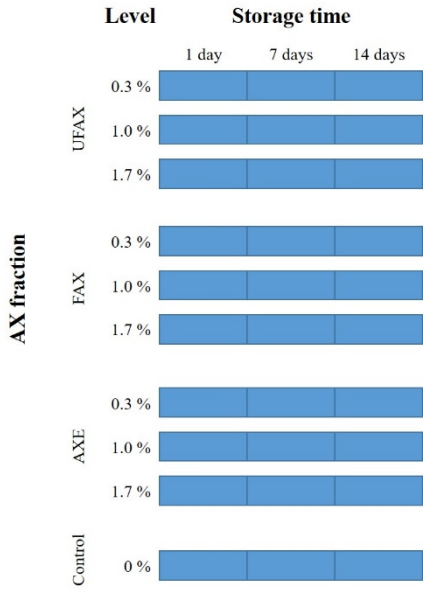

Figure 4. Overview of the experimental design.

The storage-dependency and destructive or non-destructive nature of measurements determined at what point they were carried out. Generally, on each baking day, four random doughs were prepared and baked. Dough properties were measured during dough-making. Each dough produced four loaves, and weight and volume (non-destructive measurements) were determined for all loaves on the day of baking. Texture analysis and moisture content (destructive measurements) were the storage-dependent parameters which were measured on day 1. 7 and 14. Although not storage dependent, image analysis was also a destructive measurement. Therefore, images for analysis were produced on day 1, 7 and 14 when loaves were sliced for moisture content and texture analysis.

3.4. Flour and dough measurements

3.4.1. Moisture content of flour

All flour was mixed to obtain one homogenous batch. Moisture content was determined gravimetrically in triplicates after oven drying at 105 °C overnight.

3.4.2. Baking absorption and dough development time

Baking absorption was measured as the amount of water required to obtain an optimal final dough consistency (410±30 BU) in the farinograph (Brabender GmbH & Co KG, Duisburg, Germany, see Appendix I, Figure I). This optimal dough consistency was determined by the test baker as described in Appendix I. DDT was determined as the time from water addition to dough peak consistency, in accordance with AACC method 54-21 (AACC 2000).

3.5. Breadmaking

Wheat pan breads were prepared with a farinograph (see Appendix I, Figure I) using the straight-dough procedure. The ingredients of the bread were as follows: wheat flour (or flour plus AX fraction), 100; oil, 2.5; sugar, 5; salt, 1.5; yeast, 4,6; microencapsulated sorbic acid, 0.15, water, variable. The amount of flour in each dough was equivalent to 300 g on a 14 % moisture content basis. Part of the flour was replaced by AX fractions to obtain an actual AX content of 0.3 %, 1.0 % and 1.7 % (of flour), respectively. The AXE suspension was freeze-dried and ground into a fine powder before use. AX fractions (AXE, FAX and UFAX) were dissolved in water prior to baking by stirring while heating to 80 °C and cooling to RT.

The dough was prepared by placing all ingredients except water and dissolved AX fraction in the farinograph mixing bowl and mixing for 1 minute. During continued mixing, all water along with the dissolved AX fraction was added quickly, using a funnel. Mixing was continued until reaching maximum (optimal) consistency. The dough was placed in a lightly greased bowl, covered with a tea towel and fermented for 1 h at approximately 38 °C and 50 % relative humidity. After fermentation, the dough was divided into four 100.0 g pieces and shaped to loaves by 20 rotations in an extensigraph (Brabender GmbH & Co KG, Duisburg, Germany, see Appendix I, Figure II). Each loaf was proofed in a lightly greased baking tin for 45 minutes and then baked for 10 minutes at 250 °C in a steam-filled rotating oven. After baking, the breads were cooled for about 3 hours under a tea towel and then stored in polyethylene (PE-LD) plastic bags at RT.

3.6. Bread measurements

Bread parameters were measured on the day of baking and during storage. The visual appearance of breads was also evaluated subjectively. Specific volume was determined on the day of baking. On day 1, 7 and 14 after baking, one loaf was taken out for determination of crumb structure, crumb texture and moisture content.

3.6.1. Specific volume

Loaves were weighed after cooling (around 3 hours after baking). Volume was determined using seed displacement method. Specific volume was calculated as volume divided by weight (ml/g).

3.6.2. Crumb structure by image analysis

From the loaf center, a 2.5 cm slice was cut manually and scanned on both sides in a photocopier (Ricoh IM C5500). Scanned images were processed and analyzed with the software ImageJ/Fiji. Images were cropped to the edges of the bread slice, converted to 8-bit format, segmented with the Percentile auto-threshold and subjected to the binary watershed process. An area starting at 50 pixels width and 50 pixels height and covering 130x150 pixels was selected. The structure of this area was analyzed using the function “Analyze particles” to generate particle count, total area, average size and % of total area. The process is shown in Figure 5.

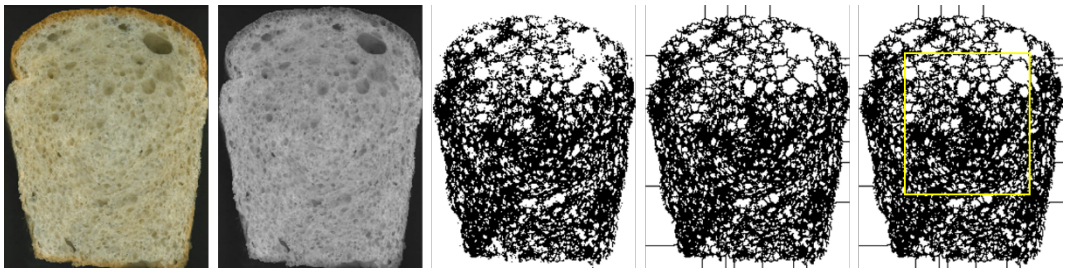

Figure 5. Image analysis of bread slices. From left to right: scanned bread slice; converted to 8-bit format; segmented using auto threshold "Percentile"; processed with "Watershed";130x150 pixel area selected for particle analysis.

3.6.3. Crumb texture by texture profile analysis

The same 2.5 cm slice used for image analysis was analyzed with TPA in a TA (TAplusDi, Stable Micro Systems) using a 50 kg load cell and a 25 mm cylinder aluminum probe. Each bread slice was centered on the base and compressed to 40 % of the height in two cycles (4 s between compressions). Pre-test speed, test speed and post-test speed were 1.70 mm/s. TPA data was collected and processed using Texture Expert Exceed software (Stable Micro Systems). The attributes derived

from the TPA were hardness, cohesiveness and springiness (see Table 1 and Figure 2).

3.6.4. Moisture content

From the center of each loaf, a 1 cm slice was cut manually. Using a 9 mm circular probe, three samples were cut out from the center of the slice and three samples from just beneath the upper crust (as shown in Figure 6). Moisture content was determined gravimetrically by oven drying the samples at 105 °C overnight.

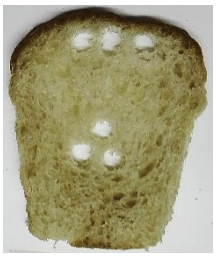

Figure 6. 1 cm slice from which samples have been cut out for crumb and crust moisture content determination

3.7. Sensory evaluation

A sensory evaluation was conducted using an untrained in-house consumer panel of 21 participants. The panel consisted of staff and students aged 25-66 (mean age: 40) at BioCenter, SLU, Uppsala, of which 62 % were female and 38 % were male. Only individuals who consume bread at least a few times per month were considered frequent consumers and thus eligible for participation.

The sensory evaluation used a two-way treatment structure and a randomized complete block design (RCBD). Control bread and 1.0 % UFAX breads were evaluated at 1 day and 7 days of age. The panellists were served two bread samples simultaneously (control and UFAX) in two blocks (1 day and 7 days), in a randomized and counterbalanced order. The panel scored the visual appearance, smell, texture, flavour and overall opinion of each sample on a 9-point labeled hedonic scale (see Figure 3).

The bread samples were prepared manually just prior to tasting by cutting approximately 1x4x4 cm slices which were placed on white paper plates. Panellists were provided water as palate cleanser and a napkin, along with a pen and a scoring sheet. The tasting environment was a neutral classroom. Details of the sensory evaluation are provided in Appendix II.

3.8. Statistical analysis

Data was analysed in Minitab® 18.1. One-way (two-tailed) ANOVA with Tukey pairwise comparison was run for all samples (AX fraction and level combination) on each measured parameter. One-way ANOVA was also run for each AX fraction on the measured parameters, to identify significant differences between fraction means. Linear regression analysis was conducted to identify correlations between measured parameters. Sensory data was analysed with a two-tailed t-test of means to identify significant differences between samples. 95 % significance level (α) was used for all statistical analysis. Raw data from all statistical analyses can be found in Appendices V-IX.

4. Results and discussion

4.1. Dough properties

Addition of 1.0 and 1.7 % FAX and UFAX significantly increased baking absorption with 8-15 %, as shown in Table 2. This is in agreement with previous findings, where AX has been observed to increase water absorption and baking absorption (Michniewicz *et al.* 1991; Biliaderis *et al.* 1995; Courtin & Delcour 2002; Hartikainen *et al.* 2014; Koegelenberg & Chimphango 2017). AXE addition, however, did not influence baking absorption at any addition level. Although all doughs had a similar final consistency, the doughs with high FAX/UFAX addition levels were generally stickier and more difficult to handle than the control. This may be related to the higher water content in these doughs.

AX addition did not have a significant effect on DDT. This is in contrast to the findings of other authors that addition of AX (Biliaderis *et al.* 1995) or processed WB (Gómez *et al.* 2011; Messia *et al.* 2016) increases DDT. However, reduced DDT for AX-supplemented doughs has also been reported (Courtin & Delcour 1998). The effect of AX addition on DDT therefore remains unclear.

Table 2. Average baking absorption and dough development time (DDT) of all doughs[a] (n=2).

Sample	Baking absorption (ml)	Increase in baking absorption compared to control (if significant)	DDT (min)
Control	181±1.0 de		11.4 a
0.3 % AXE	180±0.0 e		11.5 a
1.0 % AXE	180±0.0 e		11.8 a
1.7 % AXE	181±0.0 de		11.3 a
0.3 % FAX	183±0.7 d		11.8 a
1.0 % FAX	195±0.7 c	8 %	12.0 a
1.7 % FAX	206±0.7 b	14 %	12.5 a
0.3 % UFAX	182±0.4 de		11.5 a
1.0 % UFAX	195±0.7 c	8 %	11.5 a
1.7 % UFAX	208±0.0 a	15 %	13.0 a

± indicates standard deviation

a. Values followed by different letters are significantly different at the 0.05 level

4.2. Bread properties

4.2.1. Visual appearance of breads

The colour of the bread interior was influenced by AX addition. Breads with AX levels had a darker crumb than control, particularly at high addition levels. AXE produced the darkest crumbs, while FAX and UFAX had a lesser effect on colour. This might be due to the AXE being a coarser fraction than FAX and UFAX, which have undergone additional purification steps. The freeze-dried AXE was brown, while FAX and UFAX were light greyish. An image displaying the visual appearance of slices from all breads in this study can be found in Appendix III.

AX addition had minor effects on the exterior of the breads. Breads with higher addition levels tended to have a slightly darker crust and a more uneven crust surface than control and low addition levels. The unevenness of the surface was likely due to the dough being stickier and thus more difficult to shape into even buns with the extensigraph. Figure 7 shows the typical appearance of the produced bread loaves.

Figure 7. Representative image of bread loaves produced from one dough (here: 1.0 % UFAX).

4.2.2. Specific volume

AX addition did not have a significant effect on specific volume of breads. This is in contrast to previous studies where AX has been found to increase volume. Koegelenberg and Chimphango (2017) observed an increased specific volume when replacing 2-3 % of the flour with 0.8 and 1.2 % alkaline-extracted WB AX. Courtin and Delcour (1998) found an increase in loaf volume when HMW wheat flour AX were added to the dough.

Possibly, the number of replicates in this study was too low to reveal any effects of AX addition on specific volume. Figure 8 shows the average specific volume of all samples. Despite the lack of significant differences, the peak in specific volume seen for FAX and UFAX at 1.0 % suggests that there may be an optimum AX addition level with regards to specific volume. However, due to the lack of significant differences between samples, this hypothesis cannot be confirmed. It is also possible that the AX addition levels were too low to cause an effect on specific volume and that higher levels would have generated more pronounced effects. In the study by Courtin and Delcour (1998), the observed volume increase was bigger when higher AX addition levels (2-3 %) were used.

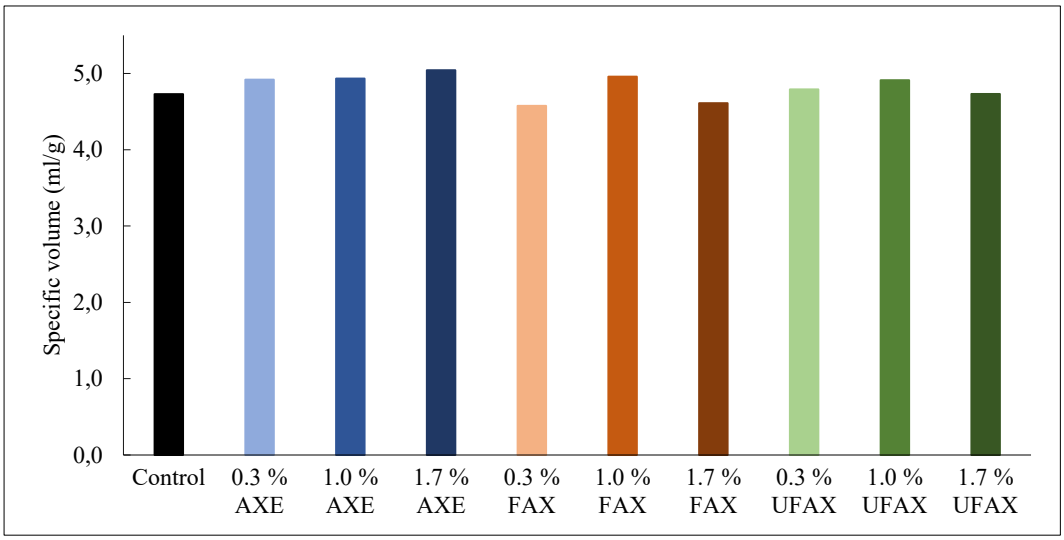

Figure 8. Average specific volume (ml/g) of samples (n=2). One replicate is the average specific volume of four loaves produced from one dough.

4.2.3. Crumb structure by image analysis

AX addition had minor effects on the crumb structure of breads, as seen in Table 3. The only significant effect was observed for 1.7 % UFAX, which gave a 22 % increase in total cell count compared to control. A high number of cells could be the result of limited cell coalescence during proofing and baking. AX may contribute to this through its stabilizing effect of AX on the film layer surrounding gas bubbles (Courtin & Delcour 2002). In contrast to the findings by Koegelenberg and Chimphango (2017), who observed bigger air cells in AX-fortified bread, no effect on the average cell size was found in this study.

Table 3. Crumb structure properties of samples[a, b] obtained through image analysis

Sample	Cell count	Total cell area	Average cell size	% cell area of total area
Control	408±12 b	5638±366 a	13.9±1.2 ab	28.9±1.9 a
0.3 % AXE	425±4 b	5371±386 a	12.7±1.2 ab	27.5±2.0 a
1.0 % AXE	449±13 ab	5394±255 a	12.1±0.2 ab	27.7±1.3 a
1.7 % AXE	436±13 ab	5673±473 a	13.2±1.5 ab	29.1±2.4 a
0.3 % FAX	428±2 b	5578±370 a	13.1±1.0 ab	28.6±1.9 a
1.0 % FAX	438±11 ab	6236±283 a	14.6±0.2 a	32.0±1.5 a
1.7 % FAX	458±13 ab	5799±231 a	12.7±0.9 ab	29.7±1.2 a
0.3 % UFAX	433±26 b	5712±121 a	13.3±0.4 ab	29.3±0.6 a
1.0 % UFAX	462±37 ab	5717±53 a	12.6±1.2 ab	29.3±0.3 a
1.7 % UFAX	497±11 a	5382±234 a	10.9±0.2 b	27.6±1.2 a

± indicates standard deviation

a. Values followed by different letters (column) are significantly different at the 0.05 level

b. Values are means of duplicates. One replicate is the average of 6 slices.

4.2.4. Crumb texture by TPA

Hardness

Hardness increased over time for all samples (see Figure 9), from an average of 2.6 N on day 1 to an average of 9.3 N on day 14. There were no significant differences in hardness between the samples on any day. However, as discussed in section 4.3, AX addition did have a reducing effect on hardness when comparing AX fraction averages. In earlier studies, AX has been found to reduce crumb hardness of stored bread due to retarded retrogradation (Koegelenberg & Chimphango 2017) or increased crumb moisture content (Biliaderis *et al.* 1995). This suggest that AX can reduce crumb hardness of stored bread. Possibly, there is an effect on hardness that the statistical power of the present study failed to recognise when comparing all AX fraction and addition level combinations. This could be due to the low number of replicates or the small effects produced by the selected addition levels. Future research is thus needed to establish if and how the AX fractions influence hardness.

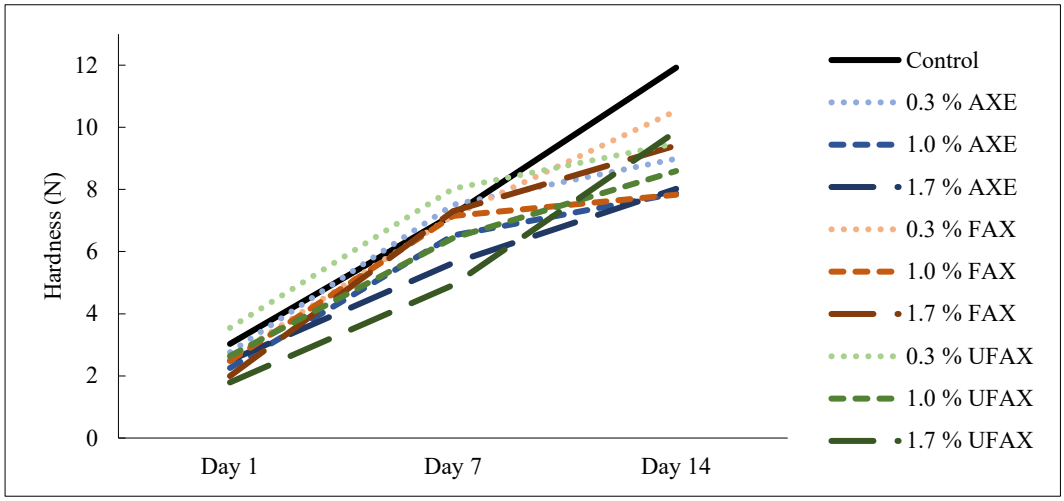

Figure 9. Average hardness of samples on day 1, day 7 and day 14 (n=2).

Cohesiveness

Cohesiveness decreased over time (see Figure 10) from an average of 0.79 on day 1 to an average of 0.44 on day 14 (44 % decrease). The decrease was higher between day 1 and 7 than between day 7 and 14.

As presented in Table 4, there were some significant differences in cohesiveness between 1.7 % UFAX and other samples. 1.7 % UFAX was consistently the most cohesive sample. It was significantly more cohesive than control and 0.3-1.0 % AXE on day 7, and more cohesive than 1.0-1.7 % AXE and 0.3 % UFAX breads on day 14. There was no significant effect of FAX or AXE addition on cohesiveness. It is unclear why only the 1.7 % UFAX had an effect on cohesiveness, as the 0.3 and 1.0 % UFAX were no different from 0.3 or 1.0 % AXE or FAX.

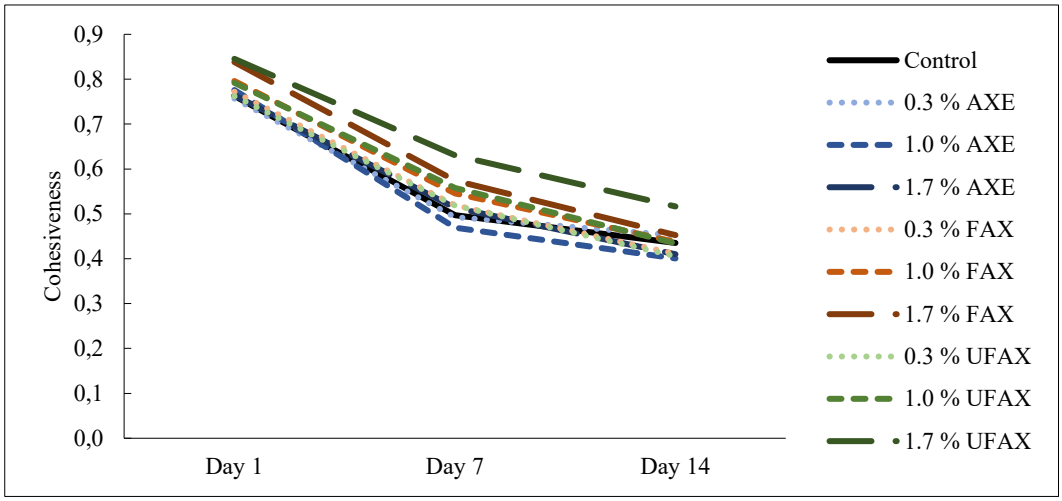

Figure 10. Average cohesiveness of samples on day 1, day 7 and day 14 for all samples (n=2).

Table 4. Average cohesiveness of samples on day 1, day 7 and day 14 (n=2).

Sample	Cohesiveness day 1	Cohesiveness day 7	Cohesiveness day 14
Control	0.76±0.03 a	0.50±0.04 b	0.44±0.03 ab
0.3 % AXE	0.76±0.01 a	0.49±0.03 b	0.45±0.06 ab
1.0 % AXE	0.78±0.02 a	0.47±0.02 b	0.40±0.02 b
1.7 % AXE	0.76±0.00 a	0.51±0.03 ab	0.41±0.01 b
0.3 % FAX	0.77±0.01 a	0.52±0.02 ab	0.41±0.02 ab
1.0 % FAX	0.80±0.00 a	0.55±0.02 ab	0.44±0.00 ab
1.7 % FAX	0.84±0.02 a	0.57±0.01 ab	0.45±0.01 ab
0.3 % UFAX	0.76±0.04 a	0.52±0.02 ab	0.41±0.04 b
1.0 % UFAX	0.79±0.05 a	0.56±0.02 ab	0.43±0.00 ab
1.7 % UFAX	0.85±0.00 a	0.63±0.06 a	0.52±0.00 a

± indicates standard deviation

a. Values followed by different letters (column) are significantly different at the 0.05 level.

Springiness

Just like cohesiveness, springiness of the bread samples decreased during storage (illustrated in Figure 11), from an average of 0.98 on day 1 to an average of 0.93 on day 14 (5 % decrease). No significant effects of AX addition on springiness were observed[1].

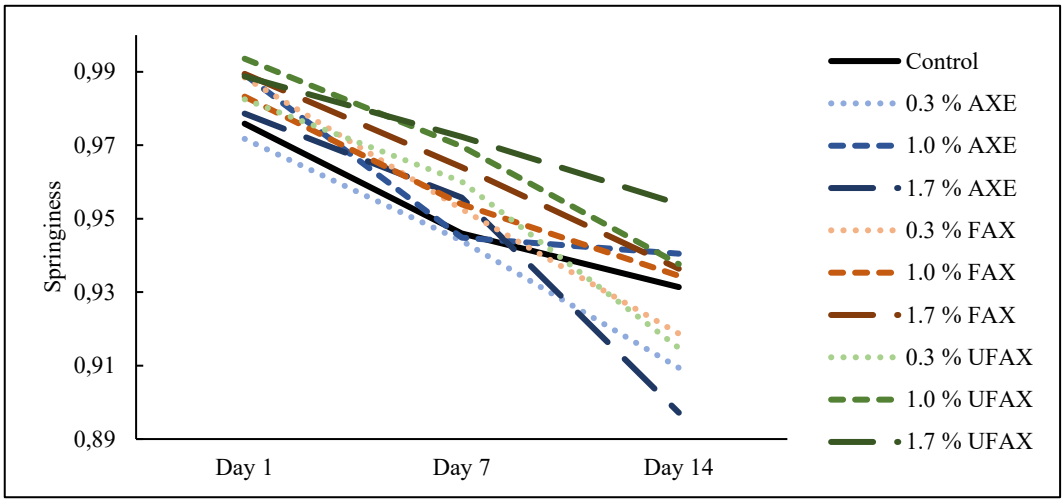

Figure 11. Average springiness of samples on day 1, day 7 and day 14 (n=2).

In a previous study, Curti *et al.* (2015) investigated the effect of addition of two bran fractions on cohesiveness and springiness of breads during 7 days of storage. Similar to the present findings, they observed that cohesiveness and springiness decreased during storage for all samples. The cohesiveness and springiness were significantly lower in bran-supplemented breads than in control. The authors suggest that this reduced cohesiveness and springiness is explained by WB WUAX interference with gluten network and competition for water, hindering proper hydration of gluten. Therefore, it may be hypothesized that WEAX would not impair cohesiveness and springiness to the same extent as WUAX. The present findings support this hypothesis, since the WEAX used did not have a negative impact on cohesiveness and springiness.

[1] Two outliers (one replicate of 1.0 % AXE day 7 and 0.3 % FAX day 7, respectively) were excluded from the graph and the data analysis of springiness, due to the values being unreasonably low and high, respectively

4.2.5. Moisture content

The crumb moisture content of the bread samples decreased from day 1 to day 14 (see Figure 12 and Table 5) with 10-14 %. Addition of 1.7 % FAX and UFAX gave a significantly moister crumb than control and AXE breads on day 1, 7 and 14. This reflects a high baking absorption in those doughs (see Table 2 and section 4.4). Additionally, 1.0 % FAX increased the crumb moisture content on day 7 compared to control, and 1.0 % UFAX increased the crumb moisture content on day 1 and day 7. In general, the breads with high AX addition level seemed to have slightly better moisture retention (i.e., a smaller moisture loss) than breads with medium or low addition level (see Table 5).

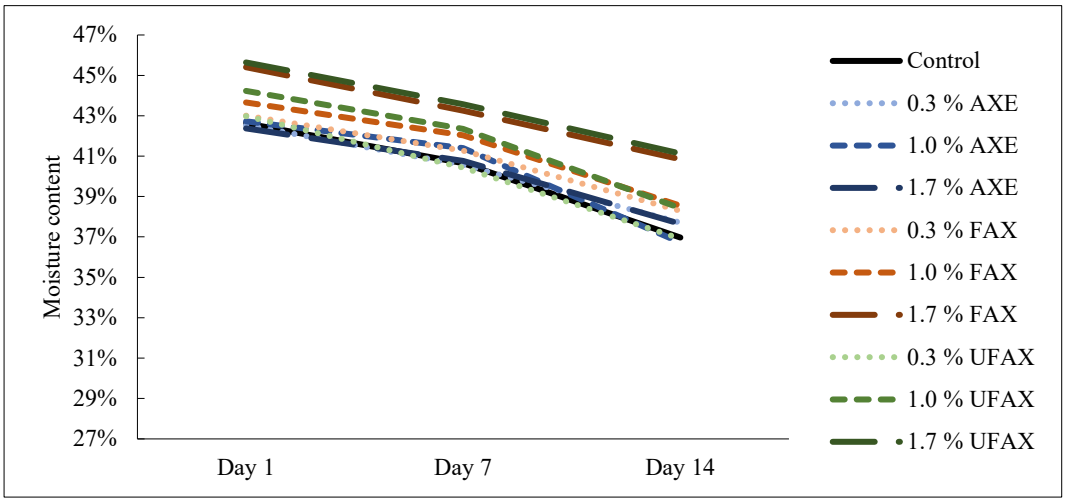

Figure 12. Average crumb moisture content at day 1, day 7 and day 14 (n=2).

Table 5. Average crumb moisture content[a] of samples on day 1, day 7 and day 14 (n=2).

Sample	Day 1 (%)	Day 7 (%)	Day 14 (%)	Loss day 1-day 14
Control	42.6±0.2 d	40.7±0.2 d	37.0±0.4 b	13 %
0.3 % AXE	42.5±0.3 d	40.6±0.3 cd	37.7±0.6 b	11 %
1.0 % AXE	42.7±0.1 d	41.4±0.3 bcd	36.7±1.0 b	14 %
1.7 % AXE	42.4±0.0 d	40.8±0.6 cd	37.6±0.5 b	11 %
0.3 % FAX	43.0±0.4 cd	41.3±0.2 bcd	38.3±0.3 b	11 %
1.0 % FAX	43.7±0.7 cd	42.0±0.6 abc	38.5±0.3 b	12 %
1.7 % FAX	45.4±0.3 ab	43.3±0.5 a	40.8±1.1 a	10 %
0.3 % UFAX	43.0±0.5 cd	40.4±0.7d	36.9±0.5 b	14 %
1.0 % UFAX	44.2±0.0 bc	42.3±0.0 ab	38.4±0.6 b	13 %
1.7 % UFAX	45.6±0.3 a	43.6±0.5 a	41.1±0.5 a	10 %

± indicates standard deviation

a. Values followed by different letters (column) are significantly different at the 0.05 level

Just like the crumb moisture content, the crust moisture content of the samples (i.e. the crumb located just beneath the crust) decreased overtime (see Figure 13 and Table 6). The loss in crust moisture content and ranged between 8 % and 22 % and was thus more variable than the crumb loss, The only significant effect of AX addition on crust moisture content was observed for 1.7 % FAX on day 14, where it was 14 % higher than control.

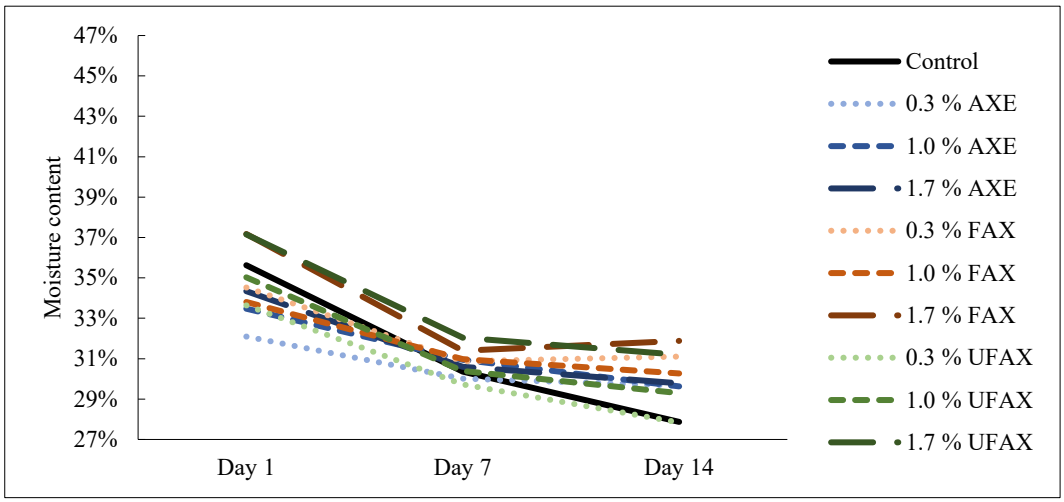

Figure 13. Average crust moisture content of samples on day 1, day 7 and day 14 (n=2)

Table 6. Average crust moisture content of samples on day 1, day 7 and day 14 (n=2).

Sample	Day 1 (%)	Day 7 (%)	Day 14 (%)	Loss day 1-day 14
Control	35.6±2.6 a	30.4±1.3 a	27.9±1.1 b	22 %
0.3 % AXE	32.1±2.4 a	30.0±0.8 a	29.7±1.2 ab	8 %
1.0 % AXE	33.5±1.0 a	30.9±0.9 a	29.6±0.6 ab	11 %
1.7 % AXE	34.3±1.4 a	30.6±0.4 a	29.8±0.1 b	13 %
0.3 % FAX	34.5±1.9 a	30.9±1.4 a	31.1±0.5 ab	10 %
1.0 % FAX	33.8±0.2 a	31.0±1.8 a	30.3±0.6 ab	10 %
1.7 % FAX	37.2±1.3 a	31.4±0.5 a	31.9±0.7 a	14 %
0.3 % UFAX	33.6±0.7 a	29.7±0.6 a	27.8±2.6 b	17 %
1.0 % UFAX	35.0±1.0 a	30.4±0.2 a	29.3±0.3 ab	16 %
1.7 % UFAX	37.2±0.3 a	32.0±1.0 a	31.2±0.8 ab	16 %

± indicates standard deviation
a. Values followed by different letters (columns) are significantly different at the 0.05 level.

From a staling perspective, a high moisture content is desirable because it leads to a slower staling rate (Cauvain 2015). In previous studies, AX has been observed to increase crumb moisture content of bread stored for 1 and 7 days at addition levels of about 0.5-1.2 % (Biliaderis *et al.* 1995; Koegelenberg & Chimphango 2017). According to Biliaderis *et al.* (1995), the increased moisture content reflected the higher water absorption in doughs with AX. Additionally, Messia *et al.* (2016) and Curti *et al.* (2015) found that bran-supplemented fresh and stored breads had higher

crumb moisture content than control. This was also ascribed to higher baking absorption for these breads.

The present findings show an overall moisture loss overtime. Moisture loss of the crumb is due to migration of moisture from the center of the loaf to the drier surface (Gray & Bemiller 2003). In a study by Curti *et al.* (2015), the moisture content of the crumb decreased during 7 days of storage, while the moisture content of the crust increased as a result of moisture migration within the bread. This is in contrast with the present findings that crust as well as crumb moisture decreases. However, in the present study the "crust" used for moisture content determination was in fact a piece of crumb just beneath the crust, which complicates the comparison. In fact, if moisture migrates from crumb to crust, it seems logic that the crumb just beneath the surface should lose more moisture to the actual crust than the center of the bread does.

4.3. Effect of type of AX fraction

Analyzing the results by AX fraction reveals possible effects of structural differences between the fractions. It also gives an indication of which fraction(s) may have potential as bread improvers. Table 7 lists dough and bread parameters where significant differences ($p<0.05$) exist between AX fractions averages, along with the obtained values for these parameters. Significant differences between fraction averages were found for baking absorption, crumb moisture content (day 1, 7 and 14), crust moisture content (day 14), hardness (day 14), cohesiveness (day 7) and cell count. FAX and UFAX gave a significantly higher baking absorption than AXE. UFAX had a moister crumb than control and AXE on day 1. On day 7 and 14, the Tukey pairwise comparison test failed to group the AX fraction means into significantly different groups, even though the p-value for the ANOVA (0.036 and 0.034, respectively) indicate that significant differences exist for crumb moisture content. FAX gave significantly moister crust on day 14 than control. AXE breads were significantly softer than control breads on day 14. UFAX breads were significantly more cohesive than the other breads on day 7. Finally, UFAX had a significantly higher cell count than control, indicating an even crumb structure with many air cells.

Table 7. Dough and bread properties with significant differences between AX fraction means (n=4 for control, n=6 for AX fractions).

AX fraction	Baking absorption (ml)	Crumb moisture content day 1 (%)	Crumb moisture content day 7 (%)	Crumb moisture content day 14 (%)	Crust moisture content day 14 (%)	Hardness day 14 (N)	Cohesive-ness day 7	Cell count
Control	180.8±1.0 ab	42.6±0.2 b	40.7±0.2 a	37.0±0.4 a	27.9±1.1 b	11.92±1.54 a	0.50±0.04 ab	408±12 b
AXE	180.3±0.5 b	42.5±0.2 b	40.9±0.4 a	37.4±0.7 a	29.7±0.6 ab	8.30±1.62 b	0.49±0.03 b	437±13 ab
FAX	194.2±10.3 a	44.0±1.2 ab	42.1±1.0 a	39.2±1.4 a	31.1±0.9 a	9.26±1.84 ab	0.55±0.03 ab	441±16 ab
UFAX	194.9±11.5 a	44.3±1.2 a	42.1±1.5 a	38.8±2.0 a	29.4±1.9 ab	9.32±1.12 ab	0.57±0.06 a	464±36 a
p-value	0.008	0.007	0.036	0.034	0.007	0.016	0.014	0.01

± indicates standard deviation

a. Values followed by different letters (columns) are significantly different at the 0.05 level

The main difference between the FAX and the UFAX fractions was the FA content. Where FAX contained some 1.3 % FA, UFAX contained virtually no FA. Comparing the results for FAX and UFAX therefore gives an indication of the effect of FA on dough and bread properties. As evident from Table 7, there were no significant differences between FAX and UFAX when comparing averages. Hence, FA content seems to have no effect on the parameters studied. This is in accordance with previous findings by Delcour *et al.* (1991), who observed no differences between feruloylated and unferuloylated rye AX with regards to effect on specific volume, baking absorption or DDT. Neither did free FA have any significant effects. According to the authors, this indicates that oxidative gelation (for which FA is necessary) is not the underlying mechanism for the improved loaf volume obtained by adding water-soluble pentosans. Koh and Ng (2009) and Nicks *et al.* (2013), on the other hand, did observe a reduced bread volume when adding freeFA to dough, which was explained by negative effects of FA on gluten strength (Koh & Ng 2009) or on yeast activity (Nicks *et al.* 2013).

The main difference between the AXE and the FAX is believed to be the MW distribution. This hypothesis is based on the fact that AXE has a higher AX content, even though the FAX has been further purified. This indicates that the AXE might contain some LMW AX that is lost during subsequent purification. In contrast to the similarities between FAX and UFAX, some differences were found between AXE and FAX. The main difference was in baking absorption. FAX addition gave a significantly higher baking absorption than AXE addition (as seen in Table 7), which did not influence baking absorption. This seems to be reflected in the lower crumb moisture content observed for AXE compared to FAX (although the difference in crumb moisture content was not significant). In a study by Courtin and Delcour (1998), it was found that HMW AX increased baking absorption, while LMW AX decreased baking absorption compared to control. Biliaderis *et al.* (1995) found a bigger increase in water absorption for HMW AX than for LMW counterparts, which was also reflected in the moisture content of the breads. This indicates that the lower baking absorption for AXE than for FAX could in fact be

due to a higher proportion of LMW AX in AXE than in FAX. However, because the actual MW distribution of the AXE was not known, it is not possible to draw any conclusions on the effect of molecular weight from this study.

4.4. Correlation between parameters

Regression analysis was conducted to investigate correlations between baking parameters and bread properties, Other authors have reported correlations between water absorption and crumb moisture content (Biliaderis *et al.* 1995) and between baking absorption and specific volume for HMW-AX (Courtin & Delcour 1998).

Significant ($p<0.05$) correlation was found between baking absorption and crumb moisture content (day 1: R-sq=91.46 %), day 7: R-sq=85.62 %, day 14: R-sq=81.87 %). This was expected since a bread with more added water should contain more water and also retain this extra water if moisture is lost at a constant rate. There was, however, no significant correlation between baking absorption and specific volume. This may reflect the overall lack of significant differences in specific volume and the plausible non-linear relationship between AX level and specific volume, as discussed in section 4.2.2.

When investigating the correlation of AX level with other parameters, a negative correlation was found between AX level and hardness, (however, the R-sq values were generally rather low (day 1: R-sq=28.87 %, day 7: R-sq=25.61 %, day 14: R-sq=20.94 %)). This suggests that AX plays a role in reducing the hardness of breadcrumbs. According to Biliaderis *et al.* (1995), the decreasing firmness in breads with higher AX levels can be explained by the higher crumb moisture content in these breads. The mechanism behind this could be the plasticizing effect of the additional water on the gluten-starch matrix (Courtin & Delcour 2002). However, as discussed by Courtin and Delcour (1998) and Koegelenberg and Chimphango (2017) baking absorption is probably not the only determining factor for AX effect on bread characteristics such as staling. Bread staling, for instance, is thought to mainly result from starch retrogradation and moisture redistribution in the bread (Gray & Bemiller 2003). And while a higher moisture content seems to result in a softer breadcrumb, it is also known that a higher moisture content can increase the rate of starch retrogradation (Courtin & Delcour 2002). According to Curti *et al.* (2015), different mechanisms may contribute to staling in different amounts, depending on the actual interactions taking place in the bread. That is, while moisture redistribution may be the dominating factor in one bread, starch retrogradation may be the main contributing factor to staling in another bread. In the present study, moisture content likely plays only a moderate role in decreasing hardness, since there was no significant difference in hardness between AXE and FAX/UFAX despite the differences in moisture content.

4.5. Sensory evaluation

The tasting panel consisted of frequent consumers of bread. 48 % of the tasting panel were every-day consumers of bread. 42 % of the panelists consumed bread a few times per week. 5 % consumed bread once a week and 5 % a few times per month. Control and 1.0 % UFAX breads were evaluated at an age of 1 and 7 days. Average scores are illustrated in Figure 14. No significant differences were found between control and UFAX, neither at day 1 nor on day 7. This lack of significant differences between samples may be due to the small panel size. Ideally, a consumer panel used in an affective test should consist of 75-150 individuals to compensate for the high variability of preferences between people and to enable identification of segments of consumers within the target group (Lawless & Heymann 2010). The panel used in this test was probably too small to detect significant differences at the 0.05 level of significance, if differences do exist.

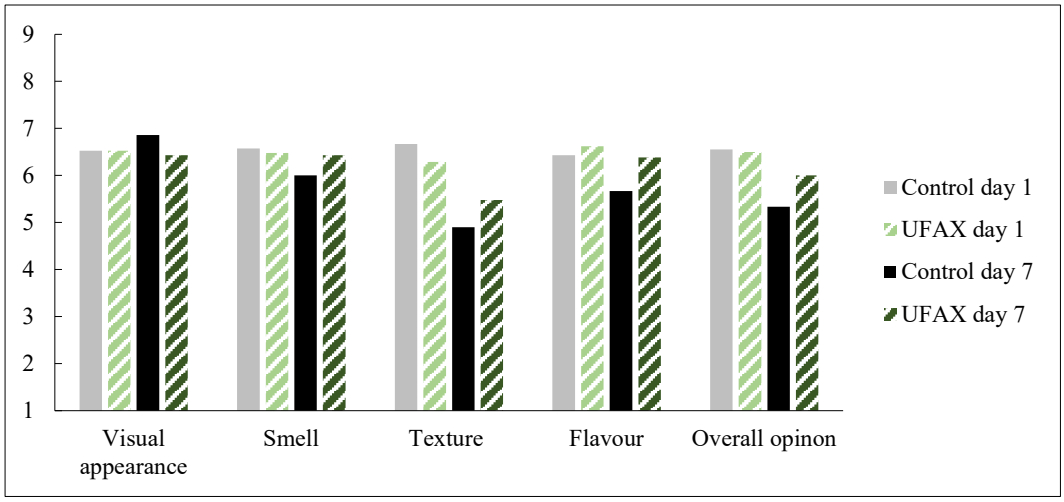

Figure 14. Average (n=21) acceptance scores (1-9, see Figure 3) for visual appearance, smell, texture, flavour and overall opinion for control and 1.0 % UFAX samples after 1 and 7 days of storage, respectively.

As mentioned above, it is possible that consumer segments exist which have different preferences with regards to the attributes evaluated. For example, a group of consumers may prefer white bread while another group of consumers prefer darker bread with visually high fiber content. In fact, when examining the individual value plot for texture of the day 7 samples (Figure 15) it seems like two different consumer segments may be present: one group that likes the texture of the 7-day breads and one group that dislikes the texture.

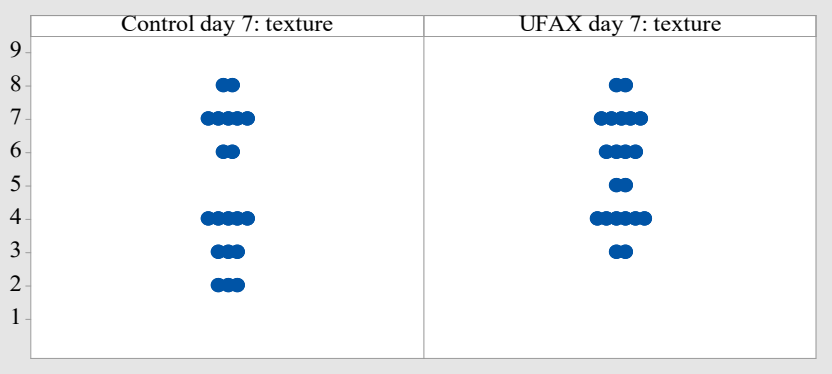

Figure 15. Individual value plot (n=21) for texture scores for control and 1.0 % UFAX breads on day 1 and day 7.

During the sensory evaluation, panelists were given the opportunity to give comments after each block of tasting. All comments are presented in Appendix IV. Some panelists mentioned that the samples were very similar, and that the breads were neutral or even bland in flavour. A few panelists wrote that the UFAX breads were richer in taste than the control. For the day 7 bread, some panelists commented that they were dry. This was not surprising after such a long storage time. In general, the opinions differ and panelists do not agree on the performance of the breads on different attributes and on which breads are preferred. This indicates that there is a large individual variation when it comes to bread preferences.

4.6. General discussion

In literature, AX is frequently reported to influence dough and bread properties, for example by improving specific volume and retarding staling (Courtin & Delcour 2002; Kaur *et al.* 2019). The results from this study indicate that AX addition may influence staling by its effect on hardness and cohesiveness of stored bread. However, it can be questioned whether this anti-staling effect is meaningful since it did not result in improved consumer liking. Specific volume was unaffected by AX addition. Effects on crumb structure were also minor, although AX addition did alter the colour of the breadcrumb. In general, rather few significant differences between samples were observed in this study. This makes it difficult to draw general conclusions on AX influence on bread staling, even though some specific effects could be seen. In the study, doughs were made in duplicates. As discussed by Bourne (2002c), food commodities usually show a large variation within the sample lot and large sample sizes are sometimes necessary to obtain reliable and reproducible results. It is thus likely that a higher number of replicates would have

generated more statistically significant findings. Furthermore, it is possible that the addition levels studied were too low to reveal any significant effects of AX addition.

The variation and complexity in structure, source, purity and isolation technique of AX makes it difficult to compare the results from this study to findings in other studies. As stated by Courtin and Delcour (1998), the reported results on AX impact on bread and dough properties in literature are divergent, likely due to these variations. In addition, the impact of AX on breadmaking is probably influenced by flour quality (Biliaderis *et al.* 1995; Courtin & Delcour 2002) and breadmaking procedure (Courtin & Delcour 1998), which also differ between studies. According to Gan *et al.* (1995), the interpretation of results from experiments with AX is problematic due to limited insight into the structural heterogenicity of AX. Furthermore, different ways to add pentosans to flour have produced different effects. Consequently, the results of this study should not be considered as universal, but rather as specific for the particular conditions and AX fractions used.

Four mechanisms are commonly proposed for AX impact on breadmaking: viscosity formation, water-holding capacity, gelling ability and interaction with gluten (Courtin & Delcour 1998). Considering the results from this study, water-holding capacity and gelling ability seem unlikely to play a major role in the impact on staling. Despite the differences in baking absorption and moisture content between AXE and FAX/UFAX, hardness during storage was similar across the fractions. The similar behaviour of FAX and UFAX indicate that FA has a minor influence on bread properties, suggesting that oxidative gelation is not involved in the mechanisms. Interaction with gluten and viscosity formation remain possible explanations of why bread with added AX fraction had slightly different properties than control. The differences between AXE and the purified fractions FAX and UFAX may lie in AXE being a coarser fraction, which may influence the solubility of AX and ability to interact with other components in the flour. Differences in MW distribution between AXE and FAX/UFAX may also play a role. However, even though some differences in MW distribution probably exists, the influence of AX MW remains unclear.

4.6.1. Arabinoxylans in industrial breadmaking

When evaluating the AX fractions and addition levels with regards to their potential use as bread improvers, the practical application in industrial baking should be considered. Firstly, dough and bread properties should not be altered in a way that complicates baking on industrial scale. In this study, it was noted that high AX addition levels and corresponding high baking absorption produced sticky doughs that were difficult to handle and shape into loaves. This might be important in an industrial setting. Secondly, the use of AX as bread improver must not influence consumers' sensory experience negatively, even if desired shelf life properties are obtained. The results indicate that there was little effect of AX addition on the

sensory experience of the bread neither on day 1 nor on day 7. If any, the effect seems to be positive. This indicates that AX addition does not impair quality, which makes it a potential candidate as a bread improver. Nevertheless, while *maintained* quality can be desired in a bread with added AX, it may also be useless to add an improver if it does not *improve* quality. Therefore, further research is needed to elucidate how consumer acceptance for stored bread can be improved with AX addition. Thirdly, for AX to be useful as a bread improver, the effect it has on bread must be of practical significance. As mentioned above, the addition levels used in this study may in fact be too low for their effects to have a practical significance, even if they had been statistically significant. Higher addition levels may give more prominent effects with regards to retarded staling, but may also have a bigger (positive or negative) influence on the sensory experience.

In general, all three fractions have potential as bread improvers. In addition to their probable effects on staling, they also contribute with an added dietary content to breads, which is beneficial from a nutritional point of view. From an industry perspective, AXE may constitute the best alternative, being the least processed of the three studied fractions. If a high water content is desired, however, FAX or UFAX are better candidates.

4.6.2. Further research

Further research should focus on exploring the role of AX MW and finding optimal AX addition levels with regards to the effect on staling. Findings from the present study suggest that MW distribution may influence the effect of AX on dough and bread properties. More research is needed to elucidate the effects of AX MW and the underlying mechanisms. Furthermore, only minor effects on bread properties and staling were observed at the AX addition levels used in this study. Therefore, future studies should investigate the effect of higher addition levels in order to identify the optimal AX fraction and addition level for use as bread improver.

5. Conclusion

The purpose of this study was to investigate the effect of WB AX addition on dough and bread quality aspects and on staling during storage, to evaluate three types of AX fractions (AXE, FAX and UFAX) in terms of their potential as bread improvers and to determine whether AX addition to bread influences consumer acceptance of freshly baked and stored bread.

From the results of this study, it can be concluded that WB AX mainly influences baking absorption, visual appearance, crumb moisture content and crumb texture. WB AX addition could potentially retard staling by reducing the hardness and increasing cohesiveness of stored bread. In general, 1.0 and 1.7 % AX addition seem to have more pronounced effect on dough and bread properties than 0.3 % addition. It is concluded that the three AX fractions have different effects on baking absorption and crumb moisture content, but similar effects on bread quality aspects and staling. Thus, all three fractions have potential as bread improvers. Finally, it is concluded that addition of 1.0 % UFAX does not influence consumer acceptance of freshly baked and stored breads.

In conclusion, the addition of 1.0-1.7 % AX from AXE, FAX or UFAX may retard staling while maintaining certain quality aspects of bread. However, few significant differences were observed in this study. The effect of AX addition therefore remains ambiguous. Further research is needed to confirm beneficial effects of WB AX in breadmaking and explore the potential of wheat bran arabinoxylans as bread improvers in the baking industry.

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Appendix I Preliminary baking trials

Prior to the baking trials with all AX fractions, preliminary baking trials were conducted to test the bread recipe, optimize the baking method and determine which AX levels to use for further testing

Method

The control bread was test-baked in a farinograph (Brabender GmbH & Co KG, Duisburg, Germany, see Figure I) with the following formulation (14 % flour moisture content basis): wheat flour, 100; rapeseed oil, 2.5; sugar, 5; salt, 1.5; yeast, 4. Dry ingredients were mixed for 1 minute in the farinograph before addition of water and further mixing until maximum consistency. The dough was fermented, divided into 100±0.1 g pieces and shaped into loaves using an extensigraph (Brabender GmbH & Co KG, Duisburg, Germany, see Figure II). The loaves were proofed in baking pans. The appearance and consistency of the dough was evaluated subjectively by the test baker to identify desirable properties and optimize the baking procedure. The optimal baking time was determined by visual inspection of bread crust and crumb after different baking times. The breads were stored at RT to assess the growth of moulds and the need for addition of preservatives.

Baking trials were conduced with 1.0 % (flour content basis) freeze-dried AXE to make an initial assessment of the effect of AX addition on dough and bread properties after different storage times.

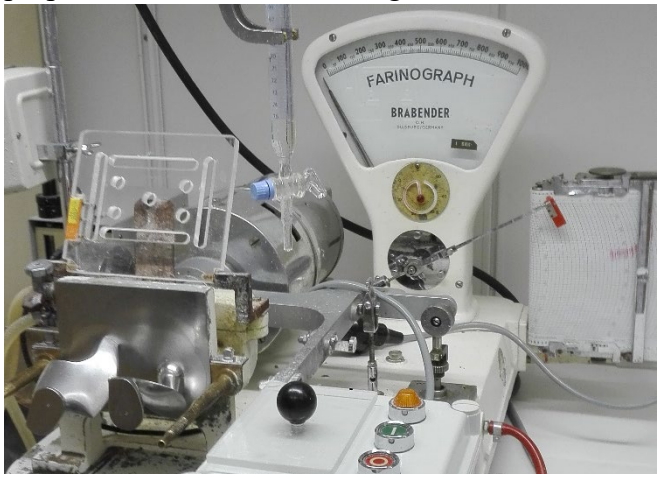

Figure I. The farinograph used in baking. The mixing blades are seen on the bottom left.

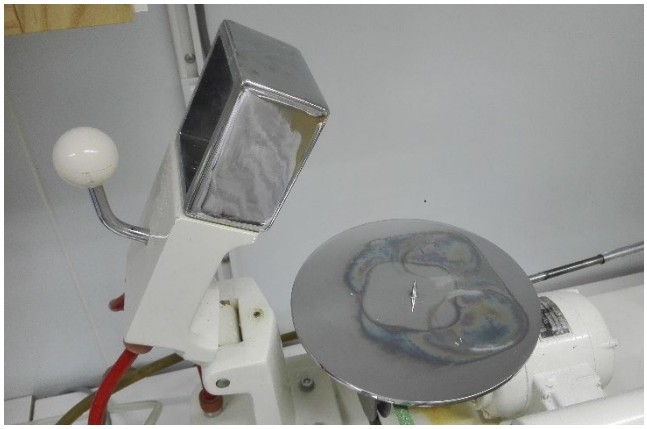

Figure II. The extensigraph used to shape the loaves after fermentation.

Results

The test baking of the control bread produced a dough that was easy to handle and gave bread loaves with a satisfactory exterior surface and interior pore structure. Based on the consistency and handleability of the dough, it was decided that 400-420 BU was a suitable final consistency. Thus, the amount of water added during subsequent baking trials should always be adjusted to achieve a final dough consistency of 410±30 BU. 10 minutes was determined as the optimal baking time.

Storage of the control bread showed initial mould growth after about one week and heavy mould growth after two weeks. Therefore, it was decided to use sorbic acid as a preservative for further baking trials, and to slightly increase the yeast amount from 4 to 4.6 % to compensate for any inhibitory effect of sorbic acid.

The test baking with AXE indicated that AXE could improve certain bread quality aspects (see Table I). Replacement of 1.0 % flour with AXE increased the specific volume from 4.4 to 4.8 ml/g. It also decreased hardness at day 14 from 10,1 to 7.8 N (23 %). The cell count of the bread crumb was slightly lowered by AXE addition, but the total cell area, avg cell size and % of total area was increased. The effect on moisture content was unclear. AXE addition did not seem to impact crumb moisture content. However, the crust moisture loss was lower for the AXE bread (5 %) than for the control bread (21 %).

Table I. Properties of control and 1.0 % AXE bread tested in preliminary baking trials

Bread	Specific volume (ml/g)[a]	Moisture content (%) (crumb, crust[b])[c]			Hardness (N)[d]			Image analysis[e]			
		Day 1	Day 7	Day 14	Day 1	Day 7	Day 14	Count	Total area	Avg size	% area
Control	4.4±0.3	42±1.8. 38±0.7	41±0.8. 32±1.0	38±0.7. 30±1.3	3.4±0.4	6.3±0.2	10.1±0.2	422±55	5477±898	12.6±3.7	28.1±4.6
AXE	4.8±0.2	41±2.3. 33±1.5	41±0.5. 33±1.0	39±0.9. 32±1.4	2.1±0.6	5.1±1.0	7.8±0.1	415±33	5809±908	14.1±2.6	29.8±4.7

± indicates standard deviation
a: Average of 8 loaves from 2 doughs (4 loaves per dough)
b: "crust" means the bread crumb just beneath the upper crust of the loaf
c: Average of 2 loaves from 2 doughs, 3 replicates per loaf
d: Average of 2 loaves from 2 doughs
e: Average of 10 loaves from 2 doughs (5 loaves per dough)

Based on the results from the preliminary baking trials, it was decided to test three levels of AXE, UFAX and FAX corresponding to an AX content of 0.3, 1.0 and 1.7 % of the flour weight, in order to compare the three fractions and find the optimal level of flour replacement.

Appendix II Sensory evaluation: design structure and other details

The sensory evaluation used a two-treatment structure were the two treatments were AX addition (no addition (control) versus 1.0 % UFAX) and storage time (1 day versus 7 days). The experiment used a randomized complete block design (RCBD), where the control and 1.0 % UFAX samples were tested in one 1-day block and one 7-day block in a randomized and counterbalanced sample and block serving order. The design structure is illustrated in Figure III. Figures IV and V show the sensory testing area and an example of bread samples as presented to the sensory panelists. The randomization scheme is shown in Table II. The scoring sheet fillet out by the panellists during the sensory evaluation is presented in the end of this appendix.

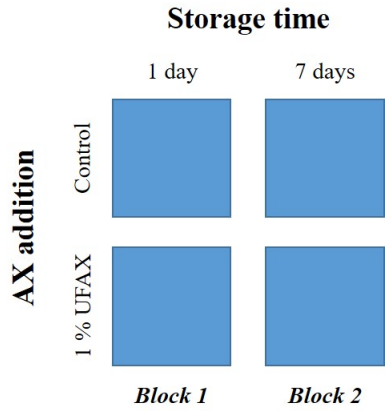

Figure III. Design structure of sensory evaluation. Each square represents one bread sample

Figure IV. Sensory testing area

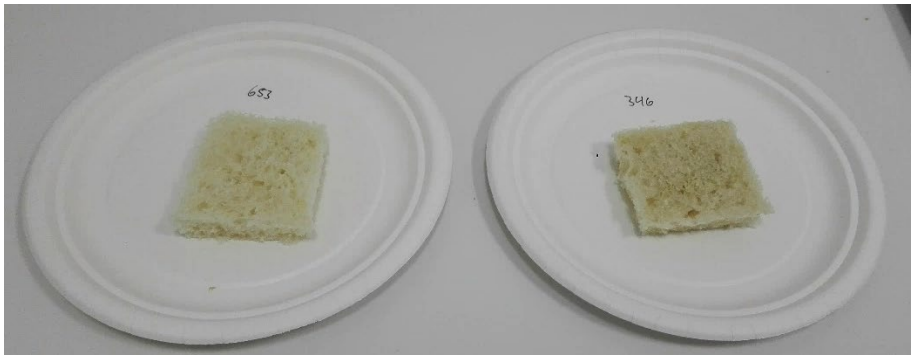

Figure V. Example of bread samples as presented to panelists in the sensory evaluation

Table II Counterbalanced randomization scheme and coding of sensory evaluation. Letters in red indicate order of serving.

Panellist number	Block order	Block 1: Day 1 breads				Block 2: Day 7 breads			
		Control		UFAX		Control		UFAX	
1	*1-2*	496	*2*	792	*1*	022	*1*	962	*2*
2	*2-1*	030	*1*	134	*2*	849	*1*	149	*2*
3	*1-2*	214	*2*	975	*1*	420	*2*	598	*1*
4	*2-1*	653	*1*	346	*2*	174	*2*	369	*1*
5	*2-1*	011	*2*	655	*1*	562	*1*	948	*2*
6	*1-2*	440	*1*	830	*2*	292	*1*	903	*2*
7	*2-1*	289	*2*	512	*1*	810	*2*	498	*1*
8	*1-2*	505	*1*	110	*2*	968	*2*	237	*1*
9	*1-2*	961	*2*	461	*1*	562	*1*	131	*2*
10	*2-1*	840	*1*	450	*2*	194	*1*	997	*2*
11	*1-2*	721	*2*	968	*1*	561	*2*	174	*1*
12	*2-1*	522	*1*	044	*2*	755	*2*	616	*1*
13	*2-1*	954	*2*	250	*1*	139	*1*	753	*2*
14	*1-2*	809	*1*	705	*2*	224	*1*	732	*2*
15	*2-1*	259	*2*	751	*1*	495	*2*	185	*1*
16	*1-2*	296	*1*	812	*2*	321	*2*	917	*1*
17	*1-2*	277	*2*	562	*1*	855	*1*	789	*2*
18	*2-1*	324	*1*	429	*2*	138	*1*	411	*2*
19	*1-2*	602	*2*	104	*1*	073	*2*	804	*1*
20	*2-1*	345	*1*	441	*2*	264	*2*	936	*1*
21	*2-1*	674	*2*	407	*1*	423	*1*	199	*2*

Tasting session

Bread

Thank you for participating in this tasting session. Please begin by reading the information on this page thoroughly and answer the following questions.

Date: 2020-05-06

Tester number:

Age:

Gender: □ Female □ Male □ Other □ Prefer not to say

Occupation: □ University staff □ Student □ Other

In the last 6 months, how often have you eaten bread? (Please not that "bread" refers to *soft bread* and **not** to crisp bread.)

□ Every day

□ A few times per week

□ Once per week

□ A few times per month

□ Once a month

□ Less than once a month

□ Never

Please rinse your mouth with water before starting. You can rinse at any time during the test if you need to.

You will receive two sets each with two pieces of bread. Your task is to evaluate the samples based on visual appearance, smell, taste and texture. Detailed instructions will be given on each page. Always rinse your mouth with water in between different samples.

If you have any questions, do not hesitate to ask the test director.

When you are ready to start the test, please indicate this to the test director to receive the first set of samples. Then go to the next page.

Tasting session part 1

Bread

Date: 2020-05-06

Tester number:

Instructions

You have received two samples. Follow the instructions below for each sample in the order given on this sheet (left to right).

1. A) Look at the samples. Do not touch, smell or taste the samples yet.
   B) Check one option below to indicate your opinion of the ***visual appearance*** of the product.

Sample number: _____	Sample number: _____
□ Like extremely	□ Like extremely
□ Like very much	□ Like very much
□ Like moderately	□ Like moderately
□ Like slightly	□ Like slightly
□ Neither like nor dislike	□ Neither like nor dislike
□ Dislike slightly	□ Dislike slightly
□ Dislike moderately	□ Dislike moderately
□ Dislike very much	□ Dislike very much
□ Dislike extremely	□ Dislike extremely

When you have finished, keep the samples in front of you and go to the next page.

Tasting session part 1

Bread

Date: 2020-05-06

Tester number:

Instructions

2. A) Smell the samples. Do not touch or taste the samples yet.
   B) Check one option below to indicate your opinion of the ***smell*** of the product.

Sample number: _____	Sample number: _____
□ Like extremely	□ Like extremely
□ Like very much	□ Like very much
□ Like moderately	□ Like moderately
□ Like slightly	□ Like slightly
□ Neither like nor dislike	□ Neither like nor dislike
□ Dislike slightly	□ Dislike slightly
□ Dislike moderately	□ Dislike moderately
□ Dislike very much	□ Dislike very much
□ Dislike extremely	□ Dislike extremely

When you have finished, keep the samples in front of you and go to the next page.

Tasting session part 1

Bread

Date: 2020-05-06

Tester number:

Instructions

1. A) Taste the samples, *focusing on their texture only*. Save half of each sample. Rinse your mouth with water in between each sample.
   B) Check one option below to indicate your opinion of the ***texture*** of the product.

Sample number: _____	Sample number: _____
□ Like extremely	□ Like extremely
□ Like very much	□ Like very much
□ Like moderately	□ Like moderately
□ Like slightly	□ Like slightly
□ Neither like nor dislike	□ Neither like nor dislike
□ Dislike slightly	□ Dislike slightly
□ Dislike moderately	□ Dislike moderately
□ Dislike very much	□ Dislike very much
□ Dislike extremely	□ Dislike extremely

When you have finished, keep the remaining samples in front of you and go to the next page.

Tasting session part 1

Bread

Date: 2020-05-06

Tester number:

Instructions

2. A) Taste the samples again, *focusing on their flavour only*. Rinse your mouth with water in between each sample.
   B) Check one option below to indicate your opinion of the ***flavour*** of the product.

Sample number: _____	Sample number: _____
□ Like extremely	□ Like extremely
□ Like very much	□ Like very much
□ Like moderately	□ Like moderately
□ Like slightly	□ Like slightly
□ Neither like nor dislike	□ Neither like nor dislike
□ Dislike slightly	□ Dislike slightly
□ Dislike moderately	□ Dislike moderately
□ Dislike very much	□ Dislike very much
□ Dislike extremely	□ Dislike extremely

When you have finished, go to the next page.

Tasting session part 1

Bread

Date: 2020-05-06

Tester number:

Instructions

5 A) Recall the two samples.
B) Check one option below to indicate your ***overall opinion*** of the samples.

Sample number: _____	Sample number: _____
□ Like extremely	□ Like extremely
□ Like very much	□ Like very much
□ Like moderately	□ Like moderately
□ Like slightly	□ Like slightly
□ Neither like nor dislike	□ Neither like nor dislike
□ Dislike slightly	□ Dislike slightly
□ Dislike moderately	□ Dislike moderately
□ Dislike very much	□ Dislike very much
□ Dislike extremely	□ Dislike extremely

3. C) If you want, you may leave additional comments in the box below.

Comments:

You have now finished the first part of the tasting session. Please indicate this to the test director to receive the next set of samples. When you have received the samples, please go to the next page.

Tasting session part 2

Bread

Date: 2020-05-06

Tester number:

Instructions

You have received two new samples. Follow the instructions below for each sample in the order given on this sheet (left to right).

6. A) Look at the samples. Do not touch, smell or taste the samples yet.
   B) Check one option below to indicate your opinion of the ***visual appearance*** of the product.

Sample number: _____	Sample number: _____
□ Like extremely	□ Like extremely
□ Like very much	□ Like very much
□ Like moderately	□ Like moderately
□ Like slightly	□ Like slightly
□ Neither like nor dislike	□ Neither like nor dislike
□ Dislike slightly	□ Dislike slightly
□ Dislike moderately	□ Dislike moderately
□ Dislike very much	□ Dislike very much
□ Dislike extremely	□ Dislike extremely

When you have finished, keep the samples in front of you and go to the next page.

Tasting session part 2

Bread

Date: 2020-05-06

Tester number:

Instructions

7. A) Smell the samples. Do not touch or taste the samples yet.
   B) Check one option below to indicate your opinion of the ***smell*** of the product.

Sample number: _____	Sample number: _____
□ Like extremely	□ Like extremely
□ Like very much	□ Like very much
□ Like moderately	□ Like moderately
□ Like slightly	□ Like slightly
□ Neither like nor dislike	□ Neither like nor dislike
□ Dislike slightly	□ Dislike slightly
□ Dislike moderately	□ Dislike moderately
□ Dislike very much	□ Dislike very much
□ Dislike extremely	□ Dislike extremely

When you have finished, keep the samples in front of you and go to the next page.

Tasting session part 2

Bread

Date: 2020-05-06

Tester number:

Instructions

8. A) Taste the samples, *focusing on their texture only*. Save half of each sample. Rinse your mouth with water in between each sample.
   B) Check one option below to indicate your opinion of the ***texture*** of the product.

Sample number: _____	Sample number: _____
□ Like extremely	□ Like extremely
□ Like very much	□ Like very much
□ Like moderately	□ Like moderately
□ Like slightly	□ Like slightly
□ Neither like nor dislike	□ Neither like nor dislike
□ Dislike slightly	□ Dislike slightly
□ Dislike moderately	□ Dislike moderately
□ Dislike very much	□ Dislike very much
□ Dislike extremely	□ Dislike extremely

When you have finished, keep the remaining samples in front of you and go to the next page.

Tasting session part 2

Bread

Date: 2020-05-06

Tester number:

Instructions

9. A) Taste the samples again, *focusing on their flavour only*. Rinse your mouth with water in between each sample.
   B) Check one option below to indicate your opinion of the ***flavour*** of the product.

Sample number: _____	Sample number: _____
□ Like extremely	□ Like extremely
□ Like very much	□ Like very much
□ Like moderately	□ Like moderately
□ Like slightly	□ Like slightly
□ Neither like nor dislike	□ Neither like nor dislike
□ Dislike slightly	□ Dislike slightly
□ Dislike moderately	□ Dislike moderately
□ Dislike very much	□ Dislike very much
□ Dislike extremely	□ Dislike extremely

When you have finished, go to the next page.

Tasting session part 2

Bread

Date: 2020-05-06

Tester number:

Instructions

10. A) Recall the two samples.
    B) Check one option below to indicate your ***overall opinion*** of the samples.

Sample number: _____	Sample number: _____
□ Like extremely	□ Like extremely
□ Like very much	□ Like very much
□ Like moderately	□ Like moderately
□ Like slightly	□ Like slightly
□ Neither like nor dislike	□ Neither like nor dislike
□ Dislike slightly	□ Dislike slightly
□ Dislike moderately	□ Dislike moderately
□ Dislike very much	□ Dislike very much
□ Dislike extremely	□ Dislike extremely

10. C) If you want, you may leave additional comments in the box below.

Comments:

You have now finished this tasting session. Thank you very much for your participation! If you have any further questions, please contact

Appendix III Visualization of breadcrumbs from all loaves produced in the study

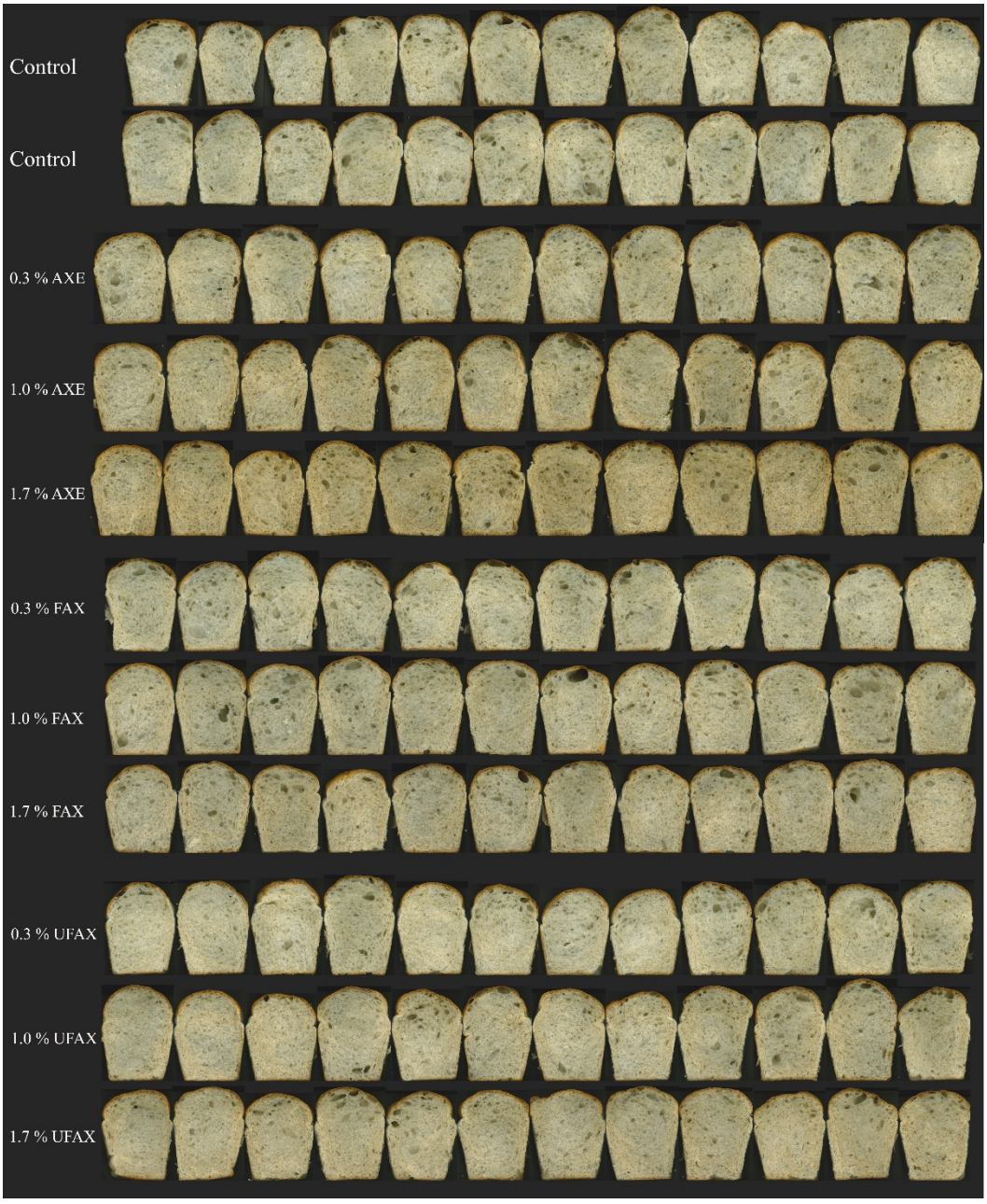

Figure VI. Bread slices from all loaves. From top to bottom: control, control, 0.3% AXE, 1.0 % AXE, 1.7 % AXE, 0.3 % FAX, 1.0 % FAX, 1.7 % FAX, 0.3 % UFAX, 1.0 % UFAX, 1.7 % UFAX

Appendix IV. Qualitative data from sensory evaluation

During the sensory evaluation, panellists were given the opportunity to write comments after each block (day 1 and day 7 breads). These comments are compiled in Table III below.

Table III. Panelists comments from the sensory evaluation.

Day 1 breads	Day 7 breads
Bread "Control day 1" with the more dense structure would make it a more suitable sandwich-bread. The crumb was also more even.	Both breads were too dry although "AX day 7" was better over all attributes compared to "Control day 7". "AX day 7" may have been somewhat dense.
"Control day 7" was slightly dry and had a slight off-taste. "AX day 7" had a nice "spongy" consistency and a nice taste.	"Control day 1" had a very nice "fluffy" consistency.
Both samples tasted good but I didn't feel much difference between them.	The only thing I didn't like in sample "AX day 7" is the smell, but overall I think it was the best between all 4.
Sample ”Control day 1” had a chewier texture. There were more lumps when chewing. Sample “AX day 1” had a malty taste and was a bit richer in taste. (Translated from Swedish)	Sample ”Control day 7” had nice, even pores. It does not look dry. The fiber spots are attractive. Sample “AX day 7” looked a bit dry. Sample “Control day 7” was dry! However, it was crispy on the surface which I liked. Did not feel a difference in taste between the samples. But I preferred “AX day 7”. (Translated from Swedish)
The sample "Control day 1" was very good, nice flavour. It was a bit spongy for my taste. Sample "AX day 1" had a good texture and appearance and had a very nice flavour.	I am not a huge fan of white bread, could have had an impact.
Very similar.	Sample "AX day 7" had a nice appearance but the texture was to hard and the taste was not as I had hoped. Sample "Control day 7" had the best flavour but was too hard as well.
Better texture to the still somewhat bland bread. Very neutral. I am looking at the pore sizes, here larger than previous. Slower rising process? Sour dough?	The two samples were a bit to dry.
Slightly preference for "AX day 1". "AX day 1" is very fluffy (in texture). Both have a nice appearance and good taste.	Fluffy bland bread with little taste to it, goes for both. Darker flavour to "AX day 7", and slightly

	better. Overall impression not full, not what I would buy or bake myself.
"AX day 1" smells very little. Very neutral breads different but ok.	Both have a dry texture. They seems to have the same flavour. I like them but they are not my favourite.
"AX day 1" smelt more intense but has lower taste intensity while "Control day 1" is opposite smells less intense and tastes more strange/interesting?	Samples seem to be quite similar. Texture in "AX day 7"' was slightly more dense, but I liked both types similar.
White bread is general not my favorite. " AX day 1" was too weak.	Samples felt old and dry.
They are quite similar in taste and texture. The appearance differ a bit.	"Control day 7" had a slightly strong texture. Taste was ok (neutral) for both.
"Control day 1" is difficult to chew and swallow, feels sweet. (Translated from Swedish)	When just eating and evaluating the bread, I prefer one of them, but it will also depend at the end what the bread is meant for.
	Also quite similar in taste and texture (but much drier than the first two). Differ in colour.

Appendix V Raw data from statistical analysis: parameters versus sample

Method

Null hypothesis	All means are equal
Alternative hypothesis	Not all means are equal
Significance level	α = 0,05

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Sample	10	0.3 % AXE; 0.3 % FAX; 0.3 % UFAX; 1.0 % AXE; 1.0 % FAX; 1.0 % UFAX; 1.7 % AXE; 1.7 % FAX; 1.7 % UFAX; Control

Parameter	Analysis of variance						Means					Tukey pairwise comparison						
Baking absorption	**Source**	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**	**Sample**	**N**	**Mean**	**StDev**	**95% CI**	**Sample**	**N**	**Mean**	**Grouping**			
	Sample	9	2271.82	252.424	621.35	0.000	0.3 % AXE	2	180	0	(179.0; 181.0)	1.7 % UFAX	2	208	A			
	Error	12	4.87	0.406			0.3 % FAX	2	182.5	0.707	(181.518; 183.482)	1.7 % FAX	2	205.5		B		
	Total	21	2276.69				0.3 % UFAX	2	182.25	0.354	(181.268; 183.232)	1.0 % UFAX	2	194.5			C	
							1.0 % AXE	2	180	0	(179.0; 181.0)	1.0 % FAX	2	194.5			C	
	Model summary						1.0 % FAX	2	194.5	0.707	(193.518; 195.482)	0.3 % FAX	2	182.5				D
	S	**R-sq**	**R-sq(adj)**	**R-sq(pred)**			1.0 % UFAX	2	194.5	0.707	(193.518; 195.482)	0.3 % UFAX	2	182.25				D E
	0.637377	99.79%	99.63%	99.41%			1.7 % AXE	2	181	0	(180.0; 182.0)	1.7 % AXE	2	181				D E
							1.7 % FAX	2	205.5	0.707	(204.518; 206.482)	Control	4	180.75				D E
							1.7 % UFAX	2	208	0	(207.0; 209.0)	1.0 % AXE	2	180				E
							Control	4	180.75	0.957	(180.056; 181.444)	0.3 % AXE	2	180				E
							Pooled StDev = 0.637377					Means that do not share a letter are significantly different.						
Dough development time	**Analysis of Variance**						**Means**					**Tukey Pairwise Comparisons**						
	Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**	**Sample**	**N**	**Mean**	**StDev**	**95% CI**	**Sample**	**N**	**Mean**	**Grouping**			
	Sample	9	5.801	0.6446	1.9	0.148	0.3 % AXE	2	11.5	0.707	(10.604; 12.396)	1.7 % UFAX	2	13	A			
	Error	12	4.062	0.3385			0.3 % FAX	2	11.75	0.354	(10.854; 12.646)	1.7 % FAX	2	12.5	A			
	Total	21	9.864				0.3 % UFAX	2	11.5	0	(10.60; 12.40)	1.0 % FAX	2	12	A			
							1.0 % AXE	2	11.75	0.354	(10.854; 12.646)	1.0 % AXE	2	11.75	A			
	Model Summary						1.0 % FAX	2	12	0	(11.10; 12.90)	0.3 % FAX	2	11.75	A			
	S	**R-sq**	**R-sq(adj)**	**R-sq(pred)**			1.0 % UFAX	2	11.5	0	(10.60; 12.40)	1.0 % UFAX	2	11.5	A			
	0.581843	58.81%	27.92%	0.00%			1.7 % AXE	2	11.25	1.061	(10.354; 12.146)	0.3 % UFAX	2	11.5	A			
							1.7 % FAX	2	12.5	0.707	(11.604; 13.396)	0.3 % AXE	2	11.5	A			
							1.7 % UFAX	2	13	0	(12.10; 13.90)	Control	4	11.375	A			
							Control	4	11.375	0.75	(10.741; 12.009)	1.7 % AXE	2	11.25	A			

Pooled StDev = 0.581843

Means that do not share a letter are significantly different.

Specific volume

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Sample	9	0.4554	0.0506	1.82	0.165
Error	12	0.3338	0.02782		
Total	21	0.7892			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.16679	57.70%	25.98%	0.00%

Means

Sample	N	Mean	StDev	95% CI
0.3 % AXE	2	4.9189	0.0787	(4.6620; 5.1759)
0.3 % FAX	2	4.5756	0.1144	(4.3187; 4.8326)
0.3 % UFAX	2	4.791	0.194	(4.534; 5.048)
1.0 % AXE	2	4.9332	0.1144	(4.6762; 5.1901)
1.0 % FAX	2	4.958	0.147	(4.701; 5.215)
1.0 % UFAX	2	4.9115	0.1327	(4.6545; 5.1685)
1.7 % AXE	2	5.0424	0.0337	(4.7854; 5.2993)
1.7 % FAX	2	4.61	0.161	(4.353; 4.867)
1.7 % UFAX	2	4.7312	0.0676	(4.4742; 4.9881)
Control	4	4.729	0.253	(4.547; 4.911)

Tukey Pairwise Comparisons

Sample	N	Mean	Grouping
1.7 % AXE	2	5.0424	A
1.0 % FAX	2	4.958	A
1.0 % AXE	2	4.9332	A
0.3 % AXE	2	4.9189	A
1.0 % UFAX	2	4.9115	A
0.3 % UFAX	2	4.791	A
1.7 % UFAX	2	4.7312	A
Control	4	4.729	A
1.7 % FAX	2	4.61	A
0.3 % FAX	2	4.5756	A

Pooled StDev = 0.166790

Means that do not share a letter are significantly different.

Image cell count

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Sample	9	13127	1458.5	5.27	0.005
Error	12	3320	276.7		
Total	21	16446			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
16.6332	79.81%	64.67%	25.35%

Means

Sample	N	Mean	StDev	95% CI
0.3 % AXE	2	425.42	4.12	(399.79; 451.04)
0.3 % FAX	2	428.33	2.12	(402.71; 453.96)
0.3 % UFAX	2	432.8	26.3	(407.1; 458.4)
1.0 % AXE	2	448.58	13.08	(422.96; 474.21)
1.0 % FAX	2	437.58	10.96	(411.96; 463.21)
1.0 % UFAX	2	461.6	37.4	(436.0; 487.2)
1.7 % AXE	2	435.67	12.96	(410.04; 461.29)
1.7 % FAX	2	457.92	13.08	(432.29; 483.54)

Tukey Pairwise Comparisons

Sample	N	Mean	Grouping	
1.7 % UFAX	2	496.92	A	
1.0 % UFAX	2	461.6	A	B
1.7 % FAX	2	457.92	A	B
1.0 % AXE	2	448.58	A	B
1.0 % FAX	2	437.58	A	B
1.7 % AXE	2	435.67	A	B
0.3 % UFAX	2	432.8		B
0.3 % FAX	2	428.33		B

							1.7 % UFAX	2	496.92	11.43	(471.29; 522.54)	0.3 % AXE	2	425.42	B
							Control	4	408.08	12.26	(389.96; 426.20)	Control	4	408.08	B
							Pooled StDev = 16.6332					Means that do not share a letter are significantly different.			
Image total area	**Analysis of Variance**						**Means**					**Tukey Pairwise Comparisons**			
	Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**	**Sample**	**N**	**Mean**	**StDev**	**95% CI**	**Sample**	**N**	**Mean**	**Grouping**
	Sample	9	1191118	132346	1.34	0.311	0.3 % AXE	2	5371	386	(4887; 5854)	1.0 % FAX	2	6236	A
	Error	12	1183161	98597			0.3 % FAX	2	5578	370	(5095; 6062)	1.7 % FAX	2	5799	A
	Total	21	2374279				0.3 % UFAX	2	5712.4	120.8	(5228.6; 6196.2)	1.0 % UFAX	2	5717.2	A
							1.0 % AXE	2	5394	255	(4910; 5877)	0.3 % UFAX	2	5712.4	A
	Model Summary						1.0 % FAX	2	6236	283	(5752; 6720)	1.7 % AXE	2	5673	A
	S	**R-sq**	**R-sq(adj)**	**R-sq(pred)**			1.0 % UFAX	2	5717.2	52.8	(5233.4; 6200.9)	Control	4	5638	A
	314.001	50.17%	12.79%	0.00%			1.7 % AXE	2	5673	473	(5189; 6157)	0.3 % FAX	2	5578	A
							1.7 % FAX	2	5799	231	(5315; 6282)	1.0 % AXE	2	5394	A
							1.7 % UFAX	2	5382	234	(4898; 5866)	1.7 % UFAX	2	5382	A
							Control	4	5638	366	(5296; 5980)	0.3 % AXE	2	5371	A
							Pooled StDev = 314.001					Means that do not share a letter are significantly different.			
Image average cell size	**Analysis of Variance**						**Means**					**Tukey Pairwise Comparisons**			
	Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**	**Sample**	**N**	**Mean**	**StDev**	**95% CI**	**Sample**	**N**	**Mean**	**Grouping**
	Sample	9	20.09	2.232	2.4	0.079	0.3 % AXE	2	12.741	1.165	(11.256; 14.226)	1.0 % FAX	2	14.632	A
	Error	12	11.15	0.9291			0.3 % FAX	2	13.077	0.953	(11.592; 14.562)	Control	4	13.882	A B
	Total	21	31.24				0.3 % UFAX	2	13.334	0.429	(11.849; 14.819)	0.3 % UFAX	2	13.334	A B
							1.0 % AXE	2	12.054	0.229	(10.569; 13.539)	1.7 % AXE	2	13.17	A B
	Model Summary						1.0 % FAX	2	14.632	0.184	(13.147; 16.117)	0.3 % FAX	2	13.077	A B
	S	**R-sq**	**R-sq(adj)**	**R-sq(pred)**			1.0 % UFAX	2	12.611	1.163	(11.126; 14.096)	1.7 % FAX	2	12.746	A B

	0.9639	64.31%	37.54%	0.00%			1.7 % AXE	2	13.17	1.5	(11.69; 14.66)	0.3 % AXE	2	12.741	A	B
							1.7 % FAX	2	12.746	0.886	(11.261; 14.231)	1.0 % UFAX	2	12.611	A	B
							1.7 % UFAX	2	10.879	0.182	(9.394; 12.364)	1.0 % AXE	2	12.054	A	B
							Control	4	13.882	1.18	(12.832; 14.932)	1.7 % UFAX	2	10.879		B
							Pooled StDev = 0.963900					Means that do not share a letter are significantly different.				
Image % area	**Analysis of Variance**						**Means**					**Tukey Pairwise Comparisons**				
	Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**	**Sample**	**N**	**Mean**	**StDev**	**95% CI**	**Sample**	**N**	**Mean**	**Grouping**	
	Sample	9	31.33	3.481	1.34	0.311	0.3 % AXE	2	27.54	1.98	(25.06; 30.02)	1.0 % FAX	2	31.98	A	
	Error	12	31.12	2.593			0.3 % FAX	2	28.61	1.9	(26.13; 31.09)	1.7 % FAX	2	29.737	A	
	Total	21	62.44				0.3 % UFAX	2	29.294	0.62	(26.814; 31.775)	1.0 % UFAX	2	29.319	A	
							1.0 % AXE	2	27.659	1.309	(25.178; 30.140)	0.3 % UFAX	2	29.294	A	
	Model Summary						1.0 % FAX	2	31.98	1.45	(29.50; 34.46)	1.7 % AXE	2	29.09	A	
	S	**R-sq**	**R-sq(adj)**	**R-sq(pred)**			1.0 % UFAX	2	29.319	0.271	(26.838; 31.800)	Control	4	28.915	A	
	1.61028	50.17%	12.79%	0.00%			1.7 % AXE	2	29.09	2.43	(26.61; 31.57)	0.3 % FAX	2	28.61	A	
							1.7 % FAX	2	29.737	1.186	(27.256; 32.218)	1.0 % AXE	2	27.659	A	
							1.7 % UFAX	2	27.599	1.2	(25.118; 30.080)	1.7 % UFAX	2	27.599	A	
							Control	4	28.915	1.879	(27.161; 30.669)	0.3 % AXE	2	27.54	A	
							Pooled StDev = 1.61028					Means that do not share a letter are significantly different.				
Hardness day 1	**Analysis of Variance**						**Means**					**Tukey Pairwise Comparisons**				
	Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**	**Sample**	**N**	**Mean**	**StDev**	**95% CI**	**Sample**	**N**	**Mean**	**Grouping**	
	Sample	9	4.721	0.5245	1.06	0.457	0.3 % AXE	2	2.76	0	(1.664; 3.856)	0.3 % UFAX	2	3.545	A	
	Error	11	5.452	0.4956			0.3 % FAX	2	2.565	0.898	(1.469; 3.661)	Control	3	3.03	A	
	Total	20	10.173				0.3 % UFAX	2	3.545	1.393	(2.449; 4.641)	0.3 % AXE	2	2.76	A	
							1.0 % AXE	2	2.255	0.389	(1.159; 3.351)	1.0 % UFAX	2	2.64	A	

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.704018	46.41%	2.55%	0.00%

Sample	N	Mean	StDev	95% CI
1.0 % FAX	2	2.48	0.99	(1.384; 3.576)
1.0 % UFAX	2	2.64	0.467	(1.544; 3.736)
1.7 % AXE	2	2.495	0.148	(1.399; 3.591)
1.7 % FAX	2	1.995	0.304	(0.899; 3.091)
1.7 % UFAX	2	1.79	0.0566	(0.6943; 2.8857)
Control	3	3.03	0.787	(2.135; 3.925)

Pooled StDev = 0.704018

Sample	N	Mean	Grouping
0.3 % FAX	2	2.565	A
1.7 % AXE	2	2.495	A
1.0 % FAX	2	2.48	A
1.0 % AXE	2	2.255	A
1.7 % FAX	2	1.995	A
1.7 % UFAX	2	1.79	A

Means that do not share a letter are significantly different.

Hardness day 7

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Sample	9	15.8	1.756	1.62	0.216
Error	12	13.04	1.087		
Total	21	28.84			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1.04243	54.79%	20.87%	0.00%

Means

Sample	N	Mean	StDev	95% CI
0.3 % AXE	2	7.51	2.04	(5.90; 9.12)
0.3 % FAX	2	7.155	0.0919	(5.5490; 8.7610)
0.3 % UFAX	2	8.025	1.351	(6.419; 9.631)
1.0 % AXE	2	6.52	1.018	(4.914; 8.126)
1.0 % FAX	2	7.15	1.75	(5.54; 8.75)
1.0 % UFAX	2	6.435	0.29	(4.829; 8.041)
1.7 % AXE	2	5.635	0.177	(4.029; 7.241)
1.7 % FAX	2	7.305	0.53	(5.699; 8.911)
1.7 % UFAX	2	4.92	0.495	(3.314; 6.526)
Control	4	7.185	0.882	(6.049; 8.321)

Pooled StDev = 1.04243

Tukey Pairwise Comparisons

Sample	N	Mean	Grouping
0.3 % UFAX	2	8.025	A
0.3 % AXE	2	7.51	A
1.7 % FAX	2	7.305	A
Control	4	7.185	A
0.3 % FAX	2	7.155	A
1.0 % FAX	2	7.15	A
1.0 % AXE	2	6.52	A
1.0 % UFAX	2	6.435	A
1.7 % AXE	2	5.635	A
1.7 % UFAX	2	4.92	A

Means that do not share a letter are significantly different.

Hardness day 14

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Sample	9	43.24	4.804	1.75	0.181
Error	12	32.94	2.745		

Means

Sample	N	Mean	StDev	95% CI
0.3 % AXE	2	8.99	1.53	(6.44; 11.54)
0.3 % FAX	2	10.53	0.834	(7.978; 13.082)

Tukey Pairwise Comparisons

Sample	N	Mean	Grouping
Control	4	11.92	A
0.3 % FAX	2	10.53	A

	Total	21	76.18				0.3 % UFAX	2	9.48	2.13	(6.93; 12.04)	1.7 % UFAX	2	9.869	A
							1.0 % AXE	2	7.875	0.601	(5.323; 10.427)	0.3 % UFAX	2	9.48	A
	Model Summary						1.0 % FAX	2	7.83	0.269	(5.278; 10.382)	1.7 % FAX	2	9.41	A
	S	**R-sq**	**R-sq(adj)**	**R-sq(pred)**			1.0 % UFAX	2	8.593	0.0523	(6.0405; 11.1455)	0.3 % AXE	2	8.99	A
	1.65675	56.76%	24.33%	0.00%			1.7 % AXE	2	8.02	3	(5.47; 10.57)	1.0 % UFAX	2	8.593	A
							1.7 % FAX	2	9.41	2.96	(6.86; 11.97)	1.7 % AXE	2	8.02	A
							1.7 % UFAX	2	9.869	0.224	(7.316; 12.421)	1.0 % AXE	2	7.875	A
							Control	4	11.92	1.541	(10.115; 13.725)	1.0 % FAX	2	7.83	A
							Pooled StDev = 1.65675					Means that do not share a letter are significantly different.			
Cohesiveness day 1	**Analysis of Variance**						**Means**					**Tukey Pairwise Comparisons**			
	Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**	**Sample**	**N**	**Mean**	**StDev**	**95% CI**	**Sample**	**N**	**Mean**	**Grouping**
	Sample	9	0.018784	0.002087	3.06	0.042	0.3 % AXE	2	0.75686	0.01181	(0.71624; 0.79748)	1.7 % UFAX	2	0.845379	A
	Error	11	0.007494	0.000681			0.3 % FAX	2	0.77208	0.01012	(0.73145; 0.81270)	1.7 % FAX	2	0.8382	A
	Total	20	0.026278				0.3 % UFAX	2	0.7622	0.0361	(0.7216; 0.8028)	1.0 % FAX	2	0.796	A
							1.0 % AXE	2	0.7759	0.0164	(0.7352; 0.8165)	1.0 % UFAX	2	0.7919	A
	Model Summary						1.0 % FAX	2	0.796	0.00001 3	(0.755377; 0.836623)	1.0 % AXE	2	0.7759	A
	S	**R-sq**	**R-sq(adj)**	**R-sq(pred)**			1.0 % UFAX	2	0.7919	0.0464	(0.7513; 0.8325)	0.3 % FAX	2	0.77208	A
	0.026102	71.48%	48.15%	6.78%			1.7 % AXE	2	0.76397	0.00385	(0.72335; 0.80459)	1.7 % AXE	2	0.76397	A
							1.7 % FAX	2	0.8382	0.0196	(0.7976; 0.8788)	Control	3	0.7627	A
							1.7 % UFAX	2	0.84537 9	0.00004 5	(0.804756; 0.886002)	0.3 % UFAX	2	0.7622	A
							Control	3	0.7627	0.0396	(0.7295; 0.7959)	0.3 % AXE	2	0.75686	A
							Pooled StDev = 0.0261017					Means that do not share a letter are significantly different.			
Cohesiveness day 7	**Analysis of Variance**						**Means**					**Tukey Pairwise Comparisons**			
	Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**	**Sample**	**N**	**Mean**	**StDev**	**95% CI**	**Sample**	**N**	**Mean**	**Grouping**

	Sample	9	0.04152	0.004613	4.31	0.011	0.3 % AXE	2	0.4927	0.03	(0.4423; 0.5431)	1.7 % UFAX	2	0.6303	A	
	Error	12	0.01285	0.001071			0.3 % FAX	2	0.5192	0.0173	(0.4688; 0.5696)	1.7 % FAX	2	0.57421	A	B
	Total	21	0.05437				0.3 % UFAX	2	0.5187	0.0183	(0.4683; 0.5691)	1.0 % UFAX	2	0.5575	A	B
							1.0 % AXE	2	0.4691	0.0246	(0.4187; 0.5195)	1.0 % FAX	2	0.5458	A	B
	Model Summary						1.0 % FAX	2	0.5458	0.0234	(0.4953; 0.5962)	0.3 % FAX	2	0.5192	A	B
	S	**R-sq**	**R-sq(adj)**	**R-sq(pred)**			1.0 % UFAX	2	0.5575	0.0178	(0.5071; 0.6080)	0.3 % UFAX	2	0.5187	A	B
	0.032724	**76.36%**	**58.64%**	**27.57%**			1.7 % AXE	2	0.5136	0.0302	(0.4632; 0.5640)	1.7 % AXE	2	0.5136	A	B
							1.7 % FAX	2	0.57421	0.00746	(0.52380; 0.62463)	Control	4	0.4972		B
							1.7 % UFAX	2	0.6303	0.0588	(0.5798; 0.6807)	0.3 % AXE	2	0.4927		B
							Control	4	0.4972	0.0425	(0.4615; 0.5328)	1.0 % AXE	2	0.4691		B
							Pooled StDev = 0.0327238					Means that do not share a letter are significantly different.				

Cohesiveness day 14	**Analysis of Variance**						**Means**					**Tukey Pairwise Comparisons**				
	Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**	**Sample**	**N**	**Mean**	**StDev**	**95% CI**	**Sample**	**N**	**Mean**	**Grouping**	
	Sample	9	0.020955	0.002328	3.02	0.039	0.3 % AXE	2	0.4521	0.0597	(0.4093; 0.4948)	1.7 % UFAX	2	0.51645	A	
	Error	12	0.009251	0.000771			0.3 % FAX	2	0.411	0.0183	(0.3682; 0.4538)	1.7 % FAX	2	0.45262	A	B
	Total	21	0.030206				0.3 % UFAX	2	0.4057	0.0408	(0.3629; 0.4485)	0.3 % AXE	2	0.4521	A	B
							1.0 % AXE	2	0.4006	0.0239	(0.3579; 0.4434)	1.0 % FAX	2	0.437551	A	B
	Model Summary						1.0 % FAX	2	0.43755 1	0.00002 7	(0.394774; 0.480327)	Control	4	0.4352	A	B
	S	**R-sq**	**R-sq(adj)**	**R-sq(pred)**			1.0 % UFAX	2	0.43412 4	0.00028	(0.391348; 0.476901)	1.0 % UFAX	2	0.434124	A	B
	0.027765	69.37%	46.40%	0.00%			1.7 % AXE	2	0.41001	0.01251	(0.36723; 0.45279)	0.3 % FAX	2	0.411	A	B
							1.7 % FAX	2	0.45262	0.00811	(0.40985; 0.49540)	1.7 % AXE	2	0.41001		B
							1.7 % UFAX	2	0.51645	0.00351	(0.47367; 0.55923)	0.3 % UFAX	2	0.4057		B
							Control	4	0.4352	0.031	(0.4049; 0.4654)	1.0 % AXE	2	0.4006		B
							Pooled StDev = 0.0277652					Means that do not share a letter are significantly different.				

Springiness day 1

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Sample	9	0.000943	0.000105	0.83	0.607
Error	11	0.001396	0.000127		
Total	20	0.002339			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.011266	40.32%	0.00%	0.00%

Means

Sample	N	Mean	StDev	95% CI
0.3 % AXE	2	0.97175	0.00698	(0.95421; 0.98928)
0.3 % FAX	2	0.98848	0.00828	(0.97095; 1.00601)
0.3 % UFAX	2	0.9825	0.0164	(0.9650; 1.0001)
1.0 % AXE	2	0.9893	0.0158	(0.9717; 1.0068)
1.0 % FAX	2	0.9833	0.0188	(0.9657; 1.0008)
1.0 % UFAX	2	0.99358	0.00545	(0.97605; 1.01111)
1.7 % AXE	2	0.97864	0.0113	(0.96110; 0.99617)
1.7 % FAX	2	0.989451	0.000524	(0.971917; 1.006984)
1.7 % UFAX	2	0.98876	0.00662	(0.97123; 1.00630)
Control	3	0.97589	0.01019	(0.96157; 0.99021)

Pooled StDev = 0.0112658

Tukey Pairwise Comparisons

Sample	N	Mean	Grouping
1.0 % UFAX	2	0.99358	A
1.7 % FAX	2	0.989451	A
1.0 % AXE	2	0.9893	A
1.7 % UFAX	2	0.98876	A
0.3 % FAX	2	0.98848	A
1.0 % FAX	2	0.9833	A
0.3 % UFAX	2	0.9825	A
1.7 % AXE	2	0.97864	A
Control	3	0.97589	A
0.3 % AXE	2	0.97175	A

Means that do not share a letter are significantly different.

Springiness day 7

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Sample	9	0.001902	0.000211	0.72	0.685
Error	10	0.002943	0.000294		
Total	19	0.004844			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.017154	39.26%	0.00%	*

Means

Sample	N	Mean	StDev	95% CI
0.3 % AXE	2	0.944	0.0236	(0.9169; 0.9710)
0.3 % FAX	1	0.9526	*	(0.9144; 0.9908)
0.3 % UFAX	2	0.9601	0.0149	(0.9330; 0.9871)
1.0 % AXE	1	0.9448	*	(0.9066; 0.9830)
1.0 % FAX	2	0.9539	0.0316	(0.9268; 0.9809)
1.0 % UFAX	2	0.96973	0.00585	(0.94270; 0.99676)
1.7 % AXE	2	0.95576	0.00717	(0.92873; 0.98279)
1.7 % FAX	2	0.964	0.0176	(0.9370; 0.9911)
1.7 % UFAX	2	0.972261	0.000157	(0.945235; 0.999288)
Control	4	0.94602	0.01599	(0.92691; 0.96513)

Tukey Pairwise Comparisons

Sample	N	Mean	Grouping
1.7 % UFAX	2	0.972261	A
1.0 % UFAX	2	0.96973	A
1.7 % FAX	2	0.964	A
0.3 % UFAX	2	0.9601	A
1.7 % AXE	2	0.95576	A
1.0 % FAX	2	0.9539	A
0.3 % FAX	1	0.9526	A
Control	4	0.94602	A
1.0 % AXE	1	0.9448	A
0.3 % AXE	2	0.944	A

Springiness day 14

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Sample	9	0.005234	0.000582	0.66	0.728
Error	12	0.01053	0.000877		
Total	21	0.015764			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.029622	33.20%	0.00%	0.00%

Means

Sample	N	Mean	StDev	95% CI
0.3 % AXE	2	0.9094	0.0321	(0.8638; 0.9550)
0.3 % FAX	2	0.91871	0.00719	(0.87307; 0.96434)
0.3 % UFAX	2	0.91481	0.0099	(0.86917; 0.96045)
1.0 % AXE	2	0.9405	0.023	(0.8948; 0.9861)
1.0 % FAX	2	0.9345	0.015	(0.8888; 0.9801)
1.0 % UFAX	2	0.9376	0.0206	(0.8920; 0.9833)
1.7 % AXE	2	0.8972	0.0403	(0.8515; 0.9428)
1.7 % FAX	2	0.936387	0.001029	(0.890749; 0.982024)
1.7 % UFAX	2	0.95403	0.01214	(0.90839; 0.99967)
Control	4	0.9314	0.0462	(0.8991; 0.9637)

Pooled StDev = 0.0296223

Tukey Pairwise Comparisons

Sample	N	Mean	Grouping
1.7 % UFAX	2	0.95403	A
1.0 % AXE	2	0.9405	A
1.0 % UFAX	2	0.9376	A
1.7 % FAX	2	0.936387	A
1.0 % FAX	2	0.9345	A
Control	4	0.9314	A
0.3 % FAX	2	0.91871	A
0.3 % UFAX	2	0.91481	A
0.3 % AXE	2	0.9094	A
1.7 % AXE	2	0.8972	A

Means that do not share a letter are significantly different.

Crumb moisture content day 1

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Sample	9	0.002712	0.000301	25.53	0.000
Error	12	0.000142	0.000012		
Total	21	0.002854			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.003436	95.04%	91.31%	81.66%

Means

Sample	N	Mean	StDev	95% CI
0.3 % AXE	2	0.42539	0.00318	(0.42010; 0.43069)
0.3 % FAX	2	0.43005	0.00356	(0.42475; 0.43534)
0.3 % UFAX	2	0.42981	0.00501	(0.42451; 0.43510)
1.0 % AXE	2	0.427243	0.001094	(0.421949; 0.432536)
1.0 % FAX	2	0.43659	0.00739	(0.43129; 0.44188)
1.0 % UFAX	2	0.442309	0.000308	(0.437016; 0.447603)
1.7 % AXE	2	0.427243	0.000013	(0.418448; 0.429035)
1.7 % FAX	2	0.45404	0.00257	(0.44875; 0.45933)

Tukey Pairwise Comparisons

Sample	N	Mean	Grouping
1.7 % UFAX	2	0.4564	A
1.7 % FAX	2	0.45404	A B
1.0 % UFAX	2	0.442309	B C
1.0 % FAX	2	0.43659	C D
0.3 % FAX	2	0.43005	C D
0.3 % UFAX	2	0.42981	C D
1.0 % AXE	2	0.427243	D
Control	4	0.42624	D

							1.7 % UFAX	2	0.4564	0.00345	(0.45111; 0.46169)	0.3 % AXE	2	0.42539			D
							Control	4	0.42624	0.00255	(0.42249; 0.42998)	1.7 % AXE	2	0.423741			D
							Pooled StDev = 0.00343602					Means that do not share a letter are significantly different.					
Crumb moisture content day 7	**Analysis of Variance**						**Means**					**Tukey Pairwise Comparisons**					
	Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**	**Sample**	**N**	**Mean**	**StDev**	**95% CI**	**Sample**	**N**	**Mean**	**Grouping**		
	Sample	9	0.002477	0.000275	16.54	0.000	0.3 % AXE	2	0.40562	0.00266	(0.39933; 0.41190)	1.7 % UFAX	2	0.43562	A		
	Error	12	0.0002	0.000017			0.3 % FAX	2	0.41264	0.00204	(0.40636; 0.41893)	1.7 % FAX	2	0.4326	A		
	Total	21	0.002677				0.3 % UFAX	2	0.40424	0.00677	(0.39796; 0.41053)	1.0 % UFAX	2	0.423488	A	B	
							1.0 % AXE	2	0.41403	0.00281	(0.40774; 0.42031)	1.0 % FAX	2	0.42024	A	B	C
	Model Summary						1.0 % FAX	2	0.42024	0.00603	(0.41396; 0.42653)	1.0 % AXE	2	0.41403		B	C D
	S	**R-sq**	**R-sq(adj)**	**R-sq(pred)**			1.0 % UFAX	2	0.423488	0.000195	(0.417203; 0.429773)	0.3 % FAX	2	0.41264		B	C D
	0.00408	92.54%	86.94%	71.33%			1.7 % AXE	2	0.40765	0.00553	(0.40137; 0.41394)	1.7 % AXE	2	0.40765			C D
							1.7 % FAX	2	0.4326	0.00503	(0.42631; 0.43888)	Control	4	0.40658			D
							1.7 % UFAX	2	0.43562	0.00532	(0.42933; 0.44190)	0.3 % AXE	2	0.40562			C D
							Control	4	0.40658	0.00217	(0.40214; 0.41103)	0.3 % UFAX	2	0.40424			D
							Pooled StDev = 0.00407951					Means that do not share a letter are significantly different.					
Crumb moisture content day 14	**Analysis of Variance**						**Means**					**Tukey Pairwise Comparisons**					
	Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**	**Sample**	**N**	**Mean**	**StDev**	**95% CI**	**Sample**	**N**	**Mean**	**Grouping**		
	Sample	9	0.004634	0.000515	14.58	0.000	0.3 % AXE	2	0.37708	0.00554	(0.36792; 0.38624)	1.7 % UFAX	2	0.4113	A		
	Error	12	0.000424	0.000035			0.3 % FAX	2	0.38293	0.00276	(0.37377; 0.39209)	1.7 % FAX	2	0.40846	A		
	Total	21	0.005058				0.3 % UFAX	2	0.36914	0.00508	(0.35999; 0.37830)	1.0 % FAX	2	0.38547		B	
							1.0 % AXE	2	0.36723	0.00997	(0.35807; 0.37639)	1.0 % UFAX	2	0.38424		B	
	Model Summary						1.0 % FAX	2	0.38547	0.00264	(0.37632; 0.39463)	0.3 % FAX	2	0.38293		B	
	S	**R-sq**	**R-sq(adj)**	**R-sq(pred)**			1.0 % UFAX	2	0.38424	0.00565	(0.37509; 0.39340)	0.3 % AXE	2	0.37708		B	

	0.005943	91.62%	85.34%	69.11%			1.7 % AXE	2	0.37649	0.00532	(0.36733; 0.38564)	1.7 % AXE	2	0.37649	B
							1.7 % FAX	2	0.40846	0.01059	(0.39931; 0.41762)	Control	4	0.36971	B
							1.7 % UFAX	2	0.4113	0.00461	(0.40215; 0.42046)	0.3 % UFAX	2	0.36914	B
							Control	4	0.36971	0.00446	(0.36323; 0.37618)	1.0 % AXE	2	0.36723	B
							Pooled StDev = 0.00594310					Means that do not share a letter are significantly different.			

Crust moisture content day 1	**Analysis of Variance**						**Means**					**Tukey Pairwise Comparisons**			
	Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**	**Sample**	**N**	**Mean**	**StDev**	**95% CI**	**Sample**	**N**	**Mean**	**Grouping**
	Sample	9	0.004855	0.000539	1.81	0.168	0.3 % AXE	2	0.321	0.0235	(0.2943; 0.3476)	1.7 % FAX	2	0.37174	A
	Error	12	0.003585	0.000299			0.3 % FAX	2	0.3452	0.0198	(0.3186; 0.3719)	1.7 % UFAX	2	0.37154	A
	Total	21	0.00844				0.3 % UFAX	2	0.3364	0.00662	(0.30977; 0.36303)	Control	4	0.3563	A
							1.0 % AXE	2	0.33475	0.01037	(0.30812; 0.36138)	1.0 % UFAX	2	0.35028	A
	Model Summary						1.0 % FAX	2	0.33807	0.00168	(0.31144; 0.36470)	0.3 % FAX	2	0.3452	A
	S	**R-sq**	**R-sq(adj)**	**R-sq(pred)**			1.0 % UFAX	2	0.35028	0.00968	(0.32365; 0.37691)	1.7 % AXE	2	0.34343	A
	0.017284	57.53%	25.67%	0.00%			1.7 % AXE	2	0.34343	0.01394	(0.31681; 0.37006)	1.0 % FAX	2	0.33807	A
							1.7 % FAX	2	0.37174	0.01252	(0.34511; 0.39836)	0.3 % UFAX	2	0.3364	A
							1.7 % UFAX	2	0.37154	0.00299	(0.34492; 0.39817)	1.0 % AXE	2	0.33475	A
							Control	4	0.3563	0.026	(0.3374; 0.3751)	0.3 % AXE	2	0.321	A
							Pooled StDev = 0.0172835					Means that do not share a letter are significantly different.			

Crust moisture content day 7	**Analysis of Variance**						**Means**					**Tukey Pairwise Comparisons**			
	Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**	**Sample**	**N**	**Mean**	**StDev**	**95% CI**	**Sample**	**N**	**Mean**	**Grouping**
	Sample	9	0.000839	0.000093	0.83	0.605	0.3 % AXE	2	0.30018	0.00759	(0.28382; 0.31655)	1.7 % UFAX	2	0.32035	A
	Error	12	0.001354	0.000113			0.3 % FAX	2	0.30872	0.014	(0.29235; 0.32508)	1.7 % FAX	2	0.31395	A
	Total	21	0.002193				0.3 % UFAX	2	0.29718	0.00584	(0.28082; 0.31355)	1.0 % FAX	2	0.3098	A
							1.0 % AXE	2	0.3095	0.0089	(0.29313; 0.32586)	1.0 % AXE	2	0.3095	A

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.010623	38.26%	0.00%	0.00%

Sample	N	Mean	StDev	95% CI
1.0 % FAX	2	0.3098	0.0176	(0.2934; 0.3262)
1.0 % UFAX	2	0.30386	0.00222	(0.28750; 0.32023)
1.7 % AXE	2	0.30598	0.00393	(0.28961; 0.32235)
1.7 % FAX	2	0.31395	0.00537	(0.29758; 0.33031)
1.7 % UFAX	2	0.32035	0.01041	(0.30398; 0.33671)
Control	4	0.30365	0.01315	(0.29208; 0.31522)

Pooled StDev = 0.0106227

Sample	N	Mean	Grouping
0.3 % FAX	2	0.30872	A
1.7 % AXE	2	0.30598	A
1.0 % UFAX	2	0.30386	A
Control	4	0.30365	A
0.3 % AXE	2	0.30018	A
0.3 % UFAX	2	0.29718	A

Means that do not share a letter are significantly different.

Crust moisture content day 14

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Sample	9	0.003923	0.000436	3.9	0.016
Error	12	0.001341	0.000112		
Total	21	0.005263			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.01057	74.53%	55.43%	12.27%

Means

Sample	N	Mean	StDev	95% CI
0.3 % AXE	2	0.29664	0.01172	(0.28036; 0.31293)
0.3 % FAX	2	0.31107	0.005	(0.29479; 0.32736)
0.3 % UFAX	2	0.2784	0.0256	(0.2621; 0.2947)
1.0 % AXE	2	0.29628	0.00636	(0.28000; 0.31256)
1.0 % FAX	2	0.30269	0.0057	(0.28640; 0.31897)
1.0 % UFAX	2	0.29295	0.00292	(0.27666; 0.30923)
1.7 % AXE	2	0.297805	0.001345	(0.281521; 0.314089)
1.7 % FAX	2	0.31882	0.00687	(0.30254; 0.33511)
1.7 % UFAX	2	0.31193	0.00765	(0.29565; 0.32821)
Control	4	0.2787	0.01057	(0.26719; 0.29022)

Pooled StDev = 0.0105695

Tukey Pairwise Comparisons

Sample	N	Mean	Grouping	
1.7 % FAX	2	0.31882	A	
1.7 % UFAX	2	0.31193	A	
0.3 % FAX	2	0.31107	A	B
1.0 % FAX	2	0.30269	A	B
1.7 % AXE	2	0.297805	A	B
0.3 % AXE	2	0.29664	A	B
1.0 % AXE	2	0.29628	A	B
1.0 % UFAX	2	0.29295	A	B
Control	4	0.2787		B
0.3 % UFAX	2	0.2784		B

Means that do not share a letter are significantly different.

Appendix VI Raw data from statistical analysis: parameter versus fraction

Method

Null hypothesis	All means are equal
Alternative hypothesis	Not all means are equal
Significance level	α = 0,05

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Fraction	4	UFAX; AXE; FAX; None

Parameter	Analysis of Variance						Model Summary				Means					Tukey Pairwise Comparisons				
Baking absorption	**Source**	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**	**S**	**R-sq**	**R-sq(adj)**	**R-sq(pred)**	**Fraction**	**N**	**Mean**	**StDev**	**95% CI**	**Fraction**	**N**	**Mean**	**Grouping**	
	Fraction	3	1078	359.19	5.39	0.008	8.16199	47.33%	38.55%	24.11%	UFAX	6	194.92	11.53	(187.92; 201.92)	UFAX	6	194.92	A	
	Error	18	1199	66.62							AXE	6	180.333	0.516	(173.333; 187.334)	FAX	6	194.17	A	
	Total	21	2277								FAX	6	194.17	10.3	(187.17; 201.17)	None	4	180.75	A	B
											None	4	180.75	0.957	(172.176; 189.324)	AXE	6	180.333		B
											Pooled StDev = 8.16199					Means that do not share a letter are significantly different.				
Dough development time	**Analysis of Variance**						**Model Summary**				**Means**					**Tukey Pairwise Comparisons**				
	Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**	**S**	**R-sq**	**R-sq(adj)**	**R-sq(pred)**	**Fraction**	**N**	**Mean**	**StDev**	**95% CI**	**Fraction**	**N**	**Mean**	**Grouping**	
	Fraction	3	1.968	0.6559	1.5	0.25	0.662312	19.95%	6.61%	0.00%	AX	6	12	0.775	(11.432; 12.568)	FAX	6	12.083	A	
	Error	18	7.896	0.4387							AXE	6	11.5	0.632	(10.932; 12.068)	AX	6	12	A	
	Total	21	9.864								FAX	6	12.083	0.492	(11.515; 12.651)	AXE	6	11.5	A	
											None	4	11.375	0.75	(10.679; 12.071)	None	4	11.375	A	
											Pooled StDev = 0.662312					Means that do not share a letter are significantly different.				
Specific volume	**Analysis of Variance**						**Model Summary**				**Means**					**Tukey Pairwise Comparisons**				
	Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**	**S**	**R-sq**	**R-sq(adj)**	**R-sq(pred)**	**Fraction**	**N**	**Mean**	**StDev**	**95% CI**	**Fraction**	**N**	**Mean**	**Grouping**	
	Fraction	3	0.2244	0.07482	2.38	0.103	0.177132	28.44%	16.51%	0.00%	UFAX	6	4.8113	0.1369	(4.6594; 4.9632)	AXE	6	4.9648	A	
	Error	18	0.5648	0.03138							AXE	6	4.9648	0.0879	(4.8129; 5.1167)	UFAX	6	4.8113	A	
	Total	21	0.7892								FAX	6	4.7147	0.2189	(4.5628; 4.8666)	None	4	4.729	A	
											None	4	4.729	0.253	(4.543; 4.915)	FAX	6	4.7147	A	
											Pooled StDev = 0.177132					Means that do not share a letter are significantly different.				
Image cell count	**Analysis of Variance**						**Model Summary**				**Means**					**Tukey Pairwise Comparisons**				
	Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**	**S**	**R-sq**	**R-sq(adj)**	**R-sq(pred)**	**Fraction**	**N**	**Mean**	**StDev**	**95% CI**	**Fraction**	**N**	**Mean**	**Grouping**	

	Fraction	3	7540	2513.3	5.08	0.01	22.2443	45.85%	36.82%	21.09%	UFAX	6	463.8	35.6	(444.7; 482.8)	UFAX	6	463.8	A	
	Error	18	8907	494.8							AXE	6	436.56	13.38	(417.48; 455.63)	FAX	6	441.28	A	B
	Total	21	16446								FAX	6	441.28	15.57	(422.20; 460.36)	AXE	6	436.56	A	B
											None	4	408.08	12.26	(384.72; 431.45)	None	4	408.08		B
											Pooled StDev = 22.2443					Means that do not share a letter are significantly different.				

Image total area	**Analysis of Variance**						**Model Summary**				**Means**					**Tukey Pairwise Comparisons**			
	Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**	**S**	**R-sq**	**R-sq(adj)**	**R-sq(pred)**	**Fraction**	**N**	**Mean**	**StDev**	**95% CI**	**Fraction**	**N**	**Mean**	**Grouping**
	Fraction	3	481694	160565	1.53	0.242	324.259	20.29%	7.00%	0.00%	UFAX	6	5603.8	209.8	(5325.7; 5881.9)	FAX	6	5871	A
	Error	18	1892585	105144							AXE	6	5479	332	(5201; 5757)	None	4	5638	A
	Total	21	2374279								FAX	6	5871	379	(5593; 6149)	UFAX	6	5603.8	A
											None	4	5638	366	(5298; 5979)	AXE	6	5479	A
											Pooled StDev = 324.259					Means that do not share a letter are significantly different.			

Image average cell size	**Analysis of Variance**						**Model Summary**				**Means**					**Tukey Pairwise Comparisons**			
	Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**	**S**	**R-sq**	**R-sq(adj)**	**R-sq(pred)**	**Fraction**	**N**	**Mean**	**StDev**	**95% CI**	**Fraction**	**N**	**Mean**	**Grouping**
	Fraction	3	8.388	2.796	2.2	0.123	1.12669	26.85%	14.66%	0.00%	UFAX	6	12.275	1.26	(11.308; 13.241)	None	4	13.882	A
	Error	18	22.85	1.269							AXE	6	12.656	0.995	(11.690; 13.622)	FAX	6	13.485	A
	Total	21	31.237								FAX	6	13.485	1.076	(12.519; 14.452)	AXE	6	12.656	A
											None	4	13.882	1.18	(12.698; 15.065)	UFAX	6	12.275	A
											Pooled StDev = 1.12669					Means that do not share a letter are significantly different.			

Image % area	**Analysis of Variance**						**Model Summary**				**Means**					**Tukey Pairwise Comparisons**			
	Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**	**S**	**R-sq**	**R-sq(adj)**	**R-sq(pred)**	**Fraction**	**N**	**Mean**	**StDev**	**95% CI**	**Fraction**	**N**	**Mean**	**Grouping**
	Fraction	3	12.67	4.223	1.53	0.242	1.6629	20.29%	7.00%	0.00%	UFAX	6	28.737	1.076	(27.311; 30.164)	FAX	6	30.108	A
	Error	18	49.77	2.765							AXE	6	28.098	1.703	(26.671; 29.524)	None	4	28.915	A

	Total	21	62.44								FAX	6	30.108	1.944	(28.681; 31.534)	UFAX	6	28.737	A
											None	4	28.915	1.879	(27.168; 30.662)	AXE	6	28.098	A
											Pooled StDev = 1.66290					Means that do not share a letter are significantly different.			

Hardness day 1

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Fraction	3	1.006	0.3354	0.62	0.61
Error	17	9.167	0.5392		
Total	20	10.173			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.734308	9.89%	0.00%	0.00%

Means

Fraction	N	Mean	StDev	95% CI
UFAX	6	2.658	1.024	(2.026; 3.291)
AXE	6	2.503	0.293	(1.871; 3.136)
FAX	6	2.347	0.672	(1.714; 2.979)
None	3	3.03	0.787	(2.136; 3.924)

Pooled StDev = 0.734308

Tukey Pairwise Comparisons

Fraction	N	Mean	Grouping
None	3	3.03	A
UFAX	6	2.658	A
AXE	6	2.503	A
FAX	6	2.347	A

Means that do not share a letter are significantly different.

Hardness day 7

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Fraction	3	2.606	0.8686	0.6	0.626
Error	18	26.234	1.4575		
Total	21	28.84			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1.20725	9.04%	0.00%	0.00%

Means

Fraction	N	Mean	StDev	95% CI
UFAX	6	6.46	1.536	(5.425; 7.495)
AXE	6	6.555	1.322	(5.520; 7.590)
FAX	6	7.202	0.821	(6.166; 8.237)
None	4	7.185	0.882	(5.917; 8.453)

Pooled StDev = 1.20725

Tukey Pairwise Comparisons

Fraction	N	Mean	Grouping
FAX	6	7.202	A
None	4	7.185	A
AXE	6	6.555	A
UFAX	6	6.46	A

Means that do not share a letter are significantly different.

Hardness day 14

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Fraction	3	32.69	10.897	4.51	0.016
Error	18	43.48	2.416		
Total	21	76.18			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1.55429	42.92%	33.40%	14.64%

Means

Fraction	N	Mean	StDev	95% CI
UFAX	6	9.316	1.122	(7.982; 10.649)
AXE	6	8.295	1.622	(6.962; 9.628)
FAX	6	9.258	1.839	(7.925; 10.591)
None	4	11.92	1.541	(10.287; 13.553)

Tukey Pairwise Comparisons

Fraction	N	Mean	Grouping	
None	4	11.92	A	
UFAX	6	9.316	A	B
FAX	6	9.258	A	B
AXE	6	8.295		B

Pooled StDev = 1.55429

Means that do not share a letter are significantly different.

Cohesiveness day 1

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Fraction	3	0.006828	0.002276	1.99	0.154
Error	17	0.019454	0.001144		
Total	20	0.026278			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.033825	25.98%	12.92%	0.00%

Means

Fraction	N	Mean	StDev	95% CI
UFAX	6	0.7998	0.046	(0.7707; 0.8290)
AXE	6	0.76557	0.01259	(0.73643; 0.79470)
FAX	6	0.8021	0.0315	(0.7730; 0.8312)
None	3	0.7627	0.0396	(0.7215; 0.8039)

Tukey Pairwise Comparisons

Fraction	N	Mean	Grouping
FAX	6	0.8021	A
UFAX	6	0.7998	A
AXE	6	0.76557	A
None	3	0.7627	A

Pooled StDev = 0.0338249

Means that do not share a letter are significantly different.

Cohesiveness day 7

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Fraction	3	0.023684	0.007894	4.63	0.014
Error	18	0.030685	0.001705		
Total	21	0.054369			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.041288	43.56%	34.15%	15.36%

Means

Fraction	N	Mean	StDev	95% CI
UFAX	6	0.5688	0.0582	(0.5334; 0.6043)
AXE	6	0.4918	0.0297	(0.4564; 0.5272)
FAX	6	0.5464	0.028	(0.5110; 0.5818)
None	4	0.4972	0.0425	(0.4538; 0.5405)

Tukey Pairwise Comparisons

Fraction	N	Mean	Grouping	
UFAX	6	0.5688	A	
FAX	6	0.5464	A	B
None	4	0.4972	A	B
AXE	6	0.4918		B

Pooled StDev = 0.0412881

Means that do not share a letter are significantly different.

Cohesiveness day 14

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Fraction	3	0.002954	0.000984	0.65	0.593
Error	18	0.027254	0.001514		
Total	21	0.030206			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.038913	9.77%	0.00%	0.00%

Means

Fraction	N	Mean	StDev	95% CI
UFAX	6	0.4521	0.0546	(0.4187; 0.4855)
AXE	6	0.4209	0.0382	(0.3875; 0.4543)
FAX	6	0.43373	0.02086	(0.40035; 0.46710)
None	4	0.4352	0.031	(0.3943; 0.4761)

Tukey Pairwise Comparisons

Fraction	N	Mean	Grouping
UFAX	6	0.4521	A
None	4	0.4352	A
FAX	6	0.43373	A
AXE	6	0.4209	A

Pooled StDev = 0.0389125

Means that do not share a letter are significantly different.

Springiness day 1

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Fraction	3	0.00046 5	0.00015 5	1.4	0.276
Error	17	0.00187 5	0.00011		
Total	20	0.00233 9			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.01050 1	19.87%	5.72%	0.00%

Means

Fraction	N	Mean	StDev	95% CI
UFAX	6	0.98829	0.00964	(0.97924; 0.99733)
AXE	6	0.97988	0.01214	(0.97084; 0.98892)
FAX	6	0.98707	0.00965	(0.97802; 0.99611)
None	3	0.97589	0.01019	(0.96310; 0.98868)

Pooled StDev = 0.0105011

Tukey Pairwise Comparisons

Fraction	N	Mean	Grouping
UFAX	6	0.98829	A
FAX	6	0.98707	A
AXE	6	0.97988	A
None	3	0.97589	A

Means that do not share a letter are significantly different.

Springiness day 7

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Fraction	3	0.00483 3	0.00161 1	2.11	0.134
Error	18	0.01373 2	0.00076 3		
Total	21	0.01856 5			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.02762 1	26.03%	13.71%	0.00%

Means

Fraction	N	Mean	StDev	95% CI
UFAX	6	0.96735	0.0092	(0.94366; 0.99104)
AXE	6	0.9374	0.0308	(0.9137; 0.9610)
FAX	6	0.9723	0.0395	(0.9486; 0.9959)
None	4	0.94602	0.01599	(0.91701; 0.97504)

Pooled StDev = 0.0276207

Tukey Pairwise Comparisons

Fraction	N	Mean	Grouping
FAX	6	0.9723	A
UFAX	6	0.96735	A
None	4	0.94602	A
AXE	6	0.9374	A

Means that do not share a letter are significantly different.

Springiness day 14

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Fraction	3	0.00131 2	0.00043 7	0.54	0.658
Error	18	0.01445 2	0.00080 3		
Total	21	0.01576 4			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.02833 6	8.32%	0.00%	0.00%

Means

Fraction	N	Mean	StDev	95% CI
UFAX	6	0.93549	0.02107	(0.91119; 0.95980)
AXE	6	0.9157	0.0322	(0.8914; 0.9400)
FAX	6	0.92985	0.01144	(0.90554; 0.95415)
None	4	0.9314	0.0462	(0.9016; 0.9611)

Pooled StDev = 0.0283356

Tukey Pairwise Comparisons

Fraction	N	Mean	Grouping
UFAX	6	0.93549	A
None	4	0.9314	A
FAX	6	0.92985	A
AXE	6	0.9157	A

Means that do not share a letter are significantly different.

Crumb moisture content day 1

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Fraction	3	0.001377	0.000459	5.59	0.007
Error	18	0.001479	0.000082		
Total	21	0.002854			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.009059	48.24%	39.62%	25.24%

Means

Fraction	N	Mean	StDev	95% CI
UFAX	6	0.44284	0.01221	(0.43507; 0.45061)
AXE	6	0.425459	0.00217	(0.417689; 0.433229)
FAX	6	0.44022	0.01174	(0.43245; 0.44799)
None	4	0.42624	0.00255	(0.41672; 0.43575)

Pooled StDev = 0.00905902

Tukey Pairwise Comparisons

Fraction	N	Mean	Grouping	
UFAX	6	0.44284	A	
FAX	6	0.44022	A	B
None	4	0.42624		B
AXE	6	0.425459		B

Means that do not share a letter are significantly different.

Crumb moisture content day 7

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Fraction	3	0.000993	0.000331	3.54	0.036
Error	18	0.001684	0.000094		
Total	21	0.002677			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.009672	37.10%	26.62%	9.24%

Means

Fraction	N	Mean	StDev	95% CI
UFAX	6	0.42112	0.01467	(0.41282; 0.42941)
AXE	6	0.4091	0.00495	(0.40080; 0.41739)
FAX	6	0.42183	0.00971	(0.41353; 0.43012)
None	4	0.40658	0.00217	(0.39642; 0.41674)

Pooled StDev = 0.00967153

Tukey Pairwise Comparisons

Fraction	N	Mean	Grouping
FAX	6	0.42183	A
UFAX	6	0.42112	A
AXE	6	0.4091	A
None	4	0.40658	A

Means that do not share a letter are significantly different.

Crumb moisture content day 14

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Fraction	3	0.001896	0.000632	3.6	0.034
Error	18	0.003162	0.000176		
Total	21	0.005058			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.013265	37.48%	27.06%	9.57%

Means

Fraction	N	Mean	StDev	95% CI
UFAX	6	0.38823	0.01952	(0.37686; 0.39960)
AXE	6	0.3736	0.00749	(0.36223; 0.38497)
FAX	6	0.39229	0.01355	(0.38092; 0.40366)
None	4	0.36971	0.00446	(0.35578; 0.38363)

Pooled StDev = 0.0132547

Tukey Pairwise Comparisons

Fraction	N	Mean	Grouping
FAX	6	0.39229	A
UFAX	6	0.38823	A
AXE	6	0.3736	A
None	4	0.36971	A

Means that do not share a letter are significantly different.

Crust moisture

Analysis of Variance

Model Summary

Means

Tukey Pairwise Comparisons

content day 1

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Fraction	3	0.00183	0.00061	1.66	0.211
Error	18	0.00661	0.00036		
Total	21	0.00844	7		

S	R-sq	R-sq(adj)	R-sq(pred)
0.01916	21.68%	8.63%	0.00%
3			

Fraction	N	Mean	StDev	95% CI
UFAX	6	0.35274	0.01673	(0.33631; 0.36918)
AXE	6	0.33304	0.01654	(0.31661; 0.34948)
FAX	6	0.35168	0.01902	(0.33525; 0.36812)
None	4	0.3563	0.026	(0.3361; 0.3764)

Pooled StDev = 0.0191630

Fraction	N	Mean	Grouping
None	4	0.3563	A
UFAX	6	0.35274	A
FAX	6	0.35168	A
AXE	6	0.33304	A

Means that do not share a letter are significantly different.

Crust moisture content day 7

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Fraction	3	0.00015	0.00005	0.45	0.724
Error	18	0.00204	0.00011		
Total	21	0.00219	3		

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.01065	6.91%	0.00%	0.00%
1			
2			
3			

Means

Fraction	N	Mean	StDev	95% CI
UFAX	6	0.30713	0.01197	(0.29800; 0.31626)
AXE	6	0.30522	0.00694	(0.29609; 0.31436)
FAX	6	0.31082	0.01064	(0.30168; 0.31995)
None	4	0.30365	0.01315	(0.29246; 0.31484)

Pooled StDev = 0.0106503

Tukey Pairwise Comparisons

Fraction	N	Mean	Grouping
FAX	6	0.31082	A
UFAX	6	0.30713	A
AXE	6	0.30522	A
None	4	0.30365	A

Means that do not share a letter are significantly different.

Crust moisture content day 14

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Fraction	3	0.00253	0.00084	5.55	0.007
Error	18	0.00273	0.00015		
Total	21	0.00526	2		

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.01232	48.07%	39.41%	23.06%
3			

Means

Fraction	N	Mean	StDev	95% CI
UFAX	6	0.29443	0.01924	(0.28386; 0.30500)
AXE	6	0.29691	0.00604	(0.28634; 0.30748)
FAX	6	0.31086	0.00855	(0.30029; 0.32143)
None	4	0.2787	0.01057	(0.26576; 0.29165)

Pooled StDev = 0.0123234

Tukey Pairwise Comparisons

Fraction	N	Mean	Grouping	
FAX	6	0.31086	A	
AXE	6	0.29691	A	B
AX	6	0.29443	A	B
None	4	0.2787		B

Means that do not share a letter are significantly different.

Appendix VII Raw data from statistical analysis: correlations with baking absorption

Parameter	Analysis of Variance						Model Summary						Regression Equation					
Crumb moisture content day 1	Source	DF	Adj SS	Adj MS	F-Value	P-Value	S	R-sq	R-sq(adj)	R-sq(pred)			Crumb moisture content day 1	=	0.2329 + 0.001071 Baking absorption (ml)			
	Regression	1	0.00261	0.00261	214.32	0	0.00349	91.46%	91.04%	89.84%								
	Baking absorption (ml)	1	0.00261	0.00261	214.32	0												
	Error	20	0.000244	0.000012			**Coefficients**						**Fits and Diagnostics for Unusual Observations**					
	Lack-of-Fit	8	0.000139	0.000017	2	0.135	Term	Coef	SE Coef	T-Value	P-Value	VIF	Obs	Crumb moisture content day 1	Fit	Resid	Std Resid	
	Pure Error	12	0.000104	0.000009			Constant	0.2329	0.0138	16.9	0		14	0.43136	0.44169	-0.01033	-3.06	R
	Total	21	0.002854				Baking absorption (ml)	0.001071	0.000073	14.64	0	1	R Large residual					
Crumb moisture content day 7	**Analysis of Variance**						**Model Summary**						**Regression Equation**					
	Source	DF	Adj SS	Adj MS	F-Value	P-Value	S	R-sq	R-sq(adj)	R-sq(pred)			Crumb moisture content day 7	=	0.2266 + 0.001003 Baking absorption (ml)			
	Regression	1	0.002292	0.002292	119.12	0	0.004386	85.62%	84.91%	82.73%								
	Baking absorption (ml)	1	0.002292	0.002292	119.12	0												

	Error	20	0.000385	0.000019			**Coefficients**						**Fits and Diagnostics for Unusual Observations**				
	Lack-of-Fit	8	0.00009	0.000011	0.46	0.865	Term	Coef	SE Coef	T-Value	P-Value	VIF	Obs	Crumb moisture content day 7	Fit	Resid	Std Resid	
	Pure Error	12	0.000295	0.000025			Constant	0.2266	0.0173	13.08	0		7	0.41601	0.4072	0.00881	2.09	R
	Total	21	0.002677				Baking absorption (ml)	0.001003	0.000092	10.91	0	1	18	0.39946	0.40921	-0.00975	-2.3	R
													R Large residual					
Crumb moisture content day 14	**Analysis of Variance**						**Model Summary**						**Regression Equation**					
	Source	DF	Adj SS	Adj MS	F-Value	P-Value	S	R-sq	R-sq(adj)	R-sq(pred)			Crumb moisture content day 14	=	0.1282 + 0.001349 Baking absorption (ml)			
	Regression	1	0.004141	0.004141	90.29	0	0.006772	81.87%	80.96%	78.05%								
	Baking absorption (ml)	1	0.004141	0.004141	90.29	0												
	Error	20	0.000917	0.000046			**Coefficients**											
	Lack-of-Fit	8	0.000525	0.000066	2.01	0.133	Term	Coef	SE Coef	T-Value	P-Value	VIF						
	Pure Error	12	0.000392	0.000033			Constant	0.1282	0.0267	4.79	0							
	Total	21	0.005058				Baking absorption (ml)	0.001349	0.000142	9.5	0	1						
Specific volume	**Analysis of Variance**						**Model Summary**						**Regression Equation**					
	Source	DF	Adj SS	Adj MS	F-Value	P-Value	S	R-sq	R-sq(adj)	R-sq(pred)			Specific volume (avg)	=	5.524 - 0.00378 Baking absorption (ml)			
	Regression	1	0.03259	0.03259	0.86	0.364	0.194502	4.13%	0.00%	0.00%								
	Baking absorption (ml)	1	0.03259	0.03259	0.86	0.364												
	Error	20	0.75662	0.03783			**Coefficients**						**Fits and Diagnostics for Unusual Observations**					
	Lack-of-Fit	8	0.48222	0.06028	2.64	0.063	Term	Coef	SE Coef	T-Value	P-Value	VIF	Obs	Specific volume	Fit	Resid	Std Resid	
	Pure Error	12	0.2744	0.02287			Constant	5.524	0.768	7.19	0		2	4.4204	4.8427	-0.4224	-2.26	R
	Total	21	0.78921				Baking absorption (ml)	-0.00378	0.00408	-0.93	0.364	1	R Large residual					

Appendix VIII Raw data from statistical analysis: correlations with AX level

Baking absorption

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	1	1077.03	1077.03	17.96	0
AX level	1	1077.03	1077.03	17.96	0
Error	20	1199.66	59.98		
Lack-of-Fit	2	16.54	8.27	0.13	0.883
Pure Error	18	1183.13	65.73		
Total	21	2276.69			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
7.74487	47.31%	44.67%	33.12%

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	179.28	2.67	67.22	0	
AX level	1085	256	4.24	0	1

Regression Equation

Baking absorption (ml) = 179.28 + 1085 AX level

Fits and Diagnostics for Unusual Observations

Obs	Baking absorption (ml)	Fit	Resid	Std Resid	
9	181	197.72	-16.72	-2.32	R
10	181	197.72	-16.72	-2.32	R

R Large residual

Specific volume

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	1	0.02401	0.02401	0.63	0.438
AX level	1	0.02401	0.02401	0.63	0.438
Error	20	0.76521	0.03826		
Lack-of-Fit	2	0.11007	0.05504	1.51	0.247
Pure Error	18	0.65513	0.0364		

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.195602	3.04%	0.00%	0.00%

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	4.77	0.0674	70.81	0	

Regression Equation

Specific volume (avg) = 4.7700 + 5.12 AX level

	Total	21	0.78921			AX level	5.12	6.47	0.79	0.438	1						
Crust moisture content day 1	**Analysis of Variance**					**Model Summary**						**Regression Equation**					
	Source	DF	Adj SS	Adj MS	F-Value	P-Value	S	R-sq	R-sq(adj)	R-sq(pred)		Crust moisture content day 1	=	0.34025 + 0.913 AX level			
	Regression	1	0.000763	0.000763	1.99	0.174	0.019592	9.05%	4.50%	0.00%							
	AX level	1	0.000763	0.000763	1.99	0.174											
	Error	20	0.007677	0.000384			**Coefficients**					**Fits and Diagnostics for Unusual Observations**					
	Lack-of-Fit	2	0.002159	0.00108	3.52	0.051	Term	Coef	SE Coef	T-Value	P-Value	VIF	Obs	Crust moisture content day 1	Fit	Resid	Std Resid	
	Pure Error	18	0.005518	0.000307			Constant	0.34025	0.00675	50.43	0		3	0.39207	0.34025	0.05182	2.82	R
	Total	21	0.00844				AX level	0.913	0.648	1.41	0.174	1	6	0.30434	0.34299	-0.03865	-2.05	R
													R Large residual					
Crust moisture content day 7	**Analysis of Variance**					**Model Summary**						**Regression Equation**					
	Source	DF	Adj SS	Adj MS	F-Value	P-Value	S	R-sq	R-sq(adj)	R-sq(pred)		Crust moisture content day 7	=	0.30151 + 0.669 AX level			
	Regression	1	0.000409	0.000409	4.59	0.045	0.009445	18.66%	14.59%	0.78%							
	AX level	1	0.000409	0.000409	4.59	0.045											
	Error	20	0.001784	0.000089			**Coefficients**										
	Lack-of-Fit	2	0.000035	0.000017	0.18	0.838	Term	Coef	SE Coef	T-Value	P-Value	VIF						
	Pure Error	18	0.001749	0.000097			Constant	0.30151	0.00325	92.7	0							
	Total	21	0.002193				AX level	0.669	0.312	2.14	0.045	1						
Crust moisture content day 14	**Analysis of Variance**					**Model Summary**						**Regression Equation**					
	Source	DF	Adj SS	Adj MS	F-Value	P-Value	S	R-sq	R-sq(adj)	R-sq(pred)		Crust moisture content day 14	=	0.28497 + 1.437 AX level			

	Regression	1	0.001889	0.001889	11.2	0.003	0.012989	35.89%	32.69%	22.58%							
	AX level	1	0.001889	0.001889	11.2	0.003											
	Error	20	0.003374	0.000169			**Coefficients**						**Fits and Diagnostics for Unusual Observations**				
	Lack-of-Fit	2	0.000405	0.000203	1.23	0.316	Term	Coef	SE Coef	T-Value	P-Value	VIF	Obs	Crust moisture content day 14	Fit	Resid	Std Resid	
	Pure Error	18	0.002969	0.000165			Constant	0.28497	0.00447	63.71	0		12	0.31461	0.28928	0.02533	2.03	R
	Total	21	0.005263				AX level	1.437	0.429	3.35	0.003	1	17	0.26033	0.28928	-0.02896	-2.32	R
													R Large residual					
Crumb moisture content day 1	**Analysis of Variance**						**Model Summary**						**Regression Equation**					
	Source	DF	Adj SS	Adj MS	F-Value	P-Value	S	R-sq	R-sq(adj)	R-sq(pred)			Crumb moisture content day 1	=	0.42534 + 1.104 AX level			
	Regression	1	0.001115	0.001115	12.82	0.002	0.009325	39.07%	36.02%	22.08%								
	AX level	1	0.001115	0.001115	12.82	0.002												
	Error	20	0.001739	0.000087			**Coefficients**						**Fits and Diagnostics for Unusual Observations**					
	Lack-of-Fit	2	0.000012	0.000006	0.06	0.94	Term	Coef	SE Coef	T-Value	P-Value	VIF	Obs	Crumb moisture content day 1	Fit	Resid	Std Resid	
	Pure Error	18	0.001727	0.000096			Constant	0.42534	0.00321	132.45	0		9	0.42373	0.4441	-0.02037	-2.34	R
	Total	21	0.002854				AX level	1.104	0.308	3.58	0.002	1	10	0.42375	0.4441	-0.02035	-2.34	R
													R Large residual					
Crumb moisture content day 7	**Analysis of Variance**						**Model Summary**						**Regression Equation**					
	Source	DF	Adj SS	Adj MS	F-Value	P-Value	S	R-sq	R-sq(adj)	R-sq(pred)			Crumb moisture content day 7	=	0.40556 + 1.201 AX level			
	Regression	1	0.001321	0.001321	19.48	0	0.008235	49.34%	46.80%	35.16%								
	AX level	1	0.001321	0.001321	19.48	0												
	Error	20	0.001356	0.000068			**Coefficients**						**Fits and Diagnostics for Unusual Observations**					
	Lack-of-Fit	2	0.000041	0.00002	0.28	0.761	Term	Coef	SE Coef	T-Value	P-Value	VIF	Obs	Crumb moisture content day 7	Fit	Resid	Std Resid	

	Pure Error	18	0.001316	0.000073			Constant	0.40556	0.00284	143.02	0		9	0.40374	0.42598	-0.02224	-2.9	R
	Total	21	0.002677				AX level	1.201	0.272	4.41	0	1	R Large residual					
Crumb moisture content day 14	**Analysis of Variance**						**Model Summary**						**Regression Equation**					
	Source	DF	Adj SS	Adj MS	F-Value	P-Value	S	R-sq	R-sq(adj)	R-sq(pred)			Crumb moisture content day 14	=	0.36919 + 1.563 AX level			
	Regression	1	0.002235	0.002235	15.83	0.001	0.011881	44.19%	41.40%	30.38%								
	AX level	1	0.002235	0.002235	15.83	0.001												
	Error	20	0.002823	0.000141			**Coefficients**						**Fits and Diagnostics for Unusual Observations**					
	Lack-of-Fit	2	0.000297	0.000148	1.06	0.368	Term	Coef	SE Coef	T-Value	P-Value	VIF	Obs	Crumb moisture content day 14	Fit	Resid	Std Resid	
	Pure Error	18	0.002526	0.00014			Constant	0.36919	0.00409	90.23	0		7	0.36018	0.38482	-0.02464	-2.13	R
	Total	21	0.005058				AX level	1.563	0.393	3.98	0.001	1	9	0.37273	0.39576	-0.02303	-2.08	R
													R Large residual					
Hardness day 1	**Analysis of Variance**						**Model Summary**						**Regression Equation**					
	Source	DF	Adj SS	Adj MS	F-Value	P-Value	S	R-sq	R-sq(adj)	R-sq(pred)			Hardness day 1	=	3.083 - 58.9 AX level			
	Regression	1	2.9365	2.93648	7.71	0.012	0.617134	28.87%	25.12%	13.82%								
	AX level	1	2.9365	2.93648	7.71	0.012												
	Error	19	7.2362	0.38085			**Coefficients**						**Fits and Diagnostics for Unusual Observations**					
	Lack-of-Fit	2	0.0321	0.01605	0.04	0.963	Term	Coef	SE Coef	T-Value	P-Value	VIF	Obs	Hardness day 1	Fit	Resid	Std Resid	
	Pure Error	17	7.2042	0.42377			Constant	3.083	0.226	13.62	0		18	4.53	2.907	1.623	2.75	R
	Total	20	10.1727				AX level	-58.9	21.2	-2.78	0.012	1	R Large residual					
Hardness day 7	**Analysis of Variance**						**Model Summary**						**Regression Equation**					
	Source	DF	Adj SS	Adj MS	F-Value	P-Value	S	R-sq	R-sq(adj)	R-sq(pred)			Hardness day 7	=	7.555 - 89.8 AX level			
	Regression	1	7.386	7.3859	6.89	0.016	1.03572	25.61%	21.89%	9.42%								

	AX level	1	7.386	7.3859	6.89	0.016								
	Error	20	21.454	1.0727			**Coefficients**							
	Lack-of-Fit	2	1.055	0.5277	0.47	0.635	Term	Coef	SE Coef	T-Value	P-Value	VIF		
	Pure Error	18	20.399	1.1333			Constant	7.555	0.357	21.18	0			
	Total	21	28.84				AX level	-89.8	34.2	-2.62	0.016	1		
Hardness day 14	**Analysis of Variance**						**Model Summary**						**Regression Equation**	
	Source	DF	Adj SS	Adj MS	F-Value	P-Value	S	R-sq	R-sq(adj)	R-sq(pred)			Hardness day 14 =	10.575 - 132.0 AX level
	Regression	1	15.95	15.948	5.3	0.032	1.73535	20.94%	16.98%	1.07%				
	AX level	1	15.95	15.948	5.3	0.032								
	Error	20	60.23	3.011			**Coefficients**							
	Lack-of-Fit	2	20.37	10.187	4.6	0.024	Term	Coef	SE Coef	T-Value	P-Value	VIF		
	Pure Error	18	39.86	2.214			Constant	10.575	0.598	17.7	0			
	Total	21	76.18				AX level	-132	57.4	-2.3	0.032	1		
Cohesiveness day 1	**Analysis of Variance**						**Model Summary**						**Regression Equation**	
	Source	DF	Adj SS	Adj MS	F-Value	P-Value	S	R-sq	R-sq(adj)	R-sq(pred)			Cohesiveness day 1 =	0.7563 + 3.40 AX level
	Regression	1	0.009747	0.009747	11.2	0.003	0.029497	37.09%	33.78%	19.80%				
	AX level	1	0.009747	0.009747	11.2	0.003								
	Error	19	0.016531	0.00087			**Coefficients**							
	Lack-of-Fit	2	0.000221	0.000111	0.12	0.892	Term	Coef	SE Coef	T-Value	P-Value	VIF		
	Pure Error	17	0.01631	0.000959			Constant	0.7563	0.0108	69.9	0			
	Total	20	0.026278				AX level	3.4	1.01	3.35	0.003	1		
Cohesiveness day 7	**Analysis of Variance**						**Model Summary**						**Regression Equation**	
	Source	DF	Adj SS	Adj MS	F-Value	P-Value	S	R-sq	R-sq(adj)	R-sq(pred)			Cohesiveness day 7 =	0.4940 + 4.24 AX level

	Regression	1	0.016489	0.016489	8.71	0.008	0.043519	30.33%	26.85%	13.55%							
	AX level	1	0.016489	0.016489	8.71	0.008											
	Error	20	0.037877	0.001894			**Coefficients**					**Fits and Diagnostics for Unusual Observations**					
	Lack-of-Fit	2	0.001277	0.000638	0.31	0.734	Term	Coef	SE Coef	T-Value	P-Value	VIF	Obs	Cohesiveness day 7	Fit	Resid	Std Resid	
	Pure Error	18	0.036601	0.002033			Constant	0.494	0.015	32.96	0		21	0.6719	0.5661	0.1057	2.61	R
	Total	21	0.054366				AX level	4.24	1.44	2.95	0.008	1	R Large residual					
Cohesiveness day 14	**Analysis of Variance**						**Model Summary**						**Regression Equation**					
	Source	DF	Adj SS	Adj MS	F-Value	P-Value	S	R-sq	R-sq(adj)	R-sq(pred)			Cohesiveness day 14	=	0.4216 + 1.70 AX level			
	Regression	1	0.002648	0.002648	1.92	0.181	0.03712	8.77%	4.20%	0.00%								
	AX level	1	0.002648	0.002648	1.92	0.181												
	Error	20	0.027558	0.001378			**Coefficients**											
	Lack-of-Fit	2	0.002592	0.001296	0.93	0.411	Term	Coef	SE Coef	T-Value	P-Value	VIF						
	Pure Error	18	0.024966	0.001387			Constant	0.4216	0.0128	32.98	0							
	Total	21	0.030206				AX level	1.7	1.23	1.39	0.181	1						
Springiness day 1	**Analysis of Variance**						**Model Summary**						**Regression Equation**					
	Source	DF	Adj SS	Adj MS	F-Value	P-Value	S	R-sq	R-sq(adj)	R-sq(pred)			Springiness day 1	=	0.97937 + 0.513 AX level			
	Regression	1	0.000223	0.000223	2	0.174	0.010555	9.51%	4.75%	0.00%								
	AX level	1	0.000223	0.000223	2	0.174												
	Error	19	0.002117	0.000111			**Coefficients**											
	Lack-of-Fit	2	0.000179	0.000089	0.78	0.472	Term	Coef	SE Coef	T-Value	P-Value	VIF						
	Pure Error	17	0.001938	0.000114			Constant	0.97937	0.00387	252.95	0							
	Total	20	0.002339				AX level	0.513	0.363	1.41	0.174	1						
Springiness day 7	**Analysis of Variance**						**Model Summary**						**Regression Equation**					

	Source	DF	Adj SS	Adj MS	F-Value	P-Value	S	R-sq	R-sq(adj)	R-sq(pred)			Springiness day 7	=	0.9542 + 0.30 AX level			
	Regression	1	0.000081	0.000081	0.09	0.77	0.030401	0.44%	0.00%	0.00%								
	AX level	1	0.000081	0.000081	0.09	0.77												
	Error	20	0.018484	0.000924			**Coefficients**						**Fits and Diagnostics for Unusual Observations**					
	Lack-of-Fit	2	0.00219	0.001095	1.21	0.321	Term	Coef	SE Coef	T-Value	P-Value	VIF	Obs	Springiness day 7	Fit	Resid	Std Resid	
	Pure Error	18	0.016294	0.000905			Constant	0.9542	0.0105	91.14	0		7	0.87985	0.95717	-0.07732	-2.61	R
	Total	21	0.018565				AX level	0.3	1	0.3	0.77	1	11	1.04506	0.95509	0.08997	3.08	R
													R Large residual					
Springiness day 14	**Analysis of Variance**						**Model Summary**						**Regression Equation**					
	Source	DF	Adj SS	Adj MS	F-Value	P-Value	S	R-sq	R-sq(adj)	R-sq(pred)			Springiness day 14	=	0.92349 + 0.527 AX level			
	Regression	1	0.000254	0.000254	0.33	0.573	0.027847	1.61%	0.00%	0.00%								
	AX level	1	0.000254	0.000254	0.33	0.573												
	Error	20	0.01551	0.000775			**Coefficients**						**Fits and Diagnostics for Unusual Observations**					
	Lack-of-Fit	2	0.001469	0.000734	0.94	0.408	Term	Coef	SE Coef	T-Value	P-Value	VIF	Obs	Springiness day 14	Fit	Resid	Std Resid	
	Pure Error	18	0.014041	0.00078			Constant	0.92349	0.00959	96.3	0		3	0.99929	0.92349	0.07579	2.9	R
	Total	21	0.015764				AX level	0.527	0.92	0.57	0.573	1	10	0.86871	0.93245	-0.06374	-2.45	R
													R Large residual					
Image cell count	**Analysis of Variance**						**Model Summary**						**Regression Equation**					
	Source	DF	Adj SS	Adj MS	F-Value	P-Value	S	R-sq	R-sq(adj)	R-sq(pred)			Image: cell count	=	415.63 + 2989 AX level			
	Regression	1	8178.7	8178.7	19.78	0	20.332	49.73%	47.22%	37.58%								
	AX level	1	8178.7	8178.7	19.78	0												
	Error	20	8267.8	413.4			**Coefficients**						**Fits and Diagnostics for Unusual Observations**					
	Lack-of-Fit	2	470.9	235.5	0.54	0.59	Term	Coef	SE Coef	T-Value	P-Value	VIF	Obs	Image cell count	Fit	Resid	Std Resid	
	Pure Error	18	7796.9	433.2			Constant	415.63	7	59.36	0		10	426.5	466.44	-39.94	-2.11	R

	Total	21	16446.5			AX level	2989	672	4.45	0	1	20	488	445.52	42.48	2.14	R
												21	505	466.44	38.56	2.03	R
												R Large residual					
Image total area	**Analysis of Variance**						**Model Summary**					**Regression Equation**					
	Source	DF	Adj SS	Adj MS	F-Value	P-Value	S	R-sq	R-sq(adj)	R-sq(pred)		Image: total area	=	5621 + 3398 AX level			
	Regression	1	10570	10570	0.09	0.768	343.781	0.45%	0.00%	0.00%							
	AX level	1	10570	10570	0.09	0.768											
	Error	20	2363709	118185			**Coefficients**					**Fits and Diagnostics for Unusual Observations**					
	Lack-of-Fit	2	156567	78283	0.64	0.54	Term	Coef	SE Coef	T-Value	P-Value	VIF	Obs	Image total area	Fit	Resid	Std Resid	
	Pure Error	18	2207142	122619			Constant	5621	118	47.48	0		14	6436	5655	781	2.33	R
	Total	21	2374279				AX level	3398	11363	0.3	0.768	1	R Large residual					
Image average cell size	**Analysis of Variance**						**Model Summary**					**Regression Equation**					
	Source	DF	Adj SS	Adj MS	F-Value	P-Value	S	R-sq	R-sq(adj)	R-sq(pred)		Image: average cell size	=	13.611 - 74.5 AX level			
	Regression	1	5.08	5.0803	3.88	0.063	1.14362	16.26%	12.08%	0.00%							
	AX level	1	5.08	5.0803	3.88	0.063											
	Error	20	26.157	1.3079			**Coefficients**										
	Lack-of-Fit	2	1.337	0.6684	0.48	0.624	Term	Coef	SE Coef	T-Value	P-Value	VIF						
	Pure Error	18	24.82	1.3789			Constant	13.611	0.394	34.56	0							
	Total	21	31.237				AX level	-74.5	37.8	-1.97	0.063	1						
Image % area	**Analysis of Variance**						**Model Summary**					**Regression Equation**					
	Source	DF	Adj SS	Adj MS	F-Value	P-Value	S	R-sq	R-sq(adj)	R-sq(pred)		Image: % area	=	28.826 + 17.4 AX level			
	Regression	1	0.278	0.278	0.09	0.768	1.76301	0.45%	0.00%	0.00%							
	AX level	1	0.278	0.278	0.09	0.768											

Error	20	62.1639	3.1082			**Coefficients**						**Fits and Diagnostics for Unusual Observations**					
Lack-of-Fit	2	4.1184	2.0592	0.64	0.54	Term	Coef	SE Coef	T-Value	P-Value	VIF	Obs	Image % area	Fit	Resid	Std Resid	
Pure Error	18	58.0455	3.2248			Constant	28.826	0.607	47.48	0		14	33.006	29.001	4.006	2.33	R
Total	21	62.442				AX level	17.4	58.3	0.3	0.768	1	R Large residual					

Appendix IX Raw data from statistical analysis: sensory evaluation

Day 1 breads

Method	**Descriptive Statistics**					**Estimation for Difference**			**Test**		
μ_1: mean of Control day 1: visual appearance	Sample	N	Mean	StDev	SE Mean	Difference	Pooled StDev	95 % CI for Difference	Null hypothesis	H_0: $\mu_1 - \mu_2 = 0$	
μ_2: mean of UFAX day 1: visual appearance	Control day 1: visual appearance	21	6.52	1.03	0.22	0	1.03	(-0.643; 0.643)	Alternative hypothesis	H_1: $\mu_1 - \mu_2 \neq 0$	
Difference: $\mu_1 - \mu_2$	UFAX day 1: visual appearance	21	6.52	1.03	0.22				T-Value	DF	P-Value
Equal variances are assumed for this analysis.									0	40	1

Method	**Descriptive Statistics**					**Estimation for Difference**			**Test**		
μ_1: mean of Control day 1: smell	Sample	N	Mean	StDev	SE Mean	Difference	Pooled StDev	95 % CI for Difference	Null hypothesis	H_0: $\mu_1 - \mu_2 = 0$	
μ_2: mean of UFAX day 1: smell	Control day 1: smell	21	6.571	0.978	0.21	0.095	1.029	(-0.547; 0.737)	Alternative hypothesis	H_1: $\mu_1 - \mu_2 \neq 0$	
Difference: $\mu_1 - \mu_2$	UFAX day 1: smell	21	6.48	1.08	0.24				T-Value	DF	P-Value
Equal variances are assumed for this analysis.									0.3	40	0.766

Method	**Descriptive Statistics**					**Estimation for Difference**			**Test**		
μ_1: mean of Control day 1: texture	Sample	N	Mean	StDev	SE Mean	Difference	Pooled StDev	95 % CI for Difference	Null hypothesis	H_0: $\mu_1 - \mu_2 = 0$	
μ_2: mean of UFAX day 1: texture	Control day 1: texture	21	6.67	1.28	0.28	0.381	1.635	(-0.639; 1.401)	Alternative hypothesis	H_1: $\mu_1 - \mu_2 \neq 0$	
Difference: $\mu_1 - \mu_2$	UFAX day 1: texture	21	6.29	1.93	0.42				T-Value	DF	P-Value
Equal variances are assumed for this analysis.									0.75	40	0.455

Method	**Descriptive Statistics**					**Estimation for Difference**			**Test**		
μ_1: mean of Control day 1: flavour	Sample	N	Mean	StDev	SE Mean	Difference	Pooled StDev	95 % CI for Difference	Null hypothesis	H_0: $\mu_1 - \mu_2 = 0$	
μ_2: mean of UFAX day 1: flavour	Control day 1: flavour	21	6.429	0.926	0.2	-0.19	1.073	(-0.860; 0.479)	Alternative hypothesis	H_1: $\mu_1 - \mu_2 \neq 0$	
Difference: $\mu_1 - \mu_2$	UFAX day 1: flavour	21	6.62	1.2	0.26				T-Value	DF	P-Value
Equal variances are assumed for this analysis.									-0.57	40	0.569

Method	**Descriptive Statistics**					**Estimation for Difference**			**Test**		
μ_1: mean of Control day 1: overall opinion	Sample	N	Mean	StDev	SE Mean	Difference	Pooled StDev	95 % CI for Difference	Null hypothesis	H_0: $\mu_1 - \mu_2 = 0$	
μ_2: mean of UFAX day 1: overall opinion	Control day 1: overall opinion	20	6.55	0.887	0.2	0.05	1.192	(-0.713; 0.813)	Alternative hypothesis	H_1: $\mu_1 - \mu_2 \neq 0$	
Difference: $\mu_1 - \mu_2$	UFAX day 1: overall opinion	20	6.5	1.43	0.32				T-Value	DF	P-Value
Equal variances are assumed for this analysis.									0.13	38	0.895

Day 7 breads

Method	**Descriptive Statistics**					**Estimation for Difference**			**Test**		
μ_1: mean of Control day 7: visual appearance	Sample	N	Mean	StDev	SE Mean	Difference	Pooled StDev	95 % CI for Difference	Null hypothesis	H_0: $\mu_1 - \mu_2 = 0$	
μ_2: mean of UFAX day 7: visual appearance	Control day 7: visual appearance	21	6.857	0.91	0.2	0.429	0.971	(-0.177; 1.034)	Alternative hypothesis	H_1: $\mu_1 - \mu_2 \neq 0$	
Difference: $\mu_1 - \mu_2$	UFAX day 7: visual appearance	21	6.43	1.03	0.22				T-Value	DF	P-Value
Equal variances are assumed for this analysis.									1.43	40	0.16

Method	**Descriptive Statistics**					**Estimation for Difference**			**Test**		
μ_1: mean of Control day 7: smell	Sample	N	Mean	StDev	SE Mean	Difference	Pooled StDev	95 % CI for Difference	Null hypothesis	H_0: $\mu_1 - \mu_2 = 0$	
μ_2: mean of UFAX day 7: smell	Control day 7: smell	21	6	1.22	0.27	-0.429	1.296	(-1.237; 0.380)	Alternative hypothesis	H_1: $\mu_1 - \mu_2 \neq 0$	
Difference: $\mu_1 - \mu_2$	UFAX day 7: smell	21	6.43	1.36	0.3				T-Value	DF	P-Value
Equal variances are assumed for this analysis.									-1.07	40	0.29

Method	**Descriptive Statistics**	**Estimation for Difference**	**Test**

μ_1: mean of Control day 7: texture	Sample	N	Mean	StDev	SE Mean	Difference	Pooled StDev	95 % CI for Difference	Null hypothesis	H_0: $\mu_1 - \mu_2 = 0$	
μ_2: mean of UFAX day 7: texture	Control day 7: texture	20	4.9	2.1	0.47	-0.576	1.861	(-1.752; 0.600)	Alternative hypothesis	H_1: $\mu_1 - \mu_2 \neq 0$	
Difference: $\mu_1 - \mu_2$	UFAX day 7: texture	21	5.48	1.6	0.35				T-Value	DF	P-Value
Equal variances are assumed for this analysis.									-0.99	39	0.328

Method	**Descriptive Statistics**					**Estimation for Difference**			**Test**		
μ_1: mean of Control day 7: flavour	Sample	N	Mean	StDev	SE Mean	Difference	Pooled StDev	95 % CI for Difference	Null hypothesis	H_0: $\mu_1 - \mu_2 = 0$	
μ_2: mean of UFAX day 7: flavour	Control day 7: flavour	21	5.67	1.59	0.35	-0.714	1.513	(-1.658; 0.230)	Alternative hypothesis	H_1: $\mu_1 - \mu_2 \neq 0$	
Difference: $\mu_1 - \mu_2$	UFAX day 7: flavour	21	6.38	1.43	0.31				T-Value	DF	P-Value
Equal variances are assumed for this analysis.									-1.53	40	0.134

Method	**Descriptive Statistics**					**Estimation for Difference**			**Test**		
μ_1: mean of Control day 7: overall opinion	Sample	N	Mean	StDev	SE Mean	Difference	Pooled StDev	95 % CI for Difference	Null hypothesis	H_0: $\mu_1 - \mu_2 = 0$	
μ_2: mean of UFAX day 7: overall opinion	Control day 7: overall opinion	21	5.33	1.65	0.36	-0.667	1.618	(-1.676; 0.342)	Alternative hypothesis	H_1: $\mu_1 - \mu_2 \neq 0$	
Difference: $\mu_1 - \mu_2$	UFAX day 7: overall opinion	21	6	1.58	0.35				T-Value	DF	P-Value
Equal variances are assumed for this analysis.									-1.34	40	0.189

Appendix X Popular science summary

A popular science summary of this thesis is found on the next page.

Can dietary fiber extend shelf life of bread?

Introduction | The world is facing several challenges related to agriculture and food production. We need to feed a growing population, but there is a limited amount of land where we can grow food. Agriculture generates greenhouse gas emissions and environmental impacts. On top of this, one third of all the food that is produced is wasted. We need to shift to a more sustainable food system, where agricultural by-products are used and not wasted, and where we do not throw away edible food.

Background

Wheat is one of our most common crops, and bread made from wheat is a staple food worldwide. Unfortunately, fresh bread is one of the most wasted foods in supermarkets and households. Bread is usually made from white flour and as such, it is low in dietary fiber. When white flour is made, the bran (the outer part of the wheat kernel) is removed because it has negative effects on bread quality. This is a waste because bran is rich in dietary fiber. However, it is possible to extract the main dietary fiber, arabinoxylan, from the wheat bran. If this arabinoxylan is added to bread, it can have positive effects on bread quality and make the bread stay fresh longer. Therefore, it could potentially be used in breadmaking to replace other additives that are used today to extend the shelf life of bread.

Photo: Jenny Svennås-Gillner, SLU

About the study

This study was a master's thesis project at SLU, Uppsala, conducted in collaboration with Lantmännen. The purpose of the study was to find out which effects arabinoxylans from wheat bran could have on bread quality and staling. Staling is the ageing process that occurs in bread when it is stored, making it hard, dry and tasteless. The study included three different types of arabinoxylans from wheat bran. They were added to doughs in different amounts to replace 0.3-1.7 % of the flour, and their effects on dough and bread properties like water absorption, volume, crumb structure, crumb texture and water content were measured.

Results

The effects of arabinoxylan addition to bread turned out to be rather small. The volume of the bread was unchanged by arabinoxylan addition. The crumb structure, meaning the number and size of the holes in the breadcrumb, was also largely unaffected by arabinoxylan addition. Two of the arabinoxylan types caused an increase in the amount of water needed to make the dough. This was also reflected in a higher water content of these breads during 14 days of storage. A high water content in bread is good because it slows down the staling rate.

However, a high water content in the dough makes it sticky and difficult to handle, which may cause processing-related issues in industrial breadmaking.

Since the main effect of staling is hardening of the bread, the effect of arabinoxylan addition on breadcrumb texture was interesting to evaluate overtime. All breads with and without arabinoxylan became harder, crumblier and less elastic during storage. Arabinoxylan addition seemed to improve the texture of stored bread slightly, mainly by giving a softer bread after 14 days. This indicates that arabinoxylan addition could reduce staling while maintaining other quality aspects of the bread.

It is important to measure bread quality not only using instruments but also from the consumers' perspective. Even if analytical instruments detect certain effects, it does not necessarily mean that consumers can notice a difference or that they will like the change. To find out what consumers think about bread with added arabinoxylan, a blind-tasting session was arranged. A panel of frequent bread-eaters got to score how much they liked bread with and without added arabinoxylan which had been stored for 1 and 7 days. Interestingly, the panel liked all breads equally, even though there were indications that the bread with added arabinoxylan was slightly more liked than the bread without arabinoxylan after for the 7 days old breads. These results show that any effects caused by arabinoxylan addition on bread quality were too small to make a difference for the consumer.

Photo: Julio Gonzales, SLU

Conclusions

The purpose of this study was to find out how three types of arabinoxylans from wheat bran affects bread quality and staling. The results show that the specific types of arabinoxylans used here have potential to slow down staling while maintaining bread quality aspects like volume and crumb structure. This means that they have potential to be used in the bread industry as an additive to extend shelf life of bread while also boosting the dietary fiber content. As such, they could play a role in the transition to a more sustainable food system where agricultural by-products are utilized and food waste is reduced. However, the effects observed in this study were small and rather few, and consumers did not like the arabinoxylan-fortified bread more than the normal bread without arabinoxylan. This means that more research is needed on the anti-staling effects of arabinoxylan. Further studies should explore optimal addition levels to reduce staling and improve consumer liking of stored bread. The importance of differences in molecular structure between the arabinoxylan types should also be investigated. More knowledge in this field will help establish the future role of wheat bran arabinoxylans in a sustainable breadmaking industry.