Composition of Fractions from Air-Classified Wheat Flour

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Abstract

The unique ability of wheat to produce leavened bread is mainly due to the gluten proteins present. As consumers are more and more attracted to bread with high fibre content the use of wheat gluten will also increase in order to obtain bread with good volume and appetizing characteristics. Air-classification is a technological method used to separate particles by size and shape by means of air-streams into two fractions, fine and coarse. When used on wheat flour it is known to alter the flour composition in the fractions obtained compared to the original flour. This method is not widely used in the milling industry but could possibly be of interest if protein rich fractions with favorable protein quality can be produced. These protein rich fractions could be an alternative to commercial gluten additives. The objective of this thesis was to evaluate air-classified flour by means of determination of protein content, wet gluten content, rheological properties and bread volume. The flour was a strong wheat flour and the air-classifier used was a Hosokawa Alpine ATP 50. The rotational speeds used for separating the flour were 5000 revolutions per minute (rpm), 6500 rpm and 8000 rpm. The result showed that the fine fraction from 8000 rpm contained high levels of proteins with good quality. The dough produced from this fraction was strong, contained high levels of wet gluten and had high water absorption. The bread produced from the same fraction had the largest volume.

Sammanfattning

Glutenproteinerna i vete är den största kända faktorn som påverkar de viskoelastiska egenskaperna i deg gjord på vetemjöl. De viskoelastiska egenskaperna ger hög volym och poröst inkråm hos bröd. I takt med att användandet av fiber och efterfrågan av fiberrika bröd ökar tros även användandet av kommersiellt gluten att öka för att förse marknaden med fiberrikt bröd med stor volym och poröst inkråm. Vindsiktning är en teknologisk metod som används för att separera material i fraktioner med stora och små partiklar. När vindsiktning används på vetemjöl är det känt att sammansättningen i mjölet förändras. Denna metod är ganska ovanlig inom malningsindustrin men kan möjligtvis vara av intresse om proteinrika fraktioner med god proteinkvalitet kan produceras. Syftet med denna uppsats var att utvärdera vindsiktat mjöl genom analys av proteinhalt, våtgluten, reologiska egenskaper och brödvolym. Mjölet var ett starkt bagerivetemjöl och vindsiktades med Hosokawa alpina ATP 50. Det varvtal som användes för att separera mjölet var 5000 varv per minut (rpm), 6500 rpm och 8000 rpm. Resultatet visade att den fina fraktionen från 8000 rpm innehöll höga halter av proteiner med god kvalitet. Degen som tillverkades från denna fraktion var den starkaste, innehöll höga halter våtgluten och hade hög vatten absorption. Brödet från samma fraktion hade den största volymen.

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1 Project Background

The use of wheat gluten in the Swedish bakeries is today quite extensive. Addition of gluten improves the baking quality since the amount and type of protein are important for the dough development (Aamodt 2004). Gluten additives strengthen the dough and produce a product with good texture and volume (Hoseney 1994). By using a high fiber flour or whole grain flour the bran particles dilute the gluten protein content or weaken the gluten protein network by physical destruction. The components in the aleurone layer that bind to gluten proteins have a negative effect on the gluten development when the fibre content is high (Noort *et al.*. 2010).

The Keyhole® symbol from the Swedish National Food Administration is a guideline for consumers who want healthy food alternatives. The foods are required to have a certain limited amount of added sugars, salt and fat and a minimum certain amount of fibre. The recommended level of fibre content is 25% of the dry matter content which leads to bread with a flat and compact structure if gluten is not added. Gluten extraction from wheat is a demanding process. The properties in the extracted gluten are somewhat altered when compared to the original gluten protein. Since the proteins are denatured by heat and extreme changes in pH it is crucial to dry wet gluten carefully to minimize the conformational changes. The commercial gluten contains about 80% protein, 10% starch, 5 % lipids and 5 % other substances such as minerals and fibers. Denatured protein is often associated with lowered water solubility and losses of biological activity. When fortifying weaker flour about 3-5% dry gluten is added (Cauvain 2003). By mixing high protein wheat flour with high fibre flour the bread could still have a good quality. When the protein level needed in the flour is higher than a natural protein level gluten additives or air-classification of sifted wheat flour can be added. Air-classification is a technique used to separate particles according to size by means of air-streams and centrifugation. The flour characteristics obtained from air-classification is depending on the settings, for example the rotational speed of the classifier wheel and the air-flow pressure affecting the air-streams used. The flour is fractioned into a coarse and a fine fraction. Since the size, shape and density differs between protein fragments (smaller) and starch granules (larger) in the flour, air-classification is useful to separate starch from proteins. See chapter 2.3 in this report for further explanation. Today (September 2010) there are no air-classified flour on the European market.

The aim with this project was to evaluate air-classification of sifted wheat flour fractions at rotational speed different settings of the air-classifier. This project will examine which flour quality that is obtained and if the fractions can be applied to bread. Previous studies have shown that protein rich fractions are suitable for bread meanwhile low protein fractions are suitable for sponge cake (Jones *et*

*al.*1959). These studies were performed with a commercial flour blend as starting material so differences in flour due to wheat hardness and varieties were concealed. Studies have also been made with focus on particle size and hard or soft wheat varieties. Addition of protein rich fractions from air-classified flour to less protein rich flours have been shown to increase the loaf volume (Maura M. Bean 1969). Other studies have also shown that fortification with high protein air-classified fractions to straight flour produce doughs with greater elasticity, water absorption and loaf volume (Dick *et al.* 1977; Pomeranz 1989). Fractions with the smallest particles have shown to have the lowest yield and highest ash and protein content. The protein quality has been found to be the most important parameter influencing rheological characteristics and baking performance (Dick *et al.* 1977).

This study focused on the effect of rotational speed of the air-classifier on total protein content and protein quality in wheat flour. Protein quality is a complex parameter which reflects the composition of polypeptides and their ability to form gluten. The polypeptides in the proteins will affect which macromolecules are built and are important for the rheological properties of gluten and dough formation (Delcour & Hoseney 1994). The protein quality can be evaluated by analyzing wet gluten content and Zeleny sedimentation value. The Zeleny sedimentation value is the ability of the proteins to swell in a lactic acid solution, the higher protein quality the higher the swelling value is. The protein composition in the obtained fractions is considered when determining the protein quality. Also baking characteristics are an indirect indication of the protein quality. The method to separate flour due to air-classification is not very common in the milling industry and is therefore interesting to look at from an industrial point of view.

2 Introduction

Air-classification is a technique used to separate particles according to size by air-streams and centrifugation. There are two fractions obtained, one fine fraction and one coarse fraction. When separating sifted wheat flour the fine fraction contains fragments of starchy endosperm protein and small starch granules. The coarse fraction contains mainly large starch granules and fragments of endosperm cells. The fraction yield and protein content vary with wheat varieties and hardness of the kernel. For bread making the protein content in flour has to be at a sufficient high level, favorably above 11% DM and for cakes it should not exceed 7% DM (Jones 1959). In order to understand the possible value of separating flour the composition of the flour itself has to be explained.

2.1 Wheat kernel morphology

The wheat kernel is the fruit of the plant and is botanically known as the caryopsis (Figure 1). The color of the kernel is determined by the pigments present in the pericarp. The pericarp consists of an outer layer known as epidermis that covers hypodermis. Beneath the hypodermis another thin seed coat that covers a nucellar tissue is present and underneath is the aleurone layer. The aleurone layer covers the starchy endosperm. Together the aleurone layer and the starchy endosperm comprise the endosperm. The starchy endosperm consists of starch granules embedded in a protein matrix. The proteins are divided into storage proteins and metabolic proteins. Glutenins and gliadins are two groups of storage protein and are together referred to as the gluten protein complex.

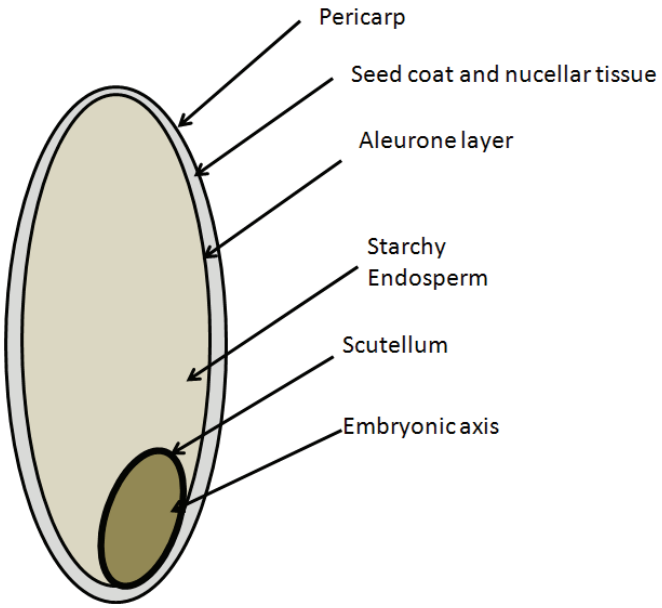

Figure 1. The wheat kernel in longitudal cross section.

The germ is the embryonic wheat plant and is a separate part of the kernel. The germ is composed of two major parts, the embryonic axis and the scutellum. The scutellum functions as a storage, digestive and absorbing organ and is therefore rich in lipids and enzymes (Eliasson 1993). From a technical point of view the kernel is constituted of three parts: The germ, the starchy endosperm and the bran (Figure 2). The bran consists of the outer parts of the kernel including the aleurone layer. The three parts are separated from each other through the milling process.

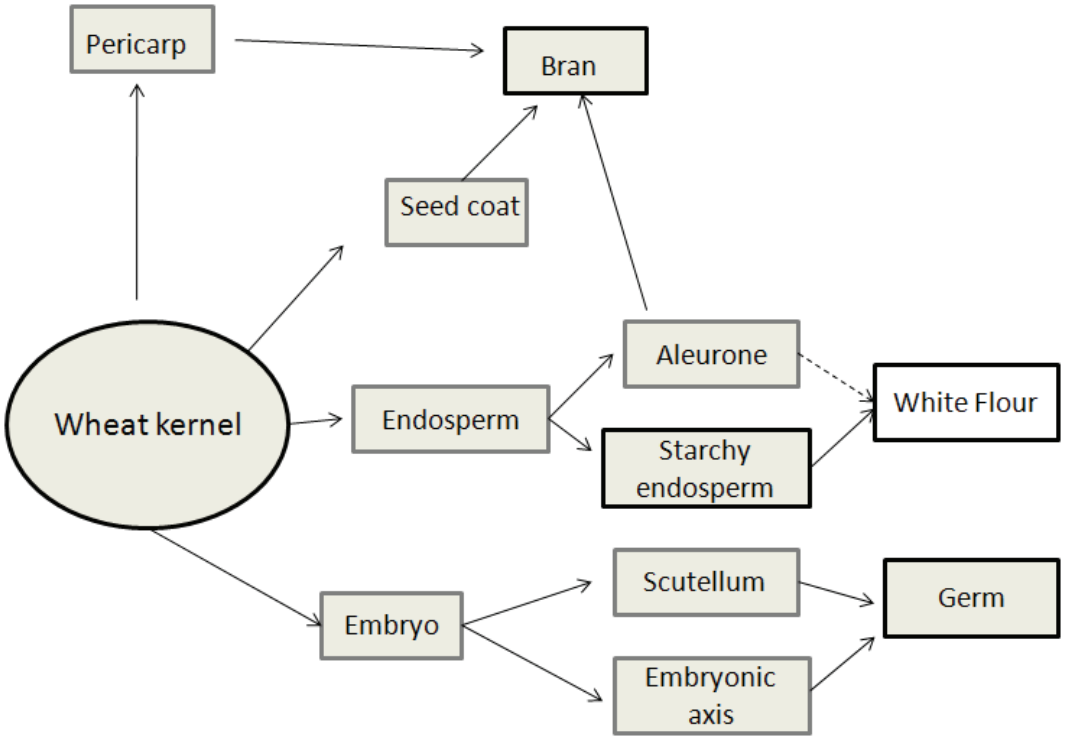

Figure 2. The technological parts of wheat kernel, bran starchy endosperm and germ . (Adapted after Eliasson 1993).

The bran protects the kernel from external damage. The bran is high in dietary fibre and ash, and constitutes about 14% of the kernel by weight (Aamodt 2004). The starchy endosperm is the part of the kernel from which the white flour is made. During the milling process it is highly preferred to extract as much as possible of the starchy endosperm for white flour without losing too much of the endosperm to the bran fraction. The most important property of the kernel that affects the flour yield is the kernel hardness (Eliasson 1993). The hardness is not fully understood but major differences found in soft, hard and durum wheats seems to be related to the presence or absence of the proteins puroindolin a and puroindolin b. One theory is that these proteins impact the interaction of gluten

proteins with the starch granule surface. If the gluten proteins are tightly bound to the starch granules the kernel becomes harder (Delcour & Hoseney 2010). Some also suggest that the hardness of the kernel is different due to cell wall thickness or the continuity of the subaleurone layer. In hard wheats the subaleurone layer forms a shell around the endosperm while in soft wheats this layer is discontinuous (Eliasson 1993).

There is also a difference in the way the kernel and the cells fracture during milling impact. In hard wheat kernels the first point of fracture occurs between the cells. On soft wheat the fracture occurs through the cell contents and the flours are seen to consist of aggregates of small disrupted particles (Cornell 1998). This indicates that the starchy endosperm cell components are more firmly bound to each other in hard wheats than in soft wheats. As the milling goes on the starchy endosperm content in hard wheats also becomes fractured. Since the interaction between the starch granules and the gluten proteins is strong in hard wheat varieties the levels of damaged starch after milling is higher than in flour from soft wheat varieties. This is because the starch granules break before the gluten protein-starch granules interaction does (Delcour & Hoseney 2010).

The North American definition of soft and hard wheats differs from the European definition. The North American definition is based upon the force required to crush the kernels hence the subaleurone layer. The soft cultivars are easy to crush while the hard cultivars are more difficult to crush. The term soft is in Europe referred to the winter and spring wheat varieties while the term hard wheat is referred to durum wheat varieties (Delcour & Hoseney 2010).

The starchy endosperm cells contain starch granules, which generally fall into two groups: 1) Small spherical granules with a size between 1 up to 10 µm, and 2) larger lenticular (biconvex formed) granules with a size of 15 to above 40 µm (Jones 1959).

2.2 Milling and Flour

Lantmännen Mills, Sweden, has different wheat varieties available to produce different types of wheat flour. The varieties are divided into three groups, A, B and E, based on protein quality. A-wheat or bread wheat is usually Swedish winter wheat varieties, used for milling of regular wheat flour. B-wheat is wheat of lower quality and protein level. E-wheat is wheat of highest quality. To obtain E-wheat the protein level should be high as well as the gluten quality. The wheat variety for this grade is most often Swedish spring wheat. To obtain the bread quality requested by the consumer flour is often a mixture of A- and E-wheat.

Bakeries require strong wheat flours with high protein levels of good quality because the dough is being kneaded by machines during a longer period of time. If the protein quality is moderate or low the dough would not hold its structure during this process and result in flat bread (Grodden 2006).

The basic processes of flour milling involve sifting, grinding, grading and purifying on the rollermill, purifier and plansifter (Pomeranz 1994) . To obtain high flour yield with good quality and long fatigue life all the starchy endosperm should ideally be in the flour and be free from bran and germ contamination.

The wheat grain is almost always milled before it is used in the production of foods for human consumption. The purpose of milling is to separate the endosperm from the bran and germ and to create smaller particles of the starchy endosperm (Eliasson 1993). Before milling the wheat kernels are rinsed and conditioned. The conditioning toughens the shell to avoid it from powder and mix with the endosperm during the milling process. The flour yield varies from 72% for white flour up to nearly 100% for whole meal flour (Cornell 1998). Bran contains high levels of ash. The ash content in the flour is an indication of how close to the bran the extracted endosperm is.

In the milling process of hard wheats a large proportion of the endosperm cells escape from disruption and become separated or constitute part of small accumulates of cell segments or cells (Jones 1959). In this form they may pass through the silk to be a part of the finished flour. Some of the agglomerates break up during milling into smaller particles ranging from 1 µm up to approximately 100 µm. When the endosperm cells break the larger starch granules becomes detached fairly easy from the protein matrix while the small granules are still tightly embedded. The matrix breaks up during milling into particles of various sizes, from large starch gra-

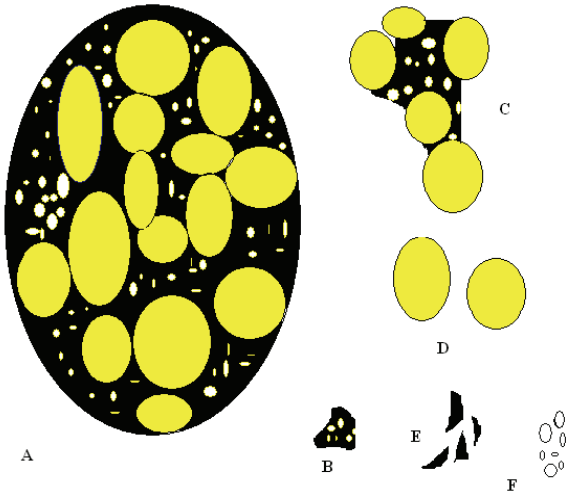

Figure 3. A schematic figure of endosperm cell (A), exposed cell contents (B), clusters of small starch granules and proteinmatrix (C), detached large starch granules (D), free wedge protein (E) and small starch granules (F). (Adapted Jones 1959)

nules to clusters of protein and small starch granules as well as free proteins (Figure 3).

2.2.1 Flour Quality

The main characteristics of a good quality bread making flour are:

- Sufficient protein in terms of content and gluten quality e.g. to provide elasticity, strength and stability of the dough.
- A balanced amount of broken starch and amylase activity to supply yeast with fermentable carbohydrates during leavening of the dough.

The chemical composition of flour is of importance for its final application. The types of proteins, minerals, lipids, enzymes and pigments vary widely between varieties (Cornell 1998; Cauvain 2003). The gluten quality will depend on the wheat selected, milling techniques and what treatment is given the flour, i.e. bleaching and conditioning. Fresh flour that has not been treated gives sticky doughs.

2.2.2 Starch

Starch is a mixture of the two polymers amylose and amylopectin. Both are classified as D-glucans since they are polymers of D-glucose. The quality of the flours depends on the amount of broken starch granules which is related to the milling techniques. Damaged starch is much more susceptible for the activity of the enzymes α- and β-amylase than undamaged starch granules (Cornell 1998). Falling Number is an indirect measurement on the amylase activity. The instrument measures the viscosity in a heated flour-water suspension by recording the time needed for a standardized object to move through the paste. The time needed is shorter if the starch is hydrolyzed by amylases to products of various sizes, which indicate a high amylase activity (Delcour & Hoseney 2010).

2.2.3 Protein

The quantity and quality of proteins in wheat are the most important factors affecting baking quality. The endosperm consists of four main groups of proteins glutenins, gliadins, albumin and globulins. The latter two are metabolic proteins i.e. enzymes. The wheat gluten complex is a viscoelastic mixture containing equal amounts of glutenins and gliadins. It is the gluten protein complex that gives rise to the special properties such as extensibility and elasticity of the dough. The unique properties of the wheat proteins to form a cohesive mass, called gluten, as

soon as the flour is being hydrated and exposed to the energy of mixing provides the basis for bread making of flour. As soon as the flour is transformed into gluten it has the ability to trap gases produced by yeast during fermentation, proofing and baking. The capture of gases, gas retention, makes the mass expand and gives softer bread after baking (Cauvain 2003). Extensibility and elasticity properties of the dough are needed for good gas expansion (Cornell 1998). The balance between elasticity and extensibility is one of the characteristics of high quality flour and one that indicates good gluten quality. Good gluten quality is comparable to the balance between the protein groups glutenin and gliadin. Their molecular properties are highly needed to obtain high loaf volumes and ideal crumb structure. An early study to determine the flour protein contribution to flour quality and doughing properties made by Hoseney & Finney (1971) showed that the glutenin proteins are responsible for mixing requirement due to its elastic properties while the gliadin proteins are considered to be responsible for the viscosity (Cornell 1998). The gluten proteins are able to form an extensive three dimensional network of molecules through di-sulfide bonds, hydrogen bonds and hydrophobic interactions.

2.2.4 Rheological Properties

Rheology is the study of the physical properties of matter. The rheological properties of dough are important factors in the determination of bread quality. Too strong doughs will not expand properly during fermentation resulting in dense unappetizing loaves with small volume. On the other hand, doughs that are too weak cannot retain gas bubbles and will result in flat loaves due to collapsed crumb or big holes in the crumb. To obtain good bread quality, mixing of the dough needs to be optimal. The mixing of doughs involves homogenizations of the various ingredients of the dough as well as development of the dough structure. The dough structure is built by the mechanics of mixing energy put into the system. The latter process is the one that is most demonstrative for the uniqueness of wheat flour properties. By putting mechanical energy in to the system the resistance to extension increases. After some critical point the resistance decreases again. Optimum bread quality is obtained by knowing when to stop mixing, usually close to, but not at, the maximum resistance. The mechanical force applied to the dough results in dimensional changes in the protein network. The changes are partially but not fully reversed when the mixing is stopped (Cauvain 2003).

There are some substances that affect the rheological properties of dough. The first one is water. Water is obligatory for making dough. The action of water is plasticizing dough and the control of water content is very important in mixing. The level of hydration in dough is typically 60 % and combined with the intrinsic

level of water in flour, which is 14 %, the total water content is about 75 %. In breadmaking the behavior of the proteins are sensitive to small changes in water content (Cauvain 2003).

The addition of sodium chloride increase the time to optimum dough development and increase the stability of the dough. Although salt might be interacting with other dough components than proteins, studies have shown that both gluten strength and extractability of proteins are modified by lower salt concentrations. Also the water absorption was affected by salt concentrations (Preston 1989). The salt affects the electrostatic interaction which leads to lowered water absorption but a stronger dough (Eliasson 1993). Too high salt levels cause an affect known as "salting out" proteins. The protein denatures because the high concentration of salt in the solution competes with the proteins for the available water and the proteins precipitate. When the salt is removed the protein may regain its original conformation and solubility, the process is reversible (Delcour & Hoseney 2010).

To study doughing properties of flour a Brabender Farinograph is often used. A dough is prepared in a holder in this machine, the water absorption is measured and the resistance to shear is recorded during mixing. The graph for strong flour shows high water absorption.

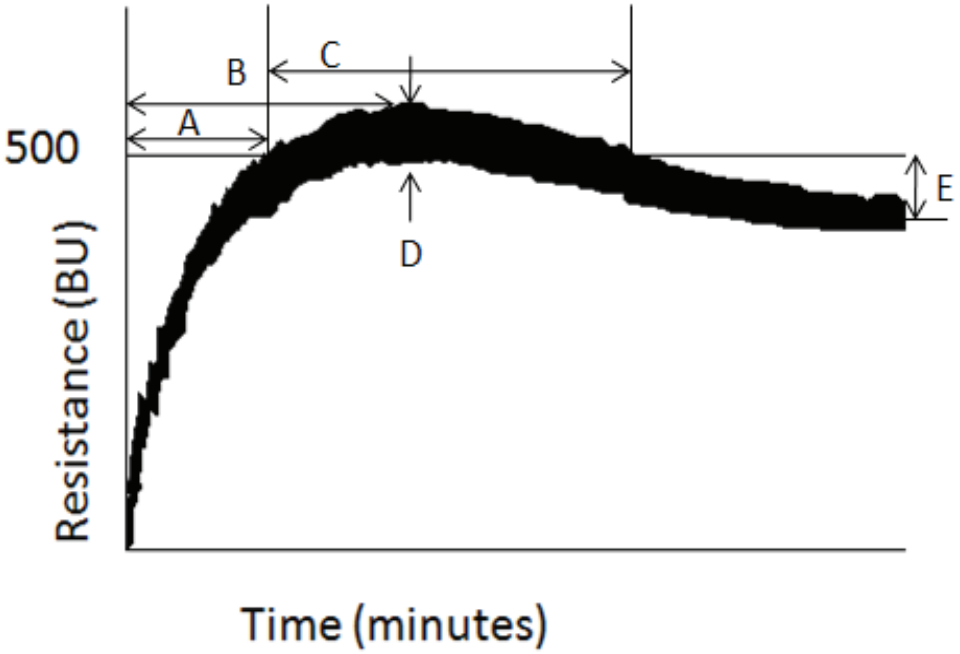

Figure 4. Farinograph curve characteristics. When recording the resistance in a dough the farinograph produce a farinogram. Arrival Time A) The time it takes for the dough to reach the resistance of 500 BU from 0 minutes; Development time B) the time it takes for the dough to reach maximum resistance; Stability C) The time the dough maintain a resistance of 500 BU; Elasticity D) Measured by the width of the curve/band at its peak; Softening E) the drop from the reference line to the centre line of the curve 10 and 12 minutes after the peak.

The water absorption is calculated from the amount of water needed to produce a dough strength of 500 Brabender Units (BU). In addition strong flours show rapid development and minimal softening or breakdown. By observing the time it takes to reach maximum consistency the development time can be observed. Soft flours also present farinograms with quick development but the softening is greater and the water absorption is lower. The Farinograph is also valuable when studying the effects of different additives such as ascorbic acid, salt or bread improvers. Most of the ingredients added to a wheat flour dough influence the result of the farinogram (Eliasson 1993).

To get a more fundamental analysis of the graph there are further parameters to use (Figure 4). The breakdown can be further analyzed by studying the drop in consistency the first 5 minutes of break down (Cornell 1998). Nowadays the farinograph is digitalized and analyzed by the computer.

The extensigraph has been widely used for quality control and for research studying flour quality and the effects of different flour additives in bread making.

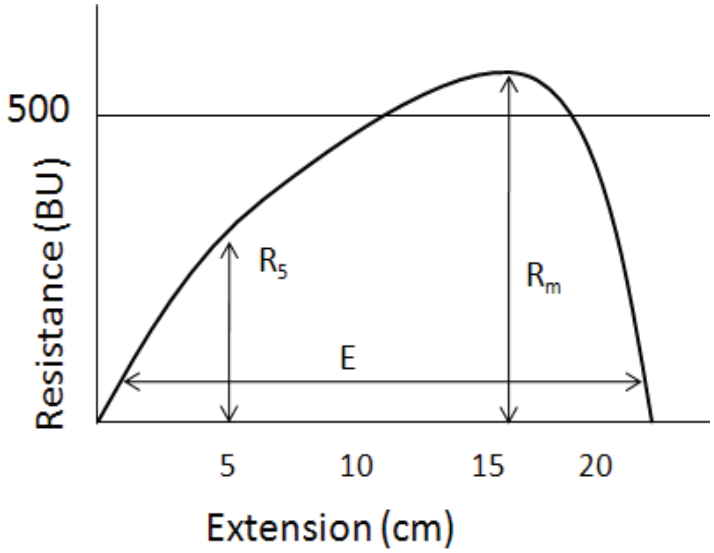

Figure 5. Extensogram showing extensibility (E), resistance to a constant extension of 5 cm (R_5), and maximum resistance (R_m). The resistance to extension is a measure of dough strength. A higher resistance to extension implies that more force is needed to stretch the dough. The dough is stretched until it ruptures which is the extensibility.

This instrument is designed to provide empirical measures of stress-strain relationships in dough. After being mixed, dough is scaled, molded into a cylindrical shape and clamped at both ends in a cradle. After a period of rest the dough is stretched through its midpoint with a hook at a constant rate of speed until the dough ruptures. This result in a resistance to extension curve called an extensigram (Figure 5). From the extensigram the maximum resistance, R_m, which is the maximum height of the curve can be acquired. Another common measurement is the R_5 which is the resistance at an extension length of 5 cm. The R-values are given in Brabender units. R_5, as a function of

time, show the structural relaxation of dough. Also the total length of the curve is of interest. For most practical applications, the curve height and area under the curve are taken as measurements of the strength of the flour. The higher the values are the stronger the flour is. The ratio of curve height to extensibility gives an estimation of the dough's viscoelastic balance i.e. long low curves gives low height/extensibility ratios and show that viscosity is dominating over elasticity (Hoseney 1994).

2.2.5 Protein analysis

Hydration of gluten proteins, the ability to absorb water, is for practical reasons synonymous with protein swelling. For a long time the capability of gluten proteins to swell in dilute acids has been an indicator for the flour quality. There is a satisfactory correlation between the swelling properties of gluten proteins and the loaf volume obtained from the original flour. The protein content must also be taken in accountancy when predicting the flour behavior since it is well known that protein content have an effect on the loaf volume.

The Zeleny method to measure sedimentation value of gluten proteins uses flour suspended in a lactic acid solution during a standard time interval. The sedimentation value is an indication of the baking quality. Higher gluten content and a better gluten quality give rise to slower sedimentation and higher Zeleny test values. The swelling of the gluten fraction in lactic acid slows down the sedimentation rate and increase the volume. The Zeleny value of flour is therefore dependent on the protein composition and is correlated to the protein content, hardness of the wheat and the loaf volume (Hrusková & Famera 2003). This method takes all gluten protein, soluble and insoluble, in account.

Another empirical test to evaluate the protein content is the Perten Glutomatic system developed in the 1980s and 1990s. The water soluble components in a gluten structure are washed out under standard conditions. The residual, the wet gluten, is centrifuged through a sieve-like vessel during a previous set period of time (ICC standard method 137/1). The material retained in the vessel is weighed and expressed as percentage of total gluten. From the wet gluten content the Gluten Index can be calculated as the quota of water insoluble mass of the total dough mass.

2.3 Air-Classification

An air-classification is an effective method to separate solids into fine and coarse fractions. The theory behind the separation process and the obtained quality of the fractions are further explained in this chapter.

2.3.1 Separation

Air classifier separates particles by two opposing forces, air-traction and centrifugal force by means of air streams. The air-traction tends to pull small particles toward the center of the rotor and centrifugal force tends to drive particles towards the circumference of the holder (Pomeranz 1988) (Figure 6). The initial material is, as mentioned, separated into two fractions. The finer particles are more likely to be carried along with the air-current (B in Figure 6) and the coarse particles which have greater mass are more likely to accumulate at the circumference and fall down by gravity into a destined container (C in Figure 6) (Pomeranz 1988).

Separation is characterized by a cut size acting as a border between the fine and coarse fraction. Particles with sizes above the cut size compose coarse fraction and those with sizes below compose fine fraction (Figure 7). Because of various random factors e.g. air-turbulence and particle collisions some fine and coarse particles may enter the wrong fraction (Shapiro & Galperin 2005). The particle separation quality is characterized by the mass content of each fraction. This is explained further in Shapiro & Galperin (2005).

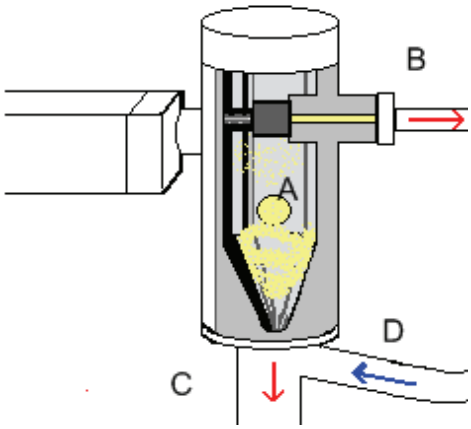

Figure 6. Schematic figure of Alpine 50 ATP Turboplex. The flour is fed in to the separating unit (A). The particles are separated by cetrifugal force and gravity formed by air currents (D). Fine particles (B) and coarse particles (C) moves to separate containers.

A study showed that not only the particle size effect the allocation leading to separation but also the type of starch and proteins in the flour and shape as well as the

surface roughness or smoothness of the particles (Dijkink *et al.* 2007). Large percentage of small starch granules and free proteins (explained in section 2.2) are present in the fine fractions.

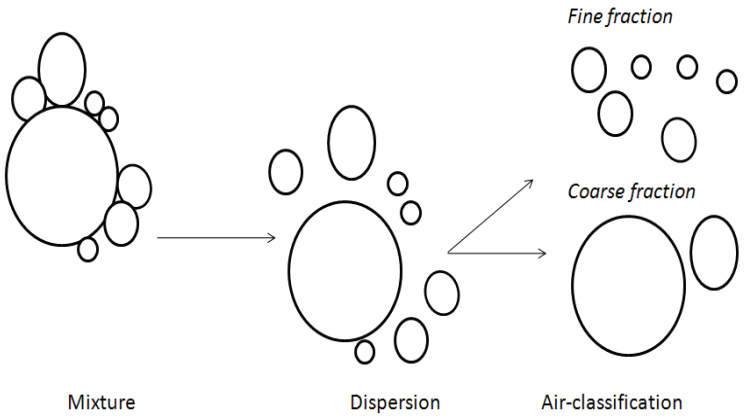

Figure 7. A schematic figure of the dispersion of a mixture during air-classification into fine and coarse fractions. The mixture is for instance the starchy endosperm agglomeration present in flour. (Adapted after Dijkink et al. 2007).

2.3.2 Fraction Properties

Hayashi *et al*. (1976) showed that cell structures can be more effectively separated for softer wheat varieties than for harder wheat types. The yield was greatest for the coarse fraction of flour from softer wheat composed of mostly large unreduced endosperm pieces. The content of damaged starch was higher in the small particle size fractions. In this experiment an impact mill was used before air-classification which resulted in the high content of damaged starch. Pin-milling before air-classification also resulted in higher yield of the fine fractions (Hayashi *et al.*. 1976). During the baking procedure in the same study the gluten in the finest fractions did not develop in a normal way during mixing; doughs became sticky and had to be scraped from the bowl sides by hand. However, the same fraction showed a good gas production during fermentation. The second fine fraction with less protein resulted in an unelastic dough with low gas production. The bread from the protein rich fraction for all of the wheat varieties in the study had a dark reddish crust, a crumb with grayish colour and soggy texture. The fractions with low protein content made breads with low volume and pale crust colour. The grain was close and the texture soggy (Hayashi *et al.*. 1976).

Table 1. Data on various fine fractions obtained from flour of 9.3 % protein content by means of multi-stage operation of a Mikroplex classifier, the coarse fraction at each stage was refed (Adapted after Jones 1959)

Maximum Particle Size (μ)	Yield (% of initial feed)	Protein Content (%)*
5.5	1.3	22.7
7	1.9	19.7
11	2.2	16.6
14	2.9	13.1
18	2.0	10.4
21	5.9	6.0
24	9.7	4.2
28	13.6	5.2
33	19.0	8.6

*expressed on a 14% moisture basis.

Previous studies have shown that the protein rich fractions are suitable for yeast leavened bread meanwhile low protein fractions are suitable for sponge cakes. These studies have been made with a commercial flour blend as starting material so differences in flour due to wheat hardness and varieties were concealed. Addition of high protein fractions from air-classified flour has been shown to increase the loaf volume of less protein rich flours (Bean 1969). Other studies have also shown that fortification of straight flour with high protein air-classified fractions yield doughs with greater elasticity, water absorption, and bread volume (Dick *et al*.. 1977; Pomeranz 1989). Fractions with the smallest particles have shown to be of lowest yield, and to have the highest ash and protein content (Dick *et al*. 1977).

Rheological dough test data have shown that the dough development time increased with increasing protein content. The water absorption did not only increase with protein content but also with decreasing particle size, hence with decreasing specific surface (Rezsoe & Gracza 1960). The particles in the fine fraction produced dough development properties optimum for bread baking. The farinograph showed characters for the coarse fractions similar to those wanted in pastry flour. To remove the coarse fractions from the fine fraction could be of economical interest since it will enhance the desired properties in bread baking. When comparing soft and hard wheats (American classification) the soft wheat is more responsive to air-classification since there is a high protein shift. The protein rich fraction removed from the flour leaves fractions that are appropriate for cake flour or starch applications (Rezsoe & Gracza 1960). The hard wheats have lower protein shifts and offer a different set of products (Rezsoe & Gracza 1960; Victor 1992). The high-protein fractions may be altered to be desirable for both pastry and bread-baking.

The diastatic activity values, i.e. enzymatic activity, have been shown to be higher in the fine particle fractions. This is an indication of accumulated amylases in the fine fraction.

2.4 Bread making

The principles in bread making are basically three steps. The first one is the preparation of the dough, the second step is fermentation and the third one is baking (Cornell 1998). In addition molding, sheeting and proving is performed between fermentation and baking.

2.4.1 Dough preparation

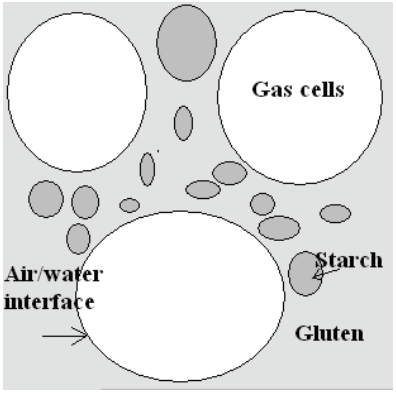

Figure 8. A simplified model of the dough structure. (Adapted after Eliasson 1993).

The formula for dough in bread production consists of flour, yeast, salt and water (Aamodt 2004). A dough is formed when gluten proteins and damaged starch granules are hydrated. The glutenin fraction of the gluten protein complex forms an extensive three dimensional network. What happens is that hydrogen bond between the amide groups on side chains of the amino acid glutamine and other groups are formed. There are also hydrophobic interactions between the aromatic rings and alkyl groups, ionic bonds between acidic and basic side chains and disulfide bonds from amino acid cysteine side chains. These reactions are fundamental for the viscoelastic properties of the dough (Cornell 1998). Dough rheology is relevant in order to understand the handling properties in the bakery and also to predict the final quality of the bread. In scientific studies rheology is of importance when studying the structure of the dough especially when measuring the effect of additives (see 2.2.4 for further explanation) (Eliasson 1993). The hydration is slow if the flour water blend is not mixed. During mixing new surfaces of the flour particles are exposed to the water molecules and the hydration is optimal. Mixing is also essential for the bonds mentioned earlier in this section to develop properly, i.e. the gluten network forms during mixing. Air is also allowed into the dough and gas cells are formed to which the gas produced during fermentation can diffuse (see 2.4.2) (Aamodt 2004). At optimum mixing time the dough will be a continuous phase of protein and starch granules and a discontinuous phase of gas cells (Figure 8).

2.4.1.1 Additives: Ascorbic Acid

Ascorbic acid has been discovered to have a positive influence on dough and bread. It is often added at the mills after milling. The theory is that ascorbic acid (AA) reacts with oxygen and forms dehydroascorbic acid (DHAA). Due to an enzymatic reaction the DHAA reacts with glutathione (G-SH) in the flour and the DHAA is reduced back to ascorbic acid (AA). G-SH exists in the flour and is able to break the disulphide bonds which weaken the dough. The latter reaction is hindered by addition of DHAA. The cross-linking between glutenin subunits is enhanced by oxidizing agents such as DHAA which improves dough stability (Aamodt 2004; Cornell 1998).

2.4.2 Fermentation

The second step in bread making is fermentation. During fermentation the yeast produces carbon dioxide which diffuses into the aqueous phase in the dough. When the aqueous phase is saturated the gas aerates and gets the dough to swell. The dough becomes lighter and receives a more cellular structure. The yeast converts glucose from starch through the glycolysis (Cornell 1998).

2.4.3 Baking

The final and third step is baking. The dough is placed in the oven after dividing and punching. At first the rate of fermentation is increased but as the temperature rises the enzymes are deactivated and no further gas production occurs. During baking all of the ethanol present vapor and some of the water also lost. This contribute to an increase in volume due to gas expansion which is the so-called “oven spring”. The starch granules disrupt and form a gel with water while the gluten forms a matrix that gives the bread its typical spongy crumb texture. At higher temperature the crust becomes golden brown and enhances the flavor development as well as appearance. The Maillard reaction gives the browning of bread during baking which is a highly desirable feature. The reactive amino acids in gluten protein complex react with glucose, which is formed during fermentation (Cornell 1998).

3 The Aim

The aim with this study was to use air-classification to separate a commercial wheat flour blend into coarse and fine fractions and to evaluate whether it is useful in the industry. Obtained flour fractions was evaluated based on protein content as well as protein quality (Section 1), rheology and baking properties such as volume. The main parameters that were considered when evaluating the flour were wet gluten quality and bread volume. The issues addressed are the following:

- How will the protein quality and quantity change in fractions compared to the original flour at different rotational speed in the air-classifier?
- Will there be any difference in wet gluten content between rotational speed and the fractions?
- Will there be any difference in bread volume between rotational speed and the fractions?

4 Materials and Methods

4.1 Pre-study

To get an estimation of what the result might be from the different settings of the air-classifier an empirical pre-study was performed on strong commercial wheat flour provided by Lantmännen Mills. The fractions were analyzed with Near Infra-red Transmitter (NIT) by the means of protein and moisture content (at Lantmännen Cerealia AB in Uppsala). The result of the pre-study implied which rotational speeds that were interesting to look at in the main study and the rotational speeds of 5000 rpm, 6500 rpm and 8000 rpm were chosen.

4.2 Flour

The flour of interest was a strong wheat flour blend (*Triticum aestivum L*) with 12 g protein/100 g flour and no added ascorbic acid. The flour was delivered by HavneMØllerne, Denmark. The flour is suited for laminated doughs and develops normally a strong, elastic gluten network. The flour was milled 1st of June 2010 at Lantmännen Cerealia Inc. in Vejle, Denmark. Approximately 77-79% of the milled seed is included in the flour.

The reason why flour without addition of ascorbic acid was chosen was to avoid majority of the ascorbic acid accumulating in one fraction and influencing the following analysis.

4.3 Air Classifier

The air-classifier used was a pilote station from Hosokawa, Alpine 50 ATP Turboplex (Figure 9).

Figure 9. The Hosokawa Alpine 50 ATP turboplex.

The flour was separated with three different rotational speed settings to obtain one fine and one coarse fraction for each setting (Table 2). Every setting was run three times to obtain statistically comparable results. The rotation speed was set to 5000, 6500 and 8000 rpm. The air flow was consistently 100m^3/h and the feed rate (setting 3 on the feeder) was also consistent for every trial.

Table 2. The rotational speed used for separating the flour of interest

Rotation (revolutions per minute)	Fraction
5000	Fine
	Coarse
6500	Fine
	Coarse
8000	Fine
	Coarse

4.4 Chemical Analysis

The chemical analyses were performed about a week after the air-classification. Analysis of all samples including original flour, which was also the reference, was performed at the quality laboratory at Lantmännen Mills in Malmö, Sweden. Moisture, protein and ash content were determined by the use of a Near Infrared Transmittor, NIT (FOSS Infratec^{TM} 1241, Hillerod, Denmark). The method was ICC standard method 202, standardized for moisture and protein and ash content measurement (AACC method 08-21). The method is standardized for normal wheat flour and it is possible that the protein content from the fractions with the highest levels might fall out of range and give an uncertainty to the measurement. The given values were therefore considered to show a trend in protein content in contrast to an exact level. To measure the protein quality in the samples the sedimentation value according to Zeleny, Wet Gluten Content (ICC standard method 116/1, and, ICC standard method 137/1) was performed. Falling Number, ICC standard method 107/1, was measured.

4.5 Rheology

The Brabender farinograph was used to determine water absorption of the flours and the mixing behavior of the dough. The method used is ICC standard method 115/1. The farinogram is approved within the range of 500±20 Brabender Units (BU).The extensograph method used was the ICC Standard Method 114/1 (

Figure 10). The farinogram used for preparing the dough was approved within an approximate range of 500±20 Brabender Units (BU).

Figure 10. The extensograph is used to measure the existensibility of dough. The dough is stretched by a hook until it ruptures while the resistance is recorded.

4.6 Baking

All the fractions were tested for baking properties by evaluating the bread volume, length, height and width as well as the crumb structure. The crumb structure was evaluated by making black and white photo copies and comparing copies with a crumb structure scale. The ingredients used are listed in Table 3 and shown in Figure 11.

Figure 11. Two fractions and all the ingredients used when baking except water. The left bowl contain a fine flour fraction and the right bowl contain a coarse flour fraction.

Table 3 List of ingredients used in the bread making

Ingredients	Amount (gram)
Flour	1000
Yeast	50
Salt	18
Sugar	18
Oil	18
Ascorbic acid	0,040
Water*	~600

**The amount of water added was the farinograph-value for water absorption.*

The dough was mixed in a Kemper^{TM} spiral mixer for 200 seconds at low speed and for approximately 420 seconds at high speed until the dough temperature was between 27-29 ºC and the dough was neither shiny nor sticky. After mixing the dough was proved for 30 minutes. Dough was divided into three 500 gram pieces which were molded with a Glimek Cone Rounder and Moulder into stand-alone loaves. The loaves were then leavened in a holding cabinet at 38 ºC with a RH of 80 % for one hour. After leavening they were baked at 220 ºC with 20 seconds steam for 25 minutes. The same equipments were used for every batch.

The evaluation of the loaves was performed between 2-5 hours after baking when the crumb temperature was equal to room temperature and while the crumb was still moist. For evaluation of the volume a laser scanner was used and the size measurements were taken by an ordinary ruler.

4.7 Statistics

Principal component analysis (PCA), which is a multivariate analysis designed for data correlated in multiple ways was performed using Unscrambler (version 10.1) (CAMO ASA, Oslo, Norway) on the baking and chemical analysis data from the fractions. The method makes it possible to get an overview of which properties that are related and which properties that are the most important when discriminating between samples.

Two variables that are close to each other in the plot represent properties that are positively related, hence vary in the same way; on the other hand, variables appearing on opposite sides are negatively related. Variables located along the longitudinal axis are independent of those along the vertical axis. All variables were weighted to equal variance. Two principal components were chosen.

Analysis of variance (ANOVA) and Tukeys pairwise comparison test were performed using Minitab 16 (Minitab inc. Pennsylvania, U.S.A). The significance level used was $p< 0.05$ for all statistical analysis. Since there was only one sample of the original flour it was not included in the statistical analyses.

5 Results and Discussion

The PCA- plot (Figure 12) gives an overview of what relationships there were between the different parameters analyzed.

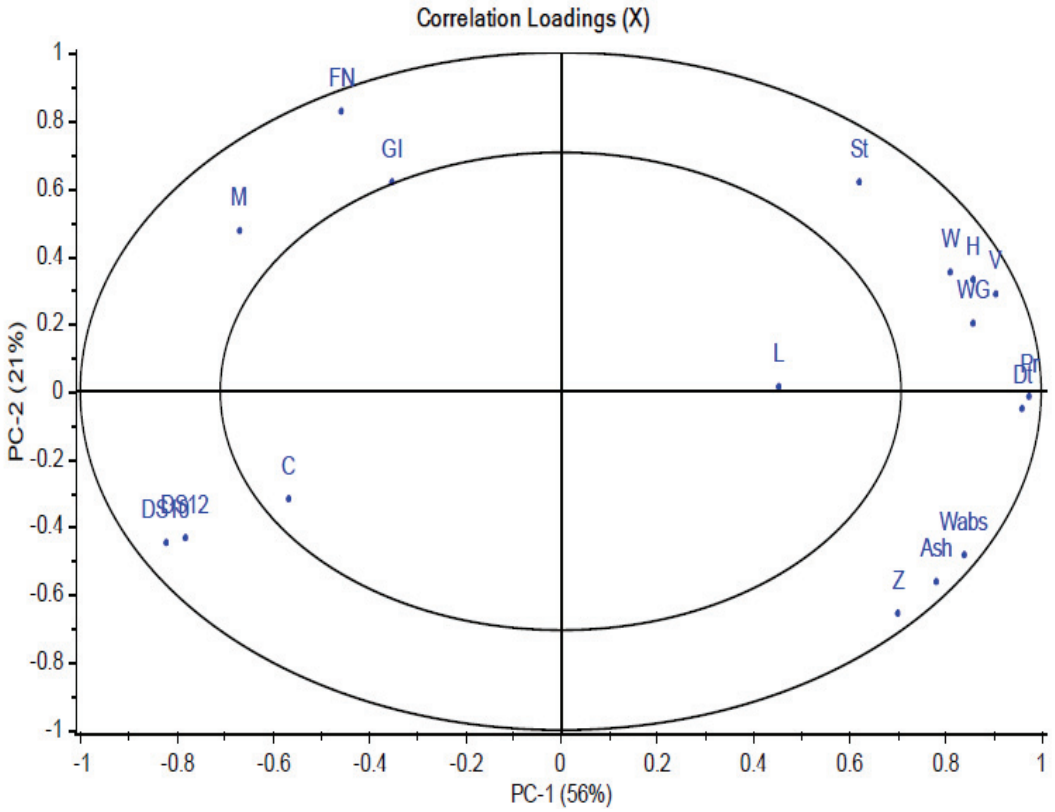

Figure 12. Parameter loading plot from PCA analysis. The variables positioned between the first and the second ellipse show an explained variation of 90-100% of the model. Pr= protein content; Z= protein sedimentation (Zeleny); WG= wet gluten content; Dt= dough development time; Wabs= water absorption; St= dough stability; V= volume; FN= Falling Number; M= moisture content; DS10= degree of softening after 10 minutes; DS12= degree of softening after 12 minutes; C= crumb structure; L= length; H= height; W= width.

As seen in this plot there were positive relationships between the protein content (Pr) and wet gluten (WG), protein sedimentation (Z), dough development time (Dt), water absorption (Wabs) and dough stability (St). There was also a positive relationship between the protein content and the volume of the breads (V) but there was a negative relationship between protein content and the degree of softening (DS). The wet gluten content had a strong positive relationship to dough stability and a strong negative relationship the degree of softening. The protein sedimentation value was positively related to the ash content and to the water absorption. The bread volume was positively related

to the dough development time, dough stability, water absorption, wet gluten, and protein content. There was a negative relation between bread volume and degree of softening. The crumb structure and the length of the bread were not explained in this model (Figure 12).

To verify the relationships shown in the PCA-plot ANOVA was used.

5.1 Flour Characteristics

The separation showed a lower yield for the fine fractions than for the coarse fraction (Table 4). The fine fraction from setting 8000 rpm showed the lowest yield. The trend also shows that the more revolutions per minute the lower the yield was for the fine fraction. This trend was expected since there is specific amount of particles of certain sizes in the flour.

Table 4. The fraction yield for each setting and fraction

Setting (revolutions per minute)	Fraction	Fraction yield (%)
5000	Fine	25
5000	Coarse	75
6500	Fine	16
6500	Coarse	84
8000	Fine	10
8000	Coarse	90

5.1.1 Protein Content

The protein content in the original flour was measured to 12.9 % of Dry Matter (DM) by Near Infrared Transmittance (NIT). The protein content in the samples was significantly different for each speed setting and for each fraction (Figure 13). The protein content in the fine fraction from 8000 rpm was higher than the fine fraction from the other two settings. The protein content was higher in the coarse fraction than in the fine fraction for the setting 5000 rpm in contrast to the other two settings where the fine fractions had the highest protein content. Even though there was a small difference between the fine and coarse fraction from the setting 6500 rpm the protein content was significantly higher in the fine fraction. Both fractions from 6500 rpm had significantly higher protein content than the fractions from 5000 rpm. There was also an interaction

between all of the settings and the fractions. This means that the rotational speed set in the air-classifier has influenced the protein content in the coarse and the fine fractions. A higher speed of 8000 rpm gave a fine fraction with high protein content but a low rotational speed of 5000 rpm gave a coarse fraction with higher protein content than the corresponding fine fraction. The higher protein content in the latter fraction might be due to conglomerates of protein and starch granules formed during milling. It is possible that the conglomerates did not separate at the lower rotational speed resulting in a higher protein content in the coarse than in the fine fraction.

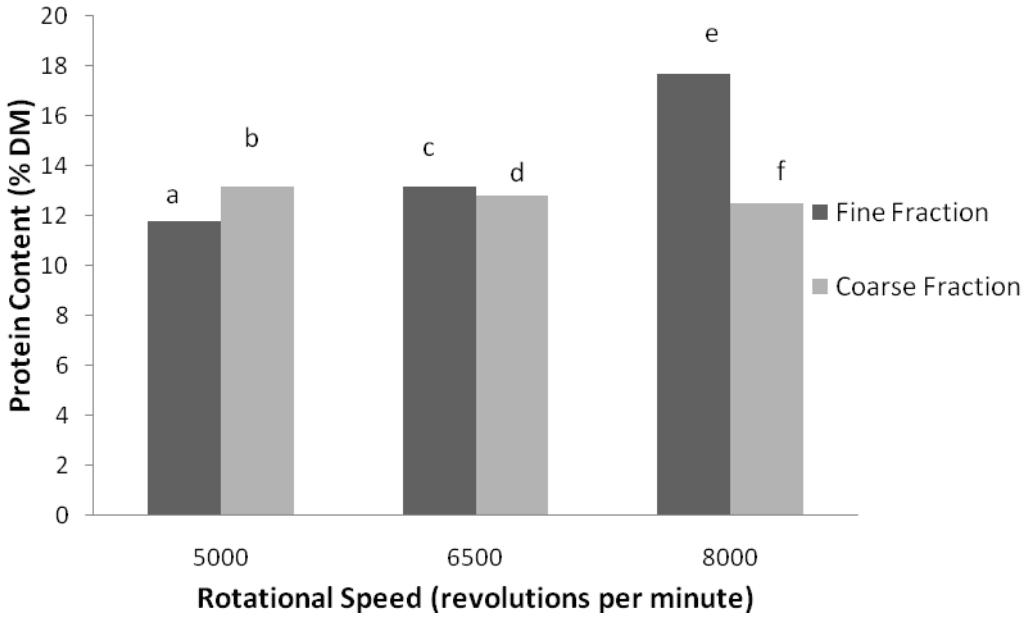

Figure 13. Protein content in the different fractions from the different settings obtained from analysis by Near Infrared Transmittance (NIT). Columns marked with different letters are significantly different, $p<0.05$.

5.1.2 Falling Number

The ANOVA analysis showed a difference for the values of the Falling Number (FN) between the two fractions for each setting (Figure 14). The coarse fraction from all three settings had higher FN than the fine fraction. The FN in the respective fractions from the speed setting 6500 rpm was not different than the fine and coarse fractions from the other two settings. The rotational speed did not impact the FN value in the fractions. The Falling number of the original flour was similar to the coarse fractions from all settings.

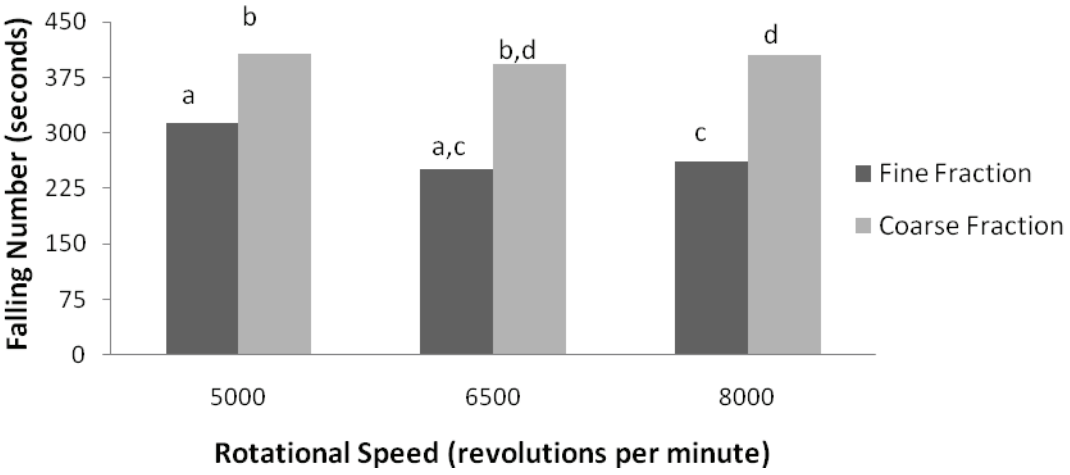

Figure 14. The result from Tukeys pairwise analysis on the data from Falling Number analysis. Columns marked with different letters are significantly different, $p<0.05$.

The lower Falling Number in the fine fractions indicates that the amylases accumulate in the fine fractions. There was a lower rate of accumulation in the fine fraction from 5000 rpm than in the fine fraction from 8000 rpm. None of the fractions from 6500 rpm showed a significant difference between the fine fractions or the coarse fractions. It might also be possible that there was a gathering of smaller starch particles in the fine fractions which resulted in thinner slurry causing a lower Falling Number.

5.1.3 Ash Content

The ash content was highly dependent on the type of fraction and setting. The fine fractions had higher ash content than the coarse ones. The ash content in the fine fraction from the setting 8000 rpm was the highest (0.86 % DM, $p<0.05$) and the coarse fractions had the same level for each setting (0.52 % DM, $p<0.05$). It is possible that the fine fractions contained higher levels of ash because ash is small particles and therefore followed the air-streams to the fine fraction. Another theory is that the ash particles are attached to the smaller particles and therefore brought to the fine fraction.

5.1.4 Protein Sedimentation

The protein sedimentation volumes obtained from the Zeleny analyses show that the fine fractions for each setting were significantly larger than the corresponding coarse fractions (Figure 15). The greatest difference between the fine and coarse fraction was seen for the 8000 rpm setting.

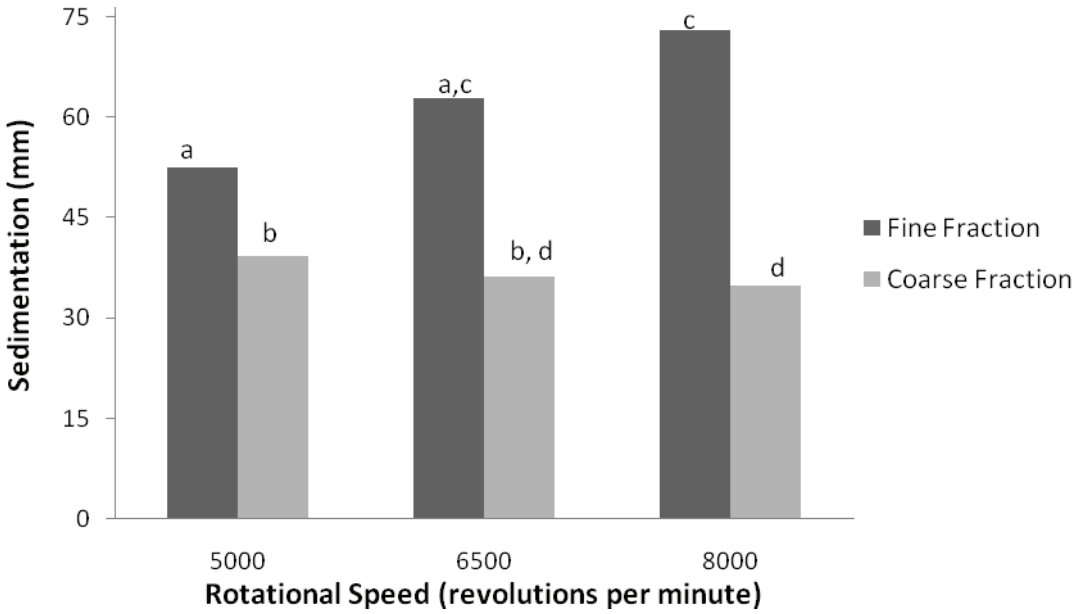

Figure 15. Zeleny show sedimentation of protein in millimeters. Columns marked with different letters are significantly different.

The protein content (Fig 13) was also higher for the fine fraction from the speed setting 8000 rpm which result in more protein able to swell which affects the result.

5.1.5 Moisture Content

The average moisture content was higher for the coarse fraction than for the fine fraction for all three speed settings (not shown). The moisture content was almost the same for 5000 rpm and 6500 rpm and the respective fine and coarse fractions. Between 5000 rpm and 8000 rpm, however, there was a significant difference between both settings and fractions showing that the coarse fraction has higher moisture content. Between 6500 rpm and 8000 rpm there was a difference only between the fractions showing that the coarse fractions had the highest moisture content (12.3 % DM and 12.4 % DM re-

spectively). These moisture contents did not differ significantly. The fine fraction from 8000 rpm had the lowest moisture content (11.4 % DM) of all fractions (fine fraction from 6500 rpm 11.7 % DM). The fractions from 5000 rpm did not differ significantly (fine fraction had 12.4 % DM and coarse fraction 12.6 % DM).

5.1.6 Wet Gluten Content

The wet gluten content was significantly higher in the coarse fractions from the settings 5000 rpm and 6500 rpm (Figure 16). There was no significant difference between these two settings though. When the settings 5000 rpm and 8000 rpm were compared there was a significant difference between these settings but the coarse and fine fractions were not significantly different (Figure 17). The settings 6500 rpm and 8000 rpm and their fractions did not differ (not shown). The higher the wet gluten content was the better quality of the wheat protein. There was however a trend showing that the wet gluten content in the fine fractions increased by the increasing rotational speed while the coarse fractions did not follow the same trend. The Gluten Index was also tested on the wet gluten content but the result showed no significance difference (not shown).

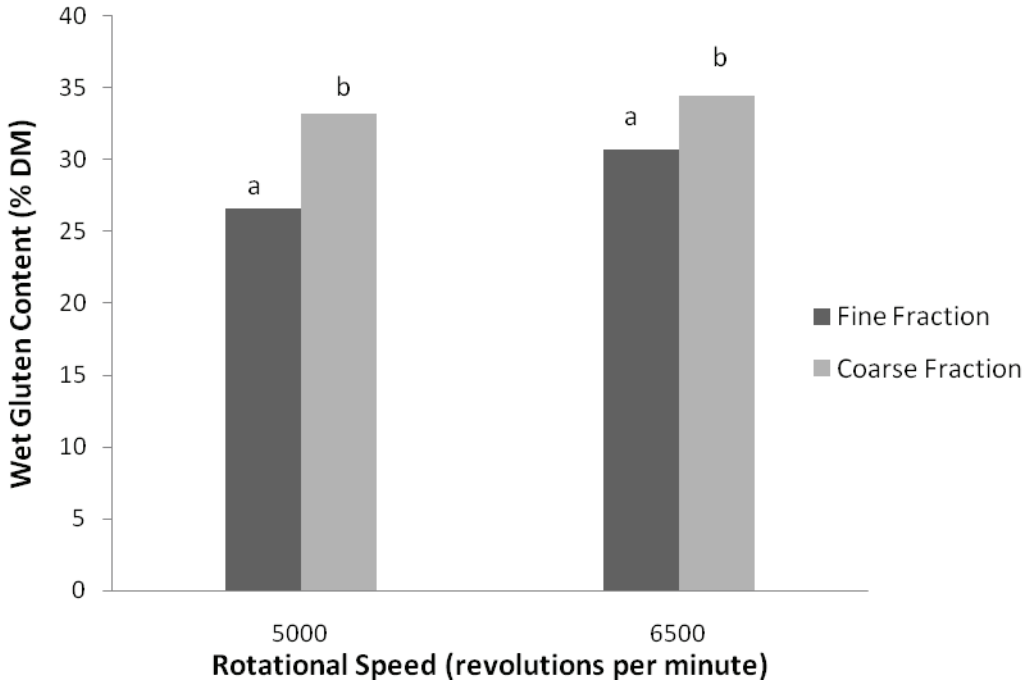

Figure 16. Result from Tukeys pairwise comparison on the data from glutomatic analysis on wet gluten from the settings 5000 rpm and 6500 rpm. The letters show if the mean values are significantly different. Columns marked with different letters are significantly different.

5.2 Rheology Properties

The characteristics of each fractions obtained by air-classification are shown in Table 5. The extensograms for the fine fractions from 8000 rpm was missing due to inabilities in performing that analysis because of stickiness and late dough development.

Table 5 Rheology characteristics

Rotation (revolutions per minute)	Fraction	DDT (min)	DST (min)	Ext 45 (mm)	Ext 90 (mm)	Rmax 45 (BU)	Rmax 90 (BU)
5000	Fine	2.7^{a}	3.2^{a}	148^{a}	126^{a}	391^{a}	648^{a}
	Coarse	2.4^{a}	15^{b}	170^{b}	135^{b}	436^{b}	791^{b}
6500	Fine	2^{a}	1.8^{a}	138^{a}	110^{a}	408^{a}	688^{a}
	Coarse	3^{a}	18.5^{b}	168^{b}	133^{b}	480^{b}	865^{b}
8000	Fine	22^{c}	21^{c}	-	-	-	-
	Coarse	2.6^{d}	9.6^{c}	168^{ns}	122^{ns}	422^{ns}	916^{ns}
Original	-	2.5^{ns}	7.9^{ns}	148^{ns}	12^{ns}	520^{ns}	936^{ns}

DDT= dough development time in Farinograph; DST= dough stability time in farinograph; Ext 45= extensibility measured as distance to rupture after 45 minutes proofing time (45); Ext 90= extensibility measured as distance to rupture after 90 minutes proofing time (90); Rmax 45= resistance to extension after 45 minutes; Rmax 90= resistance to extension after 90 minuytes; - = No measurements. ^{ns}*= the variance is not significant, p<0.05. . The letters show if the mean values are significantly different. Columns marked with different letters are significantly different*

The dough development time was significantly different between the two lower speed settings and 8000 rpm, where it was higher for both fractions from 8000 rpm (Table 5). The setting 8000 rpm had also a significantly longer dough development time for the fine fraction than for the coarse fraction (Table 5). The longer development time might be due to the higher protein content and that it probably takes longer time for all of the protein to become hydrated and develop gluten network.

The dough stability was significantly different between the fractions comparing 5000 and 6500 rpm. The stability of coarse fractions from 5000 and 6500 rpm was higher than the fine fractions. The stability for the original flour was in between the coarse and the fine fraction for these settings. When 5000 rpm and 8000 rpm were compared there was no difference between the fractions but between the settings, where the fractions from 8000 rpm had higher stability. There was no difference between settings 6500 rpm and 8000 rpm or the fractions, but there was a significant interaction, showing that the higher the rotational speed in the air-classifier was the higher was the dough stability. The rotational speed set in the air-classifier had an effect on the strength on the doug.

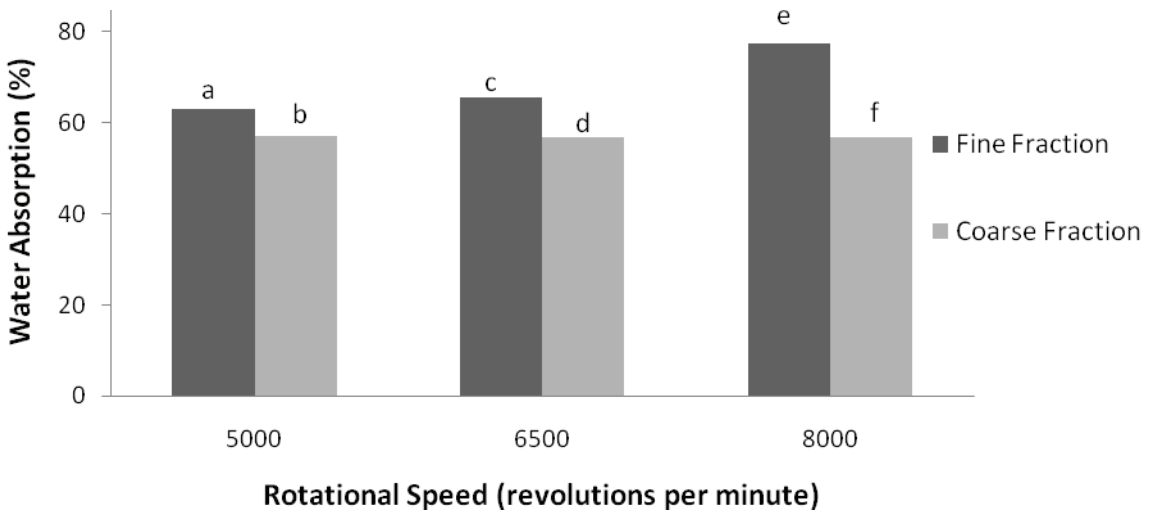

Figure 17 The water absorption from brabender farinogram. Columns marked with different letters are significantly different, $p < 0.05$.

Figure 17 show the result of the water absorption experiment performed with a farinograph. The water absorption in the fine fraction from every setting was significantly higher than the corresponding coarse one. Each setting was also significantly different from each other. The fine fraction from setting 8000 rpm had significantly higher absorption value than the fine and coarse fractions from both 5000 and 6500 rpm. There was also a significant interaction between the fractions and settings, meaning that the rotational speed settings had impact on the outcome of the result of fine and coarse fractions. It is known that water absorption is increased by high levels of protein content and damaged starch granules (Hayashi *et al.*1976). The damaged starch level was not analyzed in this study but since other results have shown that fine fractions can have an increase in damaged starch it is possible that it was the case in this experiment as well. Flours that contain high amounts of damaged starch are also known to produce sticky doughs (Hayashi *et al.* 1977) which happened in the fine fraction from 8000 rpm.

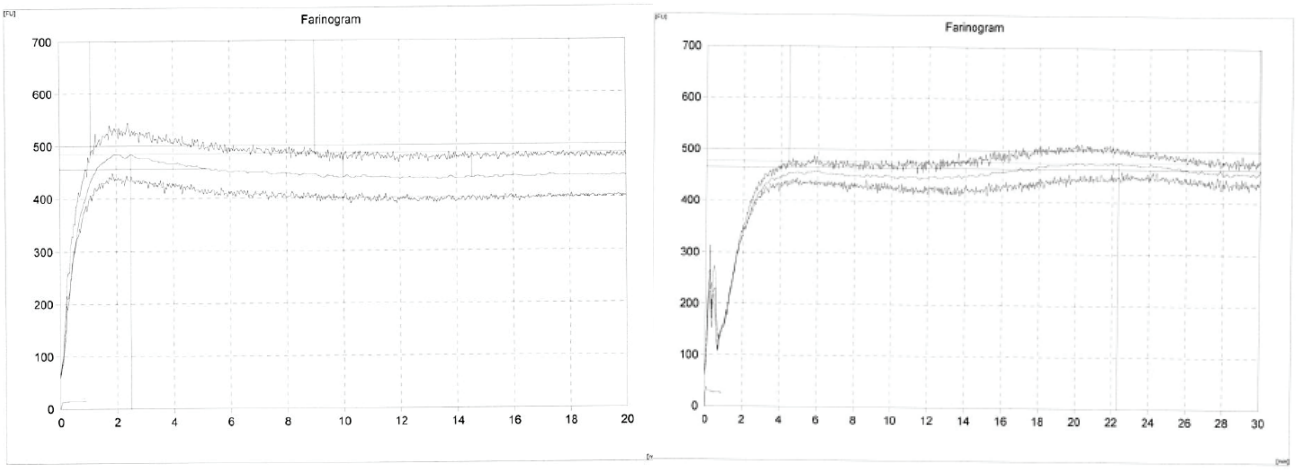

Figure 18. To the left the farinogram profile for the original flour, to the right the farinogram profile for the fine fraction of 8000 rpm.

The farinograms for the fine fractions from 8000 rpm had a rather different profile (Figure 18) than the other farinograms which might have an impact on the calculation of these values which has to be considered.

For the degree of softening there was a significant interaction between all three settings and all fractions (not shown). There was also a significant difference between the fine and coarse fractions of 5000 rpm and 6500 rpm, were the coarse fraction had a lower degree of softening showing that these fractions produced doughs able to stand tougher mechanical treatment. Between 5000 rpm and 8000 rpm there was only a significant difference between the settings where the mean value for 5000 rpm was higher than the mean value for 8000 rpm (50 BU and 27 BU respectively). The comparison between 6500 rpm and 8000 rpm show a significant difference between fractions and settings.

The extensograms for the rotational speed settings of 5000 and 6500 rpm showed a significant difference in the energy used for extending the dough, both after 45 and 90 minutes proofing time (Table 5). The energy input was higher after 90 minutes than after 45 minutes. There was also a significant difference between the fine and coarse fractions for the dough extensibility and curve maximum after 45 and 90 minutes. The coarse fractions showed higher resistance towards extension than the fine fractions. There was no difference between the settings 5000 and 6500 rpm and no interaction between fractions and setting. The ratio number in the extensograms showed no statistical significance for fractions or settings after proofing time of 45 or 90 minutes. Since the extensograph measurements for the fine fractions from 8000 rpm were missing it is hard to fully compare the protein quality in relation to extensibility between the fraction and settings.

5.3 Baking results

The bread volumes for the fine fractions from 8000 rpm were significantly larger than the other (Figure 19). They were even larger than the volume of the bread made with the original flour, which was expected when considering the protein content. The bread made with the coarse fraction from 8000 rpm was larger than both the volumes from fine and coarse fractions 6500 rpm. The other bread volumes, made from fine and coarse fractions from 5000 and 6500 rpm were not different.

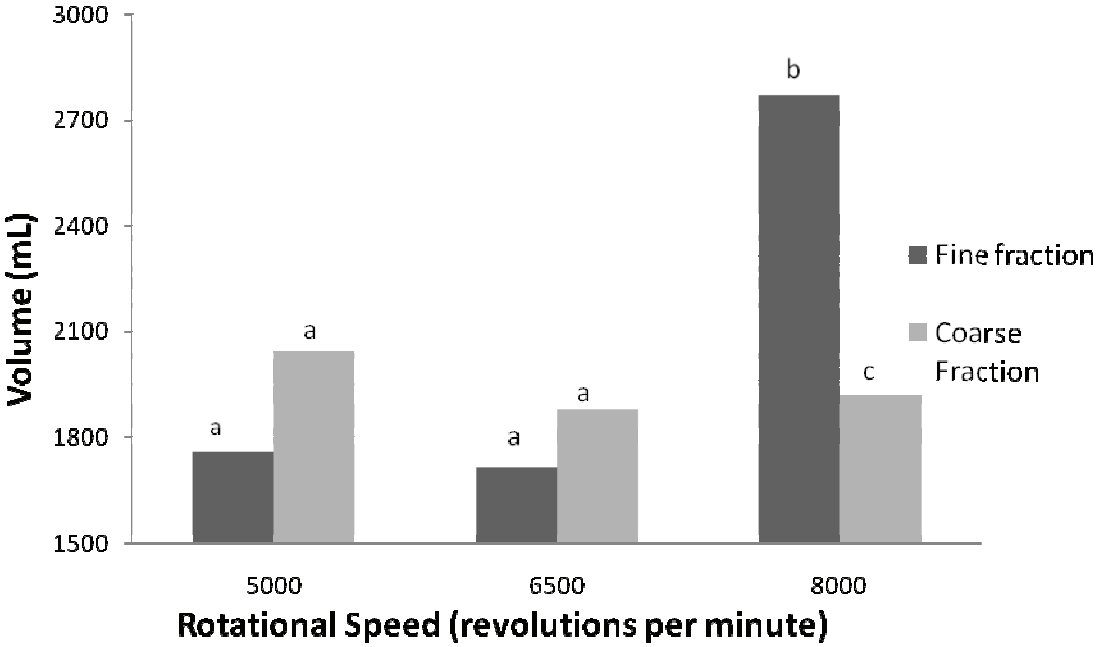

Figure 19. The bread volumes obtainedby the baking test of the different flour fractions. Columns marked with different letters are significantly different, p< 0.05.

Table 6. Correlations between parameters of interests in the experiment

Parameters	Wet Gluten	Protein content	Bread volume
Protein content	+		
Bread volume	+	+	
Water absorption	+	+	+
Dough development time	+	+	+
Dough stability	+	+	+
Degree of softening	-	-	-
Moisture content	-	ns	-
Ash content	+	+	+
Protein sedimentation	ns	+	+

+ Show a significant, positive correlation $p<0.05$; - show a significant, negative correlation $p<0.05$; ns show that there is no significant correlation.

The volume of the bread was positively correlated to protein content, wet gluten content, protein sedimentation, water absorption and dough development time (Table 6). The correlation was strongest for the fine fractions of 8000 rpm, probably due to the more extreme characters of this fraction. The fine flour fraction of 8000 rpm had many high values from the different measurements that showed positive correlations to the volume (Table 6). The results showed that there was strong protein in this fraction creating a matrix that was able to expand during fermentation and gas development.

The crust color of the breads (Figure 20) made from the fine fraction from the speed setting 8000 rpm had a dark brown colour compared to the other breads that varied between golden brown and lighter brown. One theory is that the change in color might be due to the higher water absorption in the flour fraction and the possibility that this flour contains more damaged starch and proteins. When the bread is baked the water migrates to the surface bringing along reducing sugars from the damaged starch. These sugars enhance the maillard reaction causing a dark brown crust. If there is more water on the outer layer of the bread the present proteins probably can move more freely. The tertiary and quartiary structure is then more open which increase the possibility for the reducing sugars (i.e. glucose) to react with the amino acids in the proteins. The Falling Number for this fraction was quite low which indicates a high amylase activity which might have reduced starch into smaller fragments such as glucose.

Figure 20 shows that one loaf from the fine fraction from 5000 rpm was as dark as the breads from the fine fractions from 8000 rpm. This was only because of too high temperature set in the oven for that baking procedure. It should have been as light as the other two breads from the same flour.

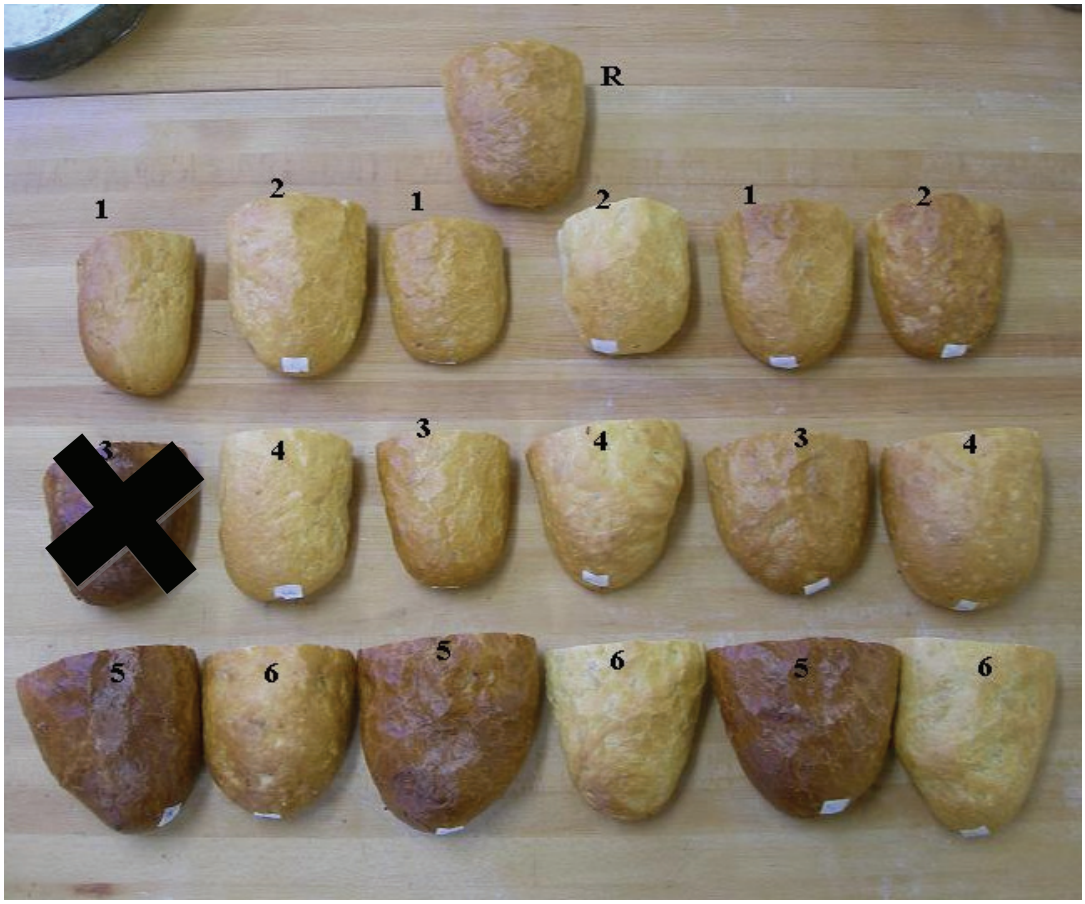

Figure 20. The baking result. R= the bread from the original flour (Reform I); 1= fine fraction from 6500 rpm; 2= coarse fration from 6500 rpm; 3= fine fraction from 5000 rpm; 4= coarse fraction from 5000 rpm; 5= fine fraction from 8000 rpm and 6= coarse fraction from 8000 rpm. The bread being crossed over was not representative due its dark color which was a result from too high oven temperature.

6 Conclusion

The result from the study verifies that protein content in wheat flour can be altered by air-classification. The effect of the rotational speed on the protein content was evident.

To obtain protein rich fractions from air-classification (~17 % DM) that has good bread making properties the rotational speed has to be high, approximately 8000 rpm. The obtained bread volume was larger than the volume for the bread made with the original flour. The wet gluten content and the protein sedimentation test were the highest for the fine fraction from 8000 rpm. The dough stability was long and the degree of softening was small showing that the fine fraction from 8000 rpm can stand long mechanical treatment which is a valuable characteristic for a flour blend made for the bread industry. The overall quality is though not optimal due to the extremely long dough development time and the stickiness of the dough. These characters may be problems for the bread manufacturers. The yield of this fraction was also very low. The least op-

timal flour fractions were the fine and the coarse from 6500 rpm because of the low volume obtained and the weakness of the protein in both these fractions. The coarse fraction from 5000 rpm also showed a rather high bread volume and wet gluten content as well as high dough stability. The volume was however still lower than the volume of the bread made with the original flour and was not significantly larger than the loaves made with the corresponding fine fraction. With the purpose to produce bread with large volume this fraction is therefore not an optimal choice.

6.1 Future aspects

There might be a rotational speed more beneficial than 8000 rpm for baking purposes. Therefore comparing the products from 8000 rpm with products from other high rotational speeds could be of interest in order to optimize the fraction yield and quality of the fractions. It might also be of interest to repeat the same experiment with different flours such as low protein quality flour or flour with lower extraction rate. Changing the original flour could perhaps have an impact on the stickiness of the dough or the darkness of the crust color.

Since the fraction yield was low for the fine fraction from 8000 rpm and the dough produced was inconvenient it might be interesting to investigate if this fraction can be added to other commercial flour blends to raise the protein content and at what concentrations it could be useful. It could also be interesting to compare the addition of this fine fraction with addition of commercial gluten. The surplus of coarse fraction is also a factor to consider and a fraction to find a sector of application for.

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