Effect of Cysteine on different Durum wheat flour fractions. Relationships between descriptive rheology and baking properties

By

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Abstract

The effect of cysteine on different durum wheat flour fractions was studied. Also, the relationships between descriptive rheology and breadmaking performance were examined. An industrial vertical vibro-sifter was used to sieve the Straight run durum flour and four fractions were obtained. In addition an industrial roller mill was used to regrind the coarse flour fraction in order to examine the impact of severe grinding. The sieve analysis showed a wide particle size distribution. The finer particles were related to higher starch damage content, lower wet gluten, lower Zeleny sedimentation volume and lower Falling Number. Analysis showed that flour particle size affected the dough behavior during fermentation but the impact on loaf volume was not critical.

Two improver formulations were used in the baking tests, called Improver A and improver B, the only difference between them was that the improver B contained 12ppm of L-cysteine. At the fermentation stage the addition of L-cysteine had a positive impact on dough expansion only on coarse flour (200μm>), while the rest fractions were not affected. The L-cysteine had a positive impact on gas formation rate on a fraction of medium size particle size (between 110μm and 200μm). Also the L-cysteine had a positive impact on loaf volume on the finest flour fraction (110<μm), on the coarse and on the reground flour, while the loaf volume of rest fractions was not affected.

A number of descriptive rheology tests were used in order to assess their predictive power on dough breadmaking performance. The results showed that the predictive ability of Farinograph on loaf volume was limited. The Consistogarph constant hydration protocol was significantly correlated with baking quality, while Consistograph adapted hydration protocol showed poor relationship with breadmaking properties. In order to assess the effect of dough consistency and the mixing procedure on biaxial extension profile as it is measured by the Alveograph four different dough mixing preparations were adopted. Results have shown that all the Alveographic modifications adopted in this study were poorly related with breadmaking performance. In contrast Rhermentometer test parameters were strongly related with loaf volume.

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Abbreviations and Symbols

Fractions abbreviations:

- CO = Coarse untreated
- COA = Coarse treated with improver A
- COB = Coarse treated with improver B
- FI = Fine untreated
- FIA = Fine treated with improver A
- FIB = Fine treated with improver B
- MI = Mid fine untreated
- MIA = Mid fine treated with improver A
- MIB = Mid fine treated with improver B
- RE = Regrind untreated
- REA = Regrind treated with improver A
- REB = Regrind treated with improver B
- SR = Straight grade flour untreated
- SRA = Straight grade flour treated with improver A
- SRB = Straight grade flour treated with improver B
- SU = Super fine untreated
- SUA = Super fine treated with improver A,
- SUB = Super fine treated with improver B

Rheological and physicochemical Parameters abbreviations: Alveograph

- AW = Water absorbing capacity, defined by Farinograph
- BA = P/L adopted, configuration ratio of the adopted method
- BF = P/L configuration ratio of the Alveograph Alveo- Farino method
- BI = P/L configuration ratio of the Alveograph Interupted method
- BS = P/L configuration ratio of the Alveograph standard method
- CD = Mixing stability, defined by Farinograph
- D250 = Pressure drop in mb after 250sec, defined by Consistograph
- D450 = Pressure drop in mb after 450sec, defined by Consistograph
- DT = development time, defined by Farinograph
- FA = PrMax maximum dough pressure recorded by Consistograph adopted hydration method
- FC = PrMax maximum dough pressure recorded by Consistograph constant hydration method
- GL = Wet gluten content

- LA = L, extensibilty defined by the Alveograph adopted method
- LF = L extensibilty defined by the Alveograph Alveo- Farino method
- LI = L extensibilty defined by the Alveograph interrupted method
- MT = mixing tolerance, defiend by the Farinograph
- PA = P tenacity defined by the Alveograph adopted method
- PF = P tenacity defined by the Alveograph adopted method
- LS = L extensibility defined by the Alveograph standard method
- PI = P tenacity defined by the Alveograph interrupted method
- PS = P tenacity defined by the Alveograph interrupted method
- TFA = TPrMax, time needed for dough maximum stiffness as defined by the Consistogarph
- WA = W deformation energy defined by the Alveograph adopted method
- WF = W deformation energy defined by the Alveograph the Alveo-Farino method
- WI = W deformation energy defined by the Alveograph interupted method
- WS = W deformation energy defined by the Alveograph interupted method
- ZS = Zeleny sedimentation

Rheofermentometer and Breadmaking Parameters abbreviations:

- Hm= Maximum development reached by the dough
- h = Dough volume at the of fermentation,
- Hmd = Difference in dough volume between maximum development and at the end of proving
- T1 = Time required for maximum development
- HG = H'm gas production curve
- TG = Time required to reach the maximum point of the HG curve
- Tx= Time when the dough begins to give off CO2
- RET = Gas still retained within the dough at the end of the test
- TV = Total volume of gas produced during the test
- ML = Dough length after moulding
- MW = Dough width after moulding
- FW = Dough length at the end of proving
- MW = Dough width at the end of proving
- BL = Loaf length
- BW = Loaf width
- BH = Loaf height
- VOL = Loaf volume

CHAPTER 1. GENERAL INTRODUCTION

1.1. WHEAT

Cereals have been cultivated since 8000BC. Wheat is grown annually on about 215 million hectares making it more widely grown than any other cereal. Wheat is regarded as the most important food grain since it provides about 20% of the total food calories to the people of the world (Bushuk and Scanlon, 1993). Among grains, wheat is unique because its proteins have the ability to form gluten (Bushuk, 1998). The gluten network trap the gas produced from yeast fermentation and contribute directly to the cellular structure of the bread (Cauvain, 2012).

All wheats belong to the genus Triticum and are divided into three groups according to number of chromosomes sets in their genome. These groups are diploid, tetraploid and hexaploid. The major classes are hexaploid and tetraploid, durum is the most important specie of the tetraploid wheat and common wheat is the general name of the hexaploid wheat (Bushuk and Scanlon, 1993; Cornell, 2012).

1.2. DURUM WHEAT PRODUCTION

Durum wheat is a minor cereal crop. It represents 5% of the total wheat crop (Table 1-1).

Table 1.1 Worldwide grain production, total cereal include barley, oats, triticale and rye

Million tons	**11/12**	**12/13**	**13/14**	**14/15 estimated**
Wheat	695	655	714	720
of which durum	37	35	38	33
Corn	875	866	997	1003
Total cereal	1850	1795	2006	2015

Source: International Grain Council
Note: Data published in December 2015

The common wheat is cropped everywhere in the world except in the tropical areas. Whereas durum wheat is mainly cropped in 3 main areas: Mediterranean, North plains between USA and Canada and in the desert areas of South West of USA and northern Mexico. The reason is that a relative dry climate with hot days and cool nights especially

during harvesting period favor durum wheat vitreosity and color (Grant et al., 2012). The 60% of the durum wheat crop is produced in the Mediterranean basin (Abad et al., 2004). The European Union is the largest producer and consumer of durum wheat (Grant et al., 2012), with the production concentrated in Italy, France, Spain and Greece which account together for about 80% of the durum wheat produced in the European Union. (Table 1-2).

Table 1-2. Worldwide durum wheat productions for 2014/15.

Million tons	**2014/15 estimated**
World total	**32.6**
EU	7.1
France	*1.5*
Greece	*0.8*
Italy	*3.7*
Spain	*0.8*
Kazakhstan	2.0
Canada	5.2
Mexico	2.3
USA	1.4
Argentina	0.3
Syria	0.8
Turkey	2.1
India	1.3
Algeria	1.3
Libya	0.1
Morocco	1.4
Tunisia	1.3
Australia	0.5
Others	5.7

Source: International Grain Council
Data published in December 2015

French wheat is considered as the best wheat produced in EU and is ideal for pasta and breadmaking. Italy is by far the largest consumer of durum wheat since it is the biggest pasta maker in the world. Canada is the second largest durum wheat producer and the

largest exporter. Durum wheat from Canada and USA is considered of high quality. Mexico is an important producer. North Africa countries, Turkey, Australia and Kazakhstan are also significant producers of durum wheat.

1.3. DURUM WHEAT AND BREADMAKING

Common wheat is the raw material of choice for leavened or flat bread. Durum wheat is preferred for pasta making, because its rheological properties are essential for pasta making and cooking quality (Feillet and Dexter, 1996). Moreover durum wheat is also used to produce foods such as couscous and bulgur, breakfast cereal and desert (Boggini et al., 2012). In addition it is also used for traditional leavened and flat breads, especially in Mediterranean countries (Quaglia 1988). According to Quaglia (1988) more than 70% of the durum wheat produced in some Middle Eastern countries is used for breadmaking. In Greece it is used in a great extent for making bread. For example the most popular bread in Greece is the "Choriatiko" which is prepared from solely from durum wheat flour (figure 1-1). In Italy more than 10% of the durum wheat consumed is destined for bread production (Palumbo et al., 2000). Its use is increasing in many other countries such as Russia, France and Canada (Boggini et al., 2012)

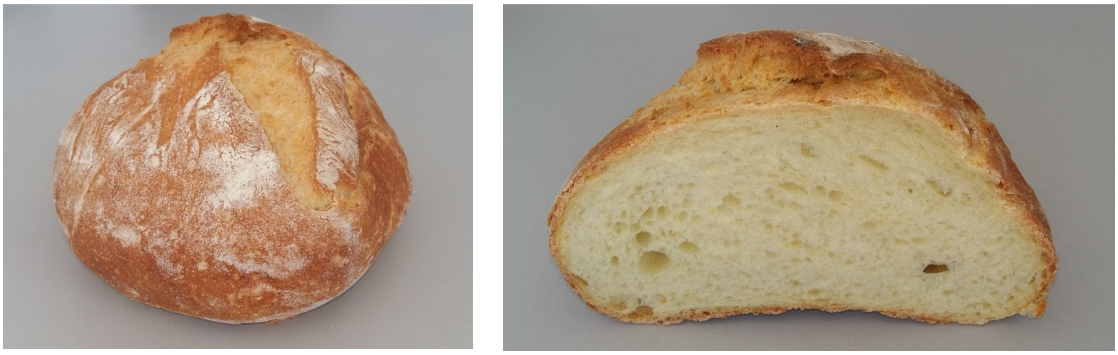


Figure 1-1. "Choriatiko" Greek traditional durum wheat bread

There is a general agreement that durum flours produce smaller loaf volumes than those of common wheat. Moreover the crumb has a yellowish color, uniform crumb structure, nutty taste and the crust color is usually darker compared to bread made from common wheat (Liu et al., 1996).

1.4. AIM AND SCOPE

Durum wheat is commonly used in traditional specialty breads in Mediterranean countries. Many studies have shown that the physicochemical and rheological properties of durum wheat have a significant impact on the breadmaking performance (Boggini and Pogna, 1989; Boggini et al., 1995; Boyacioglu and D'Appolonia, 1994; Pena et al., 1994; Dexter et al., 1981, 1994; Edwards et al., 2007; Sapirstein et al., 2007). In addition the quality of durum wheat is heavily affected by agronomic practices, environment conditions and location (Fortini et al., 1975; Hadjichristodoulou, 1979). The rheological properties of the durum wheat and the major varation in quality explain why these breads are not produced in industrial level (Sissons, 2008). There is a considerable interest in increasing the commercial appeal of durum wheat flour. Durum wheat flour with good and consistent baking quality is a desirable goal for farmers because in years of high production durum wheat would have alternative markets. Moreover the cost associated with quality inconsistency will be decreased for the millers and the bakers.

The study reported in this thesis is aimed to deliver clarity of information of the influence of durum wheat flour physicochemical properties and the impact of L-cysteine on dough rheology and breadmaking performance. In addition it is aimed to examine the relationship between the physicochemical and empirical rheology tests with the durum wheat flour baking quality.

The objectives of this study are

1. To examine the relationship between durum flour particle size with the physicochemical properties and the impact of granulation on bread making performance.
2. To asses the impact of L-cysteine on dough rheology and on breadmaking performance
3. To examine the relationship between commonly used empirical rheology tests with physicochemical properties and with bread making performance.
4. To examine the if the relationship of the Alveograph method with the breadmaking performsnce would be improved by modifying the dough mixing procedure

1.5. THESIS STRUCTURE

This thesis sets out the current knowledge relevant to the topic of durum wheat flour and breadmaking and other chapters give the experimental details of the work undertaken.

Chapter 2, of this thesis reviews the durum flour properties and various ingredients used in a bread recipe. Additionally physicochemical and empirical tests commonly used for flour evaluation are reviewed.

Chapter 3, reports the material and methods used in this study.

Chapter 4, reports the effects of durum properties and L-cysteine on baking quality.

Chapter 5, reports the relationship between the rheological tests and the properties of the durum wheat flour.

Chapter 6, reports the relationship between the rheological tests and the breadmaking performance.

Chapter 7, gives a general conclusion of all the results and recommendations are made for future work.

CHAPTER 2. DURUM WHEAT FLOUR COMPOSITION, IMPROVERS AND DOUGH ASSESMENT METHODS

2.1. INTRODUCTION

Bread is a major staple foodstuff and breadmaking is a millennia old process. Today, numerous bread types are produced and depend on the wheat type, the process employed and the ingredients used. The flour used for breadmaking is mainly derived from common wheat. However durum wheat is also used for breadmaking especially in the Mediterranean countries. Durum wheat breadmaking performance is affected by its physicochemical properties, the milling process, the breadmaking method and the improvers used. This section provides an overview of the durum wheat milling, the key components of the durum flour and the improvers commonly used. Additionally this section provides an overview of some empirical rheology and physicochemical tests commonly applied to assess the flour quality.

2.2. MILLING

The aim of the miller is to extract flour as much as possible from the kernel with the minimum bran and ash contamination (Campbell et al., 2007). Moreover flour quality consistency is of utmost importance (Webb and Owens 2003). Despite the recent advances in wheat breeding and farming the quality of the wheat delivered at the mills is not consistent (Whitworth, 1999). Agronomic practices, weather conditions and location affect the wheat quality and consistency. Therefore the wheat quality differs from year to year, from place to place and from farmer to farmer. This makes the task for consistent flour quality very tough for the miller.

Wheat milling is regarded as gradual process, which can be divided in two major sections. The breaking section and the reduction section (Figure 2-1). The primary object of the break section is to separate the endosperm from the bran into fairly large pieces, however some flour will be produced during the fracture process. The ‘break flour’ and large bran particles are sifted by the plansifters while the endosperm stocks called semolina are

directed to the purifiers. Purifiers clean the semolina from the light bran and they separate the semolina according to its particle size (Bushuk and Scanlon, 1993). Pure endosperm is directed for reduction, clear bran is sent to the collecting bin and the pieces of bran sticking to endosperm are sent to the late passages of the break system for further processing. In the reduction section the flour and semolina is ground several times in order to meet the specified particle size. Durum wheat can be milled into flour in a conventional mill, as shown in figure 2-1 and as described briefly above or, it can be milled in a durum semolina system. The primary object of semolina milling is the high extraction of pure semolina and the minimal production of flour. Semolina milling systems traditionally have longer roll surfaces than the conventional systems used to grind common wheat. This is because by reducing gradually the durum kernel the production of flour is minimized. The purification system has a pivotal role in the durum mill because the purifiers are the primary separators of the finished product and not the plansifters as in conventional mills (Fowler, 2014). The produced semolina is then remilled gradually two or three times in order to be reduced into flour with particle size below 200μm (Gruber, 2010).

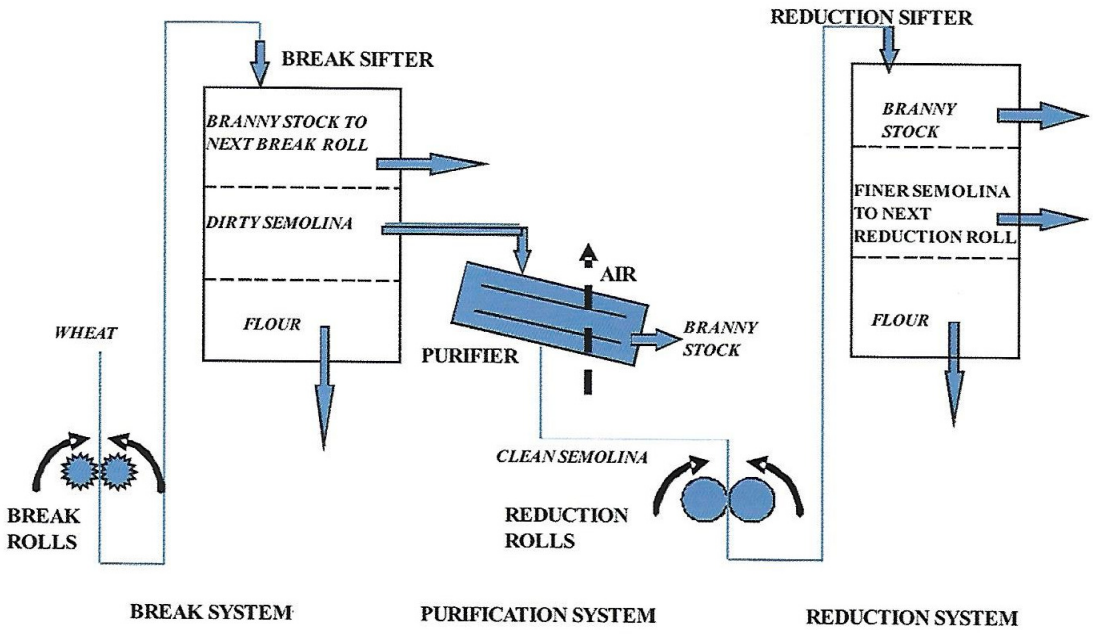


Figure 2-1. Mill operation (Nabim Handbook, 2011)

Wheat kernel hardness dictates the milling operation and has a critical impact on flour yield and particle size (Eliasson and Larsson, 1993). According to Pomeranz and Williams (1990), kernel texture is the second most important wheat quality characteristic after gluten strength. Since kernel hardness is positively related with milling performance,

energy consumed during milling, protein content, starch damage, water absorption and gassing power. Wheat hardness is a genetic trait and it is governed by the degree of the adhesion between starch granules and protein. Greenwell and Schofield (1986) have found that a low molecular weight protein called friabilin is present in the surface of the starch granule of soft wheat, while it is totally absent or in very low levels in hard wheat. It is suggested that friabilin is responsible for the texture of soft wheat. However friabilin is coded by a genome which is absent in the tetraploid durum wheat. This explains why starchy durum wheat kernels are as hard as the hardest common wheat (Dexter et al., 1986).

Environmental conditions and agronomic practices have major impacts on wheat quality characteristics and this is particurarly evident for durum wheat kernel vitreosity. It was found that insufficient nitrates during grain development have a negative impact on durum wheat vitreosity (Sallans and Simmonds, 1954). According to Hadjichristodoulou (1974) genotype and environment affects durum wheat vitreosity. Moreover rainfalls around harvest have a significant negative impact on vitreosity. Durum vitreosity is of utmost importance in wheat trading. Since, durum wheat colour is an important quality characteristic for the pasta makers and bakers. The endosperm of starchy kernels is completely white, while in partly starchy kernels there are vitreous and starchy areas (Figure 2-2). In addition less vitreous kernels are softer (Dexter 1988) leading to lower yield of semolina and higher yield of flour.

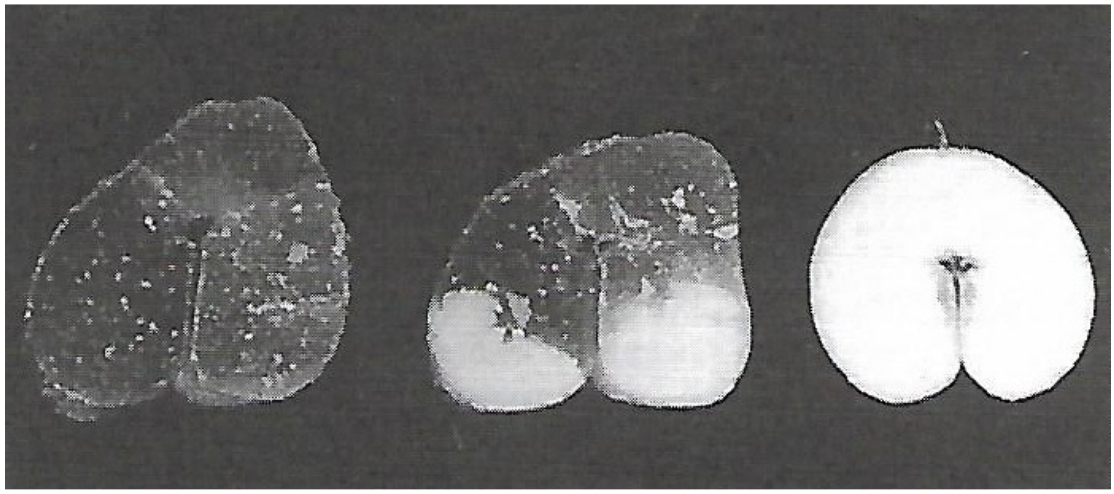


Figure 2-2. Cross section of wheat kernels showing varying degrees of vitreousness (Bushuk, 1998)

2.3. WHEAT FLOUR COMPOSITION

2.3.1. Starch

Starch represents the largest portion of wheat endosperm, making up to 70% of wheat flour (Stone, 1996). It is composed of polysacchrides of only one monosaccharide with some proteins and lipids (Chibbar et al., 2005). The glucose polymers, amylose and amylopectin are the major components of the starch. Amylose is a linear molecule of α-D-glucose linked by α—1,4 bonds. Amylopectin is a highly branched polysaccharide. It is composed of α-D-glucose linked by α-1,4 bonds which are interlinked by 1,6 bonds (Zobel, 1988). The typical levels of amylose and amylopectin in wheat starch are 25-28% and 72-75% respectively (Colonna and Buleon, 1992). The amylose/amylopectin ratio of durum wheat starch is similar to common wheat starch, with slight higher amylose content (Dexter and Matsuo 1979, Delcour et al., 2000).

The levels of lipids in wheat starch are between 0.5 and 1 % and they are generally polar, lysophospholipids and free fatty acids (Delcour and Hoseney, 2010). Polar lipids are positive related with the amylose content (Eliasson and Larsson, 1993). Starch gelatinization and retrogradation characteristics are affected by the presence of polar lipids (Eliasson and Gudmundson, 1996). Studies have shown that starch of durum wheat has slightly lower onset gelatinization temperature and the time needed to reach peak viscosity is lower compared to hexaploid wheat (Delcour et al., 2000). This may suggests that durum wheat contains more lipids (Lafiandra et al., 2012).

Durum wheat, like common wheat shows a bimodal starch particle size distribution. The small B- granules are spherical in shape with mean diameter of 5μm. While the large A-granules are lenticular with a mean diameter of 20μm (Moon and Giddings, 1993). Wheat starch is composed of about 24% B-granules (Soulaka and Morrison, 1985a,b). A study conducted by Soh et al. (2006) on durum wheat starch showed that the proportion A to B granules affected the dough rheology. By increasing the B starch granule content the water absorption capacity was increased. It was also found that the level of B-granules were negative related with peak viscosity whereas they were positively related with gelatinization temperatures.

It is widely accepted that starch has a critical impact in bread making (Hibberd, 1970). Granular and damaged starch granules absorb approximately 46% of the water in dough (Bushuk, 1998). Starch properties affect the dough behavior during mixing, fermentation and baking. The proportion of A and B granules and the starch damage content affect the dough rheology to a great extent. Starch provides yeast with fermentable sugars and plays an important role on crumb texture and crust color (Eliasson, 2012).

2.3.2. Wheat proteins

The wheat proteins content ranges from about 10-18% of wheat flour on a dry basis and despite being a minor component the protein is a major factor in determining the bread quality. When wheat proteins mixed are with water they have a unique ability to form a cohesive viscoelastic network which is able to retain gas during proof and to form a stable aerated crumb structure (Ewart, 1989). Osborne (1907) proposed a classification of wheat proteins based on their solubility in specific solvents: albumins in water, globulins soluble in salt solution, prolamins in aqueous ethanol and glutelins in diluted acid or alkaline solutions.

Gluten proteins account for about 80% of total proteins in wheat and are important since they give the viscoelastic properties of the dough. Gluten proteins are classically divided into two main fractions according to their solubility, the gliadin which is alcohol soluble and the glutenin which is alcohol insoluble.

2.3.2.1. Gliadins

Gliadins are mainly monomeric with molecular weights varying from 28,000 to 55,000 Daltons (DA) (Wieser, 2012). These proteins can be separated by polyacrylamide electrophoresis at low pH into four sub categories, α, β, γ, and ω gliadins (Woychick et al., 1961). The α, β, γ gliadins are stabilised by disulphide bonds and hydrogen bonds, while hydrophobic interactions stabilize the ω gliadins.

It is generally considered that the gliadin fraction contributes to dough viscosity and extensibility and thereby to dough expansion during fermentation. However their impact in baking performance is less important compared to glutenin fraction (Mac Ritchie, 1980).

2.3.2.2. Glutenins

It is generally considered that the glutenin fraction has a prominent role on baking performance. Glutenins are cohesive, elastic and thereby they affect the dough strength and elasticity (Islam at al., 2012). The molecular weights of the glutenins varying from about 80,000 DA to several millions (Wieser, 2012; Goesaert et al., 2009). The glutenin polymers are composed of a variety of glutenin subunits (GS), which are linked via disulphide bonds (Goesaert et al, 2006). The glutenin subunits can be divided into four groups: high molecular weight glutenin subunits (HMW-GS) with molecular weights varying from 65,000 to 90,000 DA and B-, C- and D- type low molecular weight glutenin subunits (LMW-GS) with molecular weights varying between 30,000 and 60,000 DA.

2.3.2.3. Gluten proteins in breadmaking

The combination of water addition into flour and the mechanical energy input leads to the formation of a continuous cohesive visco-elastic network (Singh and MacRitchie, 2001). The time need for full dough development and the dough resistance during mixing, is highly related with the gluten properties. Furthermore the gluten properties determine into a great extent the gas retention capacity of the fermenting dough (Gan et al., 1995). It is generally accepted the flour breadmaking performance is greatly affected by two factors.

The first factor is the gliadin to glutenin ratio of the gluten proteins. Glutenins due to their large size form a continuous network which determines the dough strength and elasticity (Belton, 1999; Ewart, 1972). While the monomeric gliadins determine the dough extensibility (Hoseney 1986). Wasik and Bushuk (1975) found that high glutenin to gliadin ratio was highly correlated with dough strength. Their findings were confirmed by later studies which proved that by increasing the glutenin to gliadin ratio the dough strength is increased (Uthayakumaran et al, 1999; Edwards et al., 2003). However for optimum breadmaking performance an appropriate balance between viscosity/extensibility and elasticity is required. The gluten strength is positive related with loaf volume. However the dough expansion during fermentation will be limited if the dough is too strong and inextensible (Goesaert et al., 2005).

The second factor is the quality of the glutenin polymer. Quality aspects like glutenin composition, structure and size distribution have a critical impact on breadmaking performance. For example the gluten elasticity maybe affected by the difference in

glutenin composition and the resulting non-covalent bond interactions (Goesaert et al. 2005). In addition it has been supported that the gluten elasticity is related with the size of glutenin polymer network (Mac Ritchie, 1992). It has been identified that the size of the glutenin network and the dough strength/ breadmaking performance are positive related (Singh and MacRitchie, 2001; Veraverbeke and Delcour, 2002).

2.3.2.4. Durum wheat gluten quality parameters

The poor breadmaking performance of durum wheat is highly related with the gluten quality parameters (Lafiandra et al., 2000). The largest part of durum wheat harvest is used in the production of pasta (Lafiandra et al., 2012). Therefore durum wheat breeding programs focus on quality factors that are critical for pasta making (Sissons, 2008). Studies showed that protein content is positive related with pasta quality (Dexter et al., 1983; Feillet and Dexter, 1996). Whereas others, showed that the protein strength is the primary factor which determines the pasta quality (D' Egidio et al., 1990; Edwards et al., 1993). The above findings explain why durum wheat breeding programs pay equal attention to protein content and strength (Sissons, 2008). The inelastic properties of the durum wheat gluten allow pasta to maintain its shape during the extrusion and drying process (Fowler, 2014). Durum wheat cultivars which exhibit very strong gluten characteristics are not well suited for high volume breads, because they usually exhibit tenacious and inelastic gluten (Quaglia, 1988). As it was noted earlier, an optimum breadmaking performance requires an appropriate balance between dough strength and extensibility. A number of studies have demonstrated that the durum wheat gluten composition have a critical impact on breadmaking quality.

Studies conducted on Italian cultivars showed that durum wheat cultivars with gliadin γ-42 associated with weak gluten and low loaf volume, whereas cultivars with gliadin γ-45 associated with stronger gluten and higher loaf volume (Boggini et al., 1988; Spina et al., 2003). Several studies have found that the gluten weakness and the low loaf volume of durum wheat are associated with the presence of high molecular weight glutenin subunit HMW-GS20 (Edwards et al., 2007; Dexter 2008; Carrillo et al., 1990; Ammar et al., 2000).

Genetically durum wheats are tetraploids and lack D genome found in hexaploid wheats (Edwards et al., 2007; Sapirstein et al, 2007). Kerber and Tipples (1969) demonstrated

that the removal of D genome from common wheat had a negative impact in the breadmaking performance of common wheat. Radaelli et al (1997) showed that the reduced extensibility and elasticity were greatly improved by the incorporation of D genome.

In addition durum wheat has high proportion of LMW-GS and low of HMW-GS compared to common wheat (Lafiandra et al., 2012). As it was noted earlier the amount of HMW-GS is related with the glutenin polymer size and the latter is positive correlated with gluten strength, elasticity and breadmaking performance.

The work of Redaelli et al. (1997) showed that a promising strategy in order to improve the baking performance of durum wheat is to incorporate the D genome of common wheat to durum wheat. Breeding wheat suitable for both bread and pasta would increase the potential use of durum wheat. This has motivated many institutions in Italy and Canada, to develop breeding programs for dual purpose durum wheats. Another promising strategy is to cross strong durum wheat lines with weaker emmer (Triticum dicoccum). Schlichting et al (2003) reported that these crossed samples showed dough extensibility and loaf volume increase, while the pasta cooking quality was improved.

2.3.3. Non Starch Polysaccharides

Non Starch Polysaccharides (NSP) is the generic term used in the cereal science for arabinoxylans (AX), β-glucan, cellulose and arabinogalactan- peptides (Delcour and Hoseney, 2010). The Non Starch Polysaccharides found in durum wheat account for 3-8% of the grain. It should be noted that common and durum wheat exhibit similar values of NSP (Stone, 1996). Arabinoxylans are by far the most important group of the NSP (Mares and Stone, 1973 a, b,) and have a critical impact on flour breadmaking properties. Arabinoxylans are classified into water extractable (WE-AX) and water unextractable (WU-AX). Studies conducted in durum semolina by Lemperreur et al., (1997) have shown that AX contents ranged between 0.58 and 3% and about one quarter was WE-AX.

When water extractable arabinoxylans are added to the dough stiffness and resistance to extension are increased while mixing time and extensibility are decreased (Jelaca and Hlynka, 1971). The higher the molecular weight of WE-AX the greater the effects on dough properties (Biliaderis et al., 1995; Courtin and Delcour 1998,). When WU-AX are

added to the dough have similar effect as the WE-AX (Jelaca and Hlynka, 1971). In addition WU-AX increase substantially the dough absorbing capacity (Courtin et al., 1999). According to literature WU –AX have a negative impact on optimal gluten development during fermentation and therefore dough stability during fermentation is negative related with WU-AX (Goesaert, 2005). Whereas WE-AX contributes positive to dough gas retention capacity during fermentation (Hoseney, 1984). It has been suggested that the WE-AX increase the viscosity of the dough liquid phase and this contributes to the gas cell stability (Gan et al., 1995).

2.3.4. Lipids

Lipids are important components, despite being only about 2.5% of the wheat flour (Morrison, 1988). Lipids are classified as starch lipids and free and non-bound non-starch lipids (Eliasson and Larsson, 1993). The former exist as amylose inclusion complexes in the starch fraction (Morrison, 1978). Non starch lipids refer to all other lipids in the flour and can be divided into polar and non-polar lipids. Polar lipids include glycolipids and phospholipids while non-polar lipids include triglycerides, diglycerides and mono acyl glycerides (Eliasson and Larsson, 1993). Non starch lipids in durum semolina represent 64%of the total lipids (Sissons, 2008).

It should be noted that only non-starch lipids are important in the initial stages of breadmaking, since starch lipids are tight bonded by starch and therefore are unavailable during the dough proving and at the early stages of baking (Goesaert et al., 2005). Studies have shown that non-polar lipids, triglycerides and free fatty acids have a negative impact on dough stability and loaf volume (Mac Ritchie and Gras, 1973). Whereas polar lids such as phospholipids and glycolipids at higher concentration improve dough tolerance and bread volume, and crumb structure (Mac Ritchie, 1977; Dubreil et al., 1997; Graybosh et al., 1993).

2.4. IMPROVER

For the work discussed in this dissertation improvers containing of ascorbic acid and enzymes have been used. L-cysteine was added to one type of improver

2.4.1. Ascorbic acid

Ascorbic acid has been widely used as an oxidant in the baking industry. In the EU it is the only permitted oxidant for use in breadmaking (Cauvain and Young, 2002). In terms of it chemistry ascorbic acid is a reducing agent, but exerts an effect similar to oxidants (Weiser, 2012). Ascorbic acid is converted to dehydroascorbic acid (DHA) by an enzyme naturally present in the flour named ascorbic acid oxidase. In order for this reaction to occur oxygen is necessary and is entrained in the dough during mixing. There are two theories for the mechanism of the ascorbic acid improver effect on dough and bread. The first proposes that DHA will oxidise the end standing glutenin thiols produced by reductants and sulfhydryl -disulphide interchange reactions during mixing and interproteins disulphide bonds will be formed (Every et al., 1999). The second theory proposes that DHA will rapidly oxidise at early stages of mixing the naturally present glutathione which otherwise will cause dough weakening by sulfhydryl-disulphide interchange reaction with gluten proteins (Grosch and Wieser, 1999).

Since ascorbic acid oxidation is oxygen dependent the amount of air incorporated during mixing affects the rate of oxidation (Wieser, 2012). Therefore the mixer type heavily affects the rate of conversion of ascorbic acid to DHA (Marsh, 1998). The action of ascorbic acid is restricted during fermentation because yeast will consume all the available oxygen (Chamberlain, 1979). Ascorbic acid is routinely added to wheat flour due to its strong positive effects on dough stability and loaf volume (Wieser 2012, Yamanda and Preston, 1992).

Ascorbic acid is applied in a range of 20-75g per 100kg of flour for straight dough breadmaking, while larger amounts are required for the Chorleywood breadmaking process.

2.4.2. Cysteine

Cysteine is a simple amino acid and is the most common reducing agent used in breadmaking (Millar and Tucker 2012). L-cysteine breaks the disulphide bonds and changes them to sulfhydryl groups (Wieser 2012). The breakage of disulphide bonds reduces the molecular weight of the glutenins distribution (Staufer 1990; Wrigley et al., 1998). The depolymerisation of the glutenins subunits have a critical impact on the mechanical and rheological properties of the dough (Fitchet and Frazier, 1986), the dough viscosity and elasticity are reduced. The time required for full dough development during mixing is lowered if a proportion of disulphide bonds broken by the reducing agent. In addition L-cysteine increases dough extensibility and reduces dough stiffness. Moreover it helps dough moulding and shape forming without structural damage (Goesaert et al., 2005). The reaction time of L-cysteine is very fast and its effects on dough rheology are quite evident at the early stages of mixing. (Haagens, 2006).

L-cysteine is often used in very strong flours which exhibit stiff dough with low extensibility. The dough softening favors the air inclusion during mixing and thereby the dough development rate is accelerated and the loaf volume is increased (Cauvain and Young, 2001, Goesaert et al., 2005; Weiser, 2012). Moreover it is often used in the production of pizza in order to reduce dough shrinkage. For the same reason, used in the production pastry products like puff pastry and croissants. L- cysteine is routinely used in production of biscuits as dough softener.

Cysteine is usually used in its hydrochloride form since it has better water solubility (Cauvain and Young 2001). It is applied at levels between 10 and 70mg per kg of flour. The use of L-cysteine requires extra care since excessive gluten weakening can cause dough instability during fermentation and a loaf with lower volume and poor crumb structure (Haagens, 2006). In addition over treatment may produce sticky dough that is difficult to handle (Fitchett and Frazier, 1986).

2.4.3. Enzymes

Enzymes have been widely adopted by the milling and baking industry. The objectives of the application of enzymes in baking technology is the optimization of the flour properties and the improvement of dough breadmaking performance (Barret, 1975; Dubois, Hammer, 1992). The effects that can be achieved by using enzymes are the

increased rate of fermentation, dough machinability, stability during proving, increased bread volume, crumb structure, crust coloration and extended shelf life.

Over the years enzymes gained importance as ingredients in the baking industry for several reasons:
Reduction of processing cost
Enzymes allow millers and bakers to cope with flour fluctuation
Enzymes can improve the commercial appeal of the final product by replacing ingredients like emulsifiers, oxidizing agents and sugar
Enzymes are considered as processing aids and do not have to be listed on final product label (Kornbrust and Matveeva, 2012)
The enzymes are used in order to produce functional changes on the flour components. Amylases attack starch, proteases and oxidases modify the protein, pentosanases the pentosanes and lipases the lipids (Kulp, 1993)

The rate at which enzymic reaction occurs is affected by several factors such as: pH, temperature, substrate concentration, enzyme concentration and enzyme inhibitors.

2.4.3.1. Amylases

For decades, amylases have been extensively used in the breadmaking industry. Amylases hydrolyse gelatinised or damaged starch and are generally ineffective on native starch granules. (Kulp, 1993). Alpha-amylases randomly hydrolyse the α-1,4 linkages of starch into smaller components known as dextrins. The dextrins serve as substrate for β-amylase to convert the starch to individual maltose molecule which can be used by yeast for CO2 production (Cauvain and Young, 2002; Popper, 2006). Alpha and β-amylases are endogenously present in flour. Alpha-amylase activity can vary depending on wheat growing, climatic and harvesting conditions (Goesaert at al., 2005). Whereas, wheat flour usually contains sufficient levels of β-amylase (Drapron and Godon, 1987). For this reason flour is routinely supplemented with α-amylase in order to favor the production of fermentable and reducing sugars (Bowels, 1996). Thereby α-amylase enhances the gas production and improves the crust color. Moreover by hydrolyzing the damaged starch, α-amylase reduced the water holding capacity thereby the released water favor the gluten development. In addition, at the early stages of baking α-amylase delaying the viscosity

increase due to amylase leaching during gelatinization (Kragh, 2003), thereby the oven spring is prolonged and the loaf volume is increased (Goesaert et al., 2005).

The traditional source of α-amylase for breadmaking was from malted barley. Today it is more common to use either fungal α-amylase from aspergillus oryzae or bacterial α-amylase (Cauvain and Young, 2002). The main difference between fungal and bacterial α-amylase lies with their heat stability (Williams and Pullen, 1998). Fungal α- amylase have low thermostability and it is inactivated approximately at 70°C, while bacterial α-amylase is very thermostable and may survive the baking process (Goesaert et al., 2005). Therefore millers and bakers prefer fungal α-amylase since it is less sensitive to overdosing (Bowels, 1996).

2.4.3.2. Xylanases

Wheat flour contains 1-3% pentosans, of which 75% are arabinoxylans. It was found that the conversion of water unextractable arabinoxylans to water extractable arabinoxylans had a positive impact on dough breadmaking properties (Hilhorst al., 2002; Goesaert et al., 2005). This can be obtained through the use of microbial endoxylanases i.e. enzymes that hydrolyse xylose backbone internally (Goesaert et al., 2005). Today, microbial endoxylanases have gained importance in the baking industry. It has been proved that by adding minute quantities of the said enzymes the dough properties are improved in terms of elasticity, extensibility and stability during fermentation, moreover the loaf volume is increased (Ronan et al., 1994; Sprossler, 1997; Courtin et al., 2001).

Different endoxylanases have different affinities for WU-AX and WE-AX. It is understood that endoxylanases that have higher affinity for the WU-AX have greater positive impact on dough and bread properties (Courtin et al., 2001). Excessive levels of endoxylanase result in sticky and very soft dough and loaf with large and asymmetrical gas cell distribution and volume (Goesaert et al., 2005).

2.4.3.3. Lipases

Surface active materials like emulsifiers are traditionaly used in order to stabilize the gas cells at the late stages of proving and early stages during baking. Emulsifiers such as diacetyl tartaric acid esters of mono-and diglycerides (DATEM) or sodium stearoyl lactylate (SSL) are commonly used in bakeries in order to get loafs with high volume and

acceptable crumb structure. It has been shown that this effect can also be achieved by using lipases instead of the above emulsifiers (de Maria et al., 2007). Lipases favor dough strength during fermentation, increase loaf volume and the resulting bread has more uniform crumb structure (Olesen et al., 1994; Qi Si, 1997). Lipases act on polar lipids present and split the triglycerides into mono –and diglycerides and free fatty acids. (Popper, 2006). The improving mechanism of lipases in dough is not fully understood (Goesaert et al., 2005). Since the amount of emulsifier formed in-situ does not explain the dough strengthening and loaf volume increase (Qi Si, 1997, Popper, 2006). Lipases should not be used in recipes that contain high level of diary fats because off flavors will be developed (Qi Si, 1997).

2.5. METHODS TO ASSESS BREAD DOUGH QUALITY

Assessing wheat bread dough properties has a long history. Beccari and Foucroy were well aware of the rheological differences between flour doughs and glutens (Shuey, 1975). Since then a large number of tests have been developed and adopted in research and in industry supporting their importance (Ktenioudaki et al. 2010a).The main techniques used for measuring cereal properties traditionally have been divided into descriptive empirical techniques and fundamental measurements (Bloksma and Bushuk, 1988).Fundamental techniques are mainly employed in research since they involve detailed sample preparation accurate and controlled measurement of stresses and strains (Campbell and Martin, 2012) . Empirical techniques are more popular in industry for several reasons:

They do not require skilled or trained personnel

They provide a great deal of information such as extensibility, consistency, viscosity etc.

They correlate with breadmaking performance

They are quick- not laborious and therefore effective for quality control

However apart from their advantages they are also associated with limitations such as:

Sample geometry is not well defined

Results dependent on test equipment

Results and data in many cases expressed in arbitrary units.

(Dobraszczyk and Morgenstern, 2003; Charalmbides et al., 2006; Stojceska et al., 2007; Ktenioudaki et al., 2010a).

Empirical techniques and methods can be subdivided according to the property of the dough or flour that are measure. The dough behavior during mixing can be assessed by the Farinograph. While the dough extensional properties can be assessed by the Alveograph. For more information regarding the empirical tets employed in this work please see appendix.

2.6. EXPERIMENTAL WORK

Any wheat including durum can be altered by the milling process and therefore knowledge of the milled fractions may establish which are best to bread manufacture. Testing of the fractions can be done using a very wide array of chemicals and physichochemicals techniques and some of the most common techniques are tested within this work and it is examined if changes in a technique would be beneficial. In addition is whether the improver suggestion could address the high level of stiffness associated with durum wheat, therefore L-cysteine was incorporated into the improver.

CHAPTER 3. MATERIALS AND METHODS

3.1. INTRODUCTION

This chapter describes the materials that were used to prepare the various samples investigated. It is also presents the sieve fractioning and the regrinding techniques that were used. In addition, it will be provided a description of the various techniques and methods that were used to analyse the samples. Finally, it will explain the preparation technique used to make the bread.

3.2. MATERIALS

The materials used for the rheological and the breadmaking tests were the following:

- The durum flour free from additives was purchased from Avlida Mills SA (Avlida, Greece). The flour was stored at -18^{o}C and was warmed to room temperature a night before it was used.
- The ascorbic acid and the L-cysteine were purchased from Muehlenchemie GmbH & Co .KG (Ahrensburg, Germany).
- The fungal amylase, the endoxylanase and the lipase enzymes with commercial names Fungamyl 2500BG, Panzea and Lipopan F respectively were purchased from Novozymes A/S (Bagsvaerd, Denmark).
- The bakery yeast with commercial name L' Hirondelle was purchased from Lesaffre SA (Aspropyrgos, Greece)
- The sea salt and deionized water were purchased from AB Vassilopoulos SA (Gerakas, Greece)

All the above improvers were stored at 4^{0}C, while sea salt and deionized water were stored at room temperatures.

The reagents used for sedimentation test and starch damage assay were the following:

- The reagents used for the Zeleny sedimentation test were isopropyl alcohol, lactic acid both were purchased from Sigma Aldrich (Gillingham ,UK) while the bromophenol blue solution with the commercial name Fluka Analytical was purchased from Honeywell (Morris Plains, USA).

- The starch damage enzyme assay kit was purchased from Megazyme u.c. (Wicklow, Ireland) and was stored at 4 ºC.

The composition of the two improvers used in this study named improver A and improver B are presented below (table 3-1)

Table 3-1. The composition of improvers used in this thesis.

Additives	Improver A	Improver B
Ascorbic acid	50ppm	50ppm
α-amylase	7ppm	7ppm
Endoxylanase	20ppm	20ppm
Lipase	15ppm	15ppm
l-cysteine	-	12ppm

Note: ppm = parts per million of flour

3.3. FLOUR SIEVE FRACTIONING AND REGRINDING

In this thesis a vertical vibro-sifter (figure 3-1) built by Akmon OE (Thessaloniki, Greece) was used to sieve the Straight run durum wheat flour purchased from the Avlida Mills.



Figure 3.3-1. Photograph of vertical vibro-sifter (Akmon OE, Thessaloniki, Greece)

Vibro-sifters are commonly used in wheat mills in order to sift sticky flour which is difficult to be sifted by plansifters. A combination of beating action and vibration movement ensures the efficiency of the sifting process. The sifting processes (Figure 3.-2) can be described as follows:

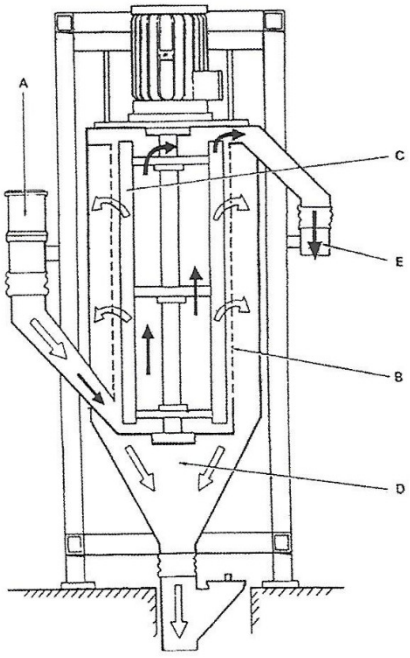


Figure 3-2. Diagram showing operation of vertical vibro-sifter (NABIM handbook, 2011).

The flour enters to the vibro-sifter (A), the beaters (C) throw the flour against the cover (B) which is kept clear by vibration. The flour particles which pass the nylon cover exit from the bottom outlet (D) of the machine while the oversized particles exit from the upper outlet (E).

The sieve fractioning procedure which was adopted in this study can be described follows:

1. The *Straight run* flour was sifted by a nylon cover with sieve opening of 200μ. The two resulted fractions named *Fine* (i.e. 200μm<) and *Coarse* (i.e. 200μm>).
2. The *Fine* fraction was sifted by a nylon cover with sieve opening of 110μ. The two resulted fractions named *Super Fine* (i.e. 110 μm<) and *Mid Fine* (i.e.110μm<*Mid Fine* <200μm)

The object of the regrinding process was to reduce the particle size of the *Coarse* fraction bellow 200μm. For that scope, in an industrial roller mill built by Buhler (Uzwil, Switzerland) 200kg of *Coarse* flour was reground three times in a pair of smooth rolls. The resulted flour named *Regrinded*.

In order to obtain homogeneous samples the resulted fractions were mixed separately in an industrial powder blender (figure 3-3) built by Zhengzhou (model JHX, Henan, China). In addition for each fraction two samples weighing 50kg were prepared in the said blender, one containing the improver A and the other containing the improver B.

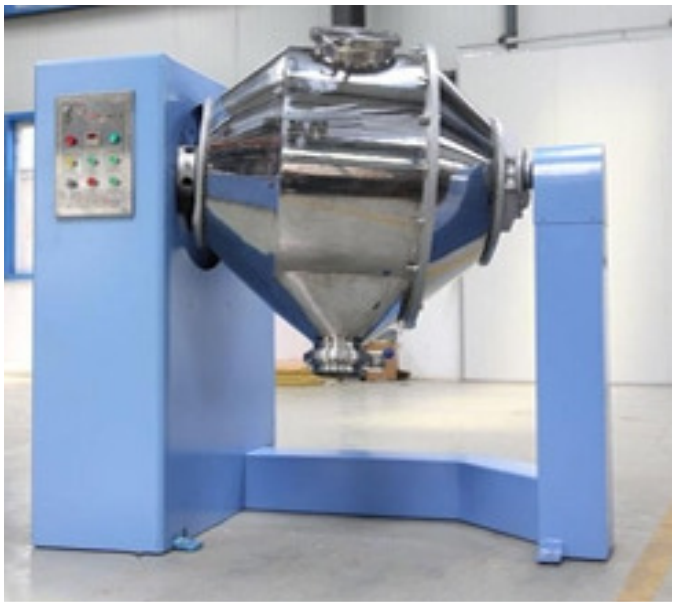


Figure3-3. Industrial powder blender (JHX, Zhengzhou, Henan, China)

3.4. PHYSICOCHEMICAL AND RHEOLOGICAL TESTS PROPERTIES TESTS

3.4.1. Physicochemical tests

In order to assess the physiochemical properties of each fraction the following tests were performed

- Flour moisture content was determined in Kern moisture analyser at temperature of 140 C° (model MLB, Kern & Sohn GmbH, Balingen, Germany)
- The percentage of the wet gluten content of each flour sample was determined in Glutomatic (model 2200, Perten, Hägersten, Sweden) according to AACC method 38-12.A
- The amylolytic activity was measured by the Falling Number apparatus (model FN1310, Perten Hägersten, Sweden) according to AACC method 56-81.03 and is expressed in seconds. For more details regarding the method please see appendix

- The sedimentation volume of the flour samples in dilute lactic acid were measured by the Zeleny sedimentation test according to ICC method 116/1 and is expressed in ml. For more details regarding the method please see appendix
- The starch damage content test of each sample was determined according to AACC method 76-31.01 and is expressed as a percentage of flour weight.

All the physicochemical tests were replicated three times for each flour fraction

3.4.2. Rheological tests

In order to assess the rheological properties of each fraction and the impact of the two improvers the following methods were used.

3.4.2.1. Dough mixing properties

3.4.2.1.1. Farinograph

The Farinograph apparatus (Brabender, Duisburg, Germany) measures the mechanical resistance of the dough during mixing and kneading. The Farinograph tests were performed according to AACC method 54-21. The readings which were interpreted from the Farinograph curve are:

WA: The needed hydration level expressed as percentage on flour weight basis in order the Farinograph curve to reach the 500BU line and it is refferd as Water Absorption capacity

DT: The time in minutes needed for dough's maximum consistency and it is reffered as Development Time

CD: Is the time in minutes at which the dough consistency is above or equal to 500BU consistency and it is refered as Stabilty.

MT: Is the difference in BU from the top of the curve at the peak to the top of the curve measured 10 minutes after the peak and is refferd as Mixing Tolerance Index.

Note, BU: Brabender Units, are arbitrary units used to express the dough resistance during mixing.

For more details regarding the Farinographic method please see appendix

3.4.2.1.2. Consistograph

The Consistograph apparatus (model NG, Chopin, Villeneuve La Garenne Cedex, France) measures the dough stiffness during mixing. The pressure of the dough applied in the sensor which is fitted in the side of the mixer bowl is expressed in millibars i.e mb. The Constant and Adopted hydration Consistograph tests (model NG, Chopin, Villeneuve La Garenne Cedex, France) were performed according to AACC method 54-50.01.

The readings which were interpreted from the Constant hydration Consistograph protocol are:

PrMax: The maximum pressure reached

WA: 1700mb equivalent hydration rate based on 15% water.

HYDHA: 2200 equivalent hydration rate based on 15% water.

The readings which were interpreted from the Adopted hydration Consistograph protocol are:

PrMax: The maximum pressure reached

TPrMax: Time to reach PrMax

D250: Pressure drop from PrMax to pressure after 250 seconds

D450: Pressure drop from PrMax to pressure after 450 seconds

WAC: WA fine tuned value after Adopted hydration test i.e equivalent hydration at 1700mb based on 15% mb flour

For more details regarding the Consistograph method please see appendix

3.4.2.2. Dough biaxial extension

The Aveograph apparatus measures the dough elasticity and extensibilty by biaxial extension.In order to assess the effect of dough consistency and the mixing procedure on bubble infaltion profile as it is measured by the Alveograph (model NG, Chopin, Villeneuve La Garenne Cedex, France) four different dough mixing preparation were adopted.

3.4.2.2.1. Standard Alveograph method

The standard Alveograph tests were performed according to AACC 54-30A. The readings which were interpreted from the Alveograph curve are:

P: Is the dough tenacity- maximum pressure achieved and is measured in millimeters at the average of the maximum heights of the curves and multiplied by 1.1

L: Is the length of the curve up to the breaking point which is related to extensibilty and is measured in millimeters

W: Is the surface under the curve and represents the energy required to inflate the dough until rupure and is measured in cm^2.

P/L: Is the configuration ratio

3.4.2.2.2. Interrupted Alveograph mixing method

In this method the dough hydration level was identical with the standard method i.e. 50% of salted water (2.5g salt/100ml water) on flour basis. The dough kneaded in the Alveograph mixer and the procedure can be described as follows:

- 1 minute for mixing flour with water
- 1 minute for manual scraping
- 2 minutes for dough mixing
- Exactly when the timer indicated 4 minutes the dough mixing procedure was stopped and the dough was left inside the Alveograph mixer for 18 minutes at 24ºC
- After this resting time the dough kneaded for another 4 minutes
- The dough then was extruded and the rest of the procedure was identical to the standard method i.e. dough patties preparation, resting time and the temperature in the Alveograph chamber.

3.4.2.2.3. Adopted hydration Alveograph method

In this method the water hydration level was determined by the Consistograph test. The level of salt in the water, the dough mixing procedure and the resting time were identical to standard method.

3.4.2.2.4. Alveo- Farino method

In this method the dough samples were mixed in the Farinograph mixer. The method can be described as follows:

- 300g of flour and 2% of salt (based on flour weight) were mixed in the Farinograph usually at 2.5% to 4% less water than its optimum (table 3-2) in order the dough consistency to meet the target of 500BU at the end of mixing. The hydration level for each fraction was the same for control, A and B improver treatments.

Table 3-2. The hydration level of each fraction for the Alveo –Farino method

Fraction	Hydration level on flour basis
Straight run	62.0%
Fine	60.0%
Super fine	61.5%
Mid fine	60.0%
Coarse	59.5%
Regrind	65%

- The temperature of the Farinograph mixing bowl was set at 30 ºC.
- The mixing procedure was the following: 1 minute of mixing flour with water, 5 minutes of dough resting inside the mixing bowl, after this the dough was mixed for another 2 minutes.
- 375 g of the dough were placed in the Alveograph mixer and mixed exactly for 30 seconds, the dough then extruded and the rest of the procedure was identical to the standard method i.e. dough patties preparation, resting time and the temperature in the Alveograph chamber.

Note, the readings which were interpreted from the Alveograph curve were the same for all Alveograph modifications.

For more details regarding the Alveograph method please see appendix.

All the rheological tests were replicated three times for each flour fraction and each improver treatment.

3.5. RHEOFERMENTOMETER AND BAKING TESTS

In order to evaluate the baking quality of each fraction and the effect of each improver on the breadmaking performance, the following procedures and measurements were adopted.

3.5.1. Dough preparation

3.5.1.1. Dough composition and mixing method

- 300g of flour, 2% of salt and 2% of fresh bakery yeast (based on flour weight) were mixed in the Farinograph usually at 3.5% to 4.5% less water than its optimum (table 3-3) in order the dough consistency to meet the target of 500BU at the end of mixing. The hydration level for each fraction was the same for A and B improver treatments.

Table 3-3. The hydration level of each fraction for the Rheofermentometer tests and the bredmaking process

sample	Hydration level
Straight run	61.0%
Fine	59.5%
Super fine	61.0%
Mid fine	59.5%
Coarse	58.5%
Regrind	64.0%

The temperature of the Farinograph mixing bowl and the mixing procedure were identical to that of Alveo-Farino method.

3.5.1.2. Dough resting

After mixing the dough was hand rounded and rested for 10 minutes in a cabinet at 22ºC. The relative humidity of the cabinet was set at 85% RH in order to prevent dough skinning. Then it was weight and hand rounded and rested for another 10 minutes in the same conditions as above. 200g of the dough were used for the Rheofermentometer test and two pieces weighing 100g each were used for the baking test.

3.5.1.3. Dough moulding

Each dough piece weight was 100g and was moulded in a Salva moulder (model Salva SA, Lezo, Spain). The geometrical properties of the moulded dough i.e. dough cylinder

length and width, were measured by calipers (Figure 3-4), exactly after the dough exited the moulder and are expressed in cm

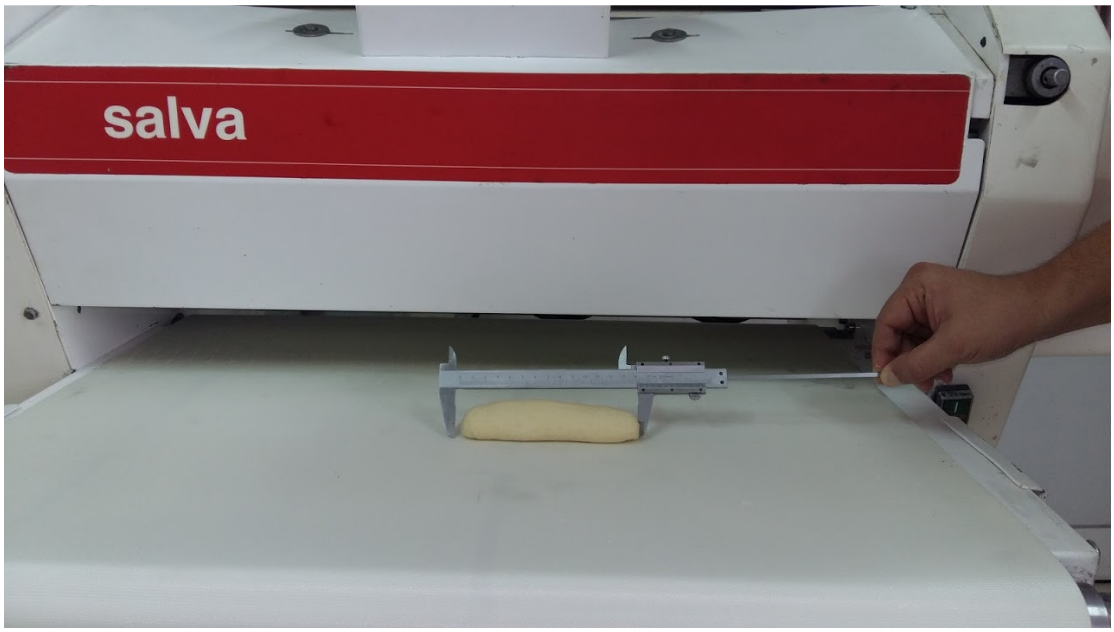


Figure 3-4. Photograph of the moulder and dough length measuring (model Salva SA, Lezo, Spain)

3.5.1.4. Dough fermentation

After moulding the two dough pieces were placed in a Miwe fermentation cabinet (model Condo, MIWE GmbH, Arnstein, Germany) (figure 3 -5) and fermented for 1 hour, at 32ºC and 85% relative humidity. At the end of fermentation the geometrical properties of each dough were measured as described above.



Figure 3-5. Photograph of fermentation cabinet (model Condo, MIWE GmbH, Arnstein, Germany)

3.5.2. Rheofermentometer test

The fermentation process was monitored using a Rheofermentometer (model F3, Chopin, Villeneuve La Garenne Cedex, France).The Rheofermentometer apparatus measures the dough volume change, the gas production and the gas retention during fermentation. The readings which were interpreted by the Rheofermentometer are:

1. Dough development curve:
    - Hm: maximum dough volume, expressed in cm
    - h: dough volume at the end of test, expressed in cm
    - T1: time required for maximum dough volume expressed in minutes
2. Gas release curve
    - H'm: maximum point of gas production, expressed in ml
    - T'1: time required for maximum gas production, expressed in hours
    - Tx: time when dough starts to release gas, expressed in minutes
    - Total volume: total volume of gas produced, expressed in ml
    - Retention Coefficient: gas retention capacity of the dough

The chosen parameters for the Rheofermentometer tests were the following:

- 200g of the dough prepared as described above were placed in the fermentation basket.
- The piston weight was 2kg,
- the test temperature was set at 32^{o}C
- the test duration was 180 minutes

For more details regarding the Rheofermentometer test please see appendix

3.5.3. Baking

Two pieces of dough were placed in a Miwe oven (model Condo, MIWE GmbH, Arnstein, Germany) and steam was injected for the first minute of baking (figure 3-6). The oven temperature was set at 220ºC and the breads were baked for 30 minutes.



Figure 3-6. Photograph of baking oven (model Condo, MIWE GmbH, Arnstein, Germany).

3.5.4. Loaf volume and geometrical properties

The loaf volume and the geometrical properties were measured three hours after baking Measurements of loaf volume were obtained by seed displacement.

The loaf volume measurement technique can be described as follows: three cups of linseed were poured into a box of known volume, in which the loaf then placed. A cup of linseed was poured into the box. Excess linseed was levelled and was weighed. The specific weight of the linseed was calculated by the commonly used technique in cereal trading called Hectoliter test weight. By knowing the specific weight of linseed the loaf volume was calculated. The loaf volume expressed in ml

The geometrical properties were measured as described previously in addition the height of the loaf was measured (figure 3-7) and a ratio of loaf width to height i.e. BH/ BW was calculated.

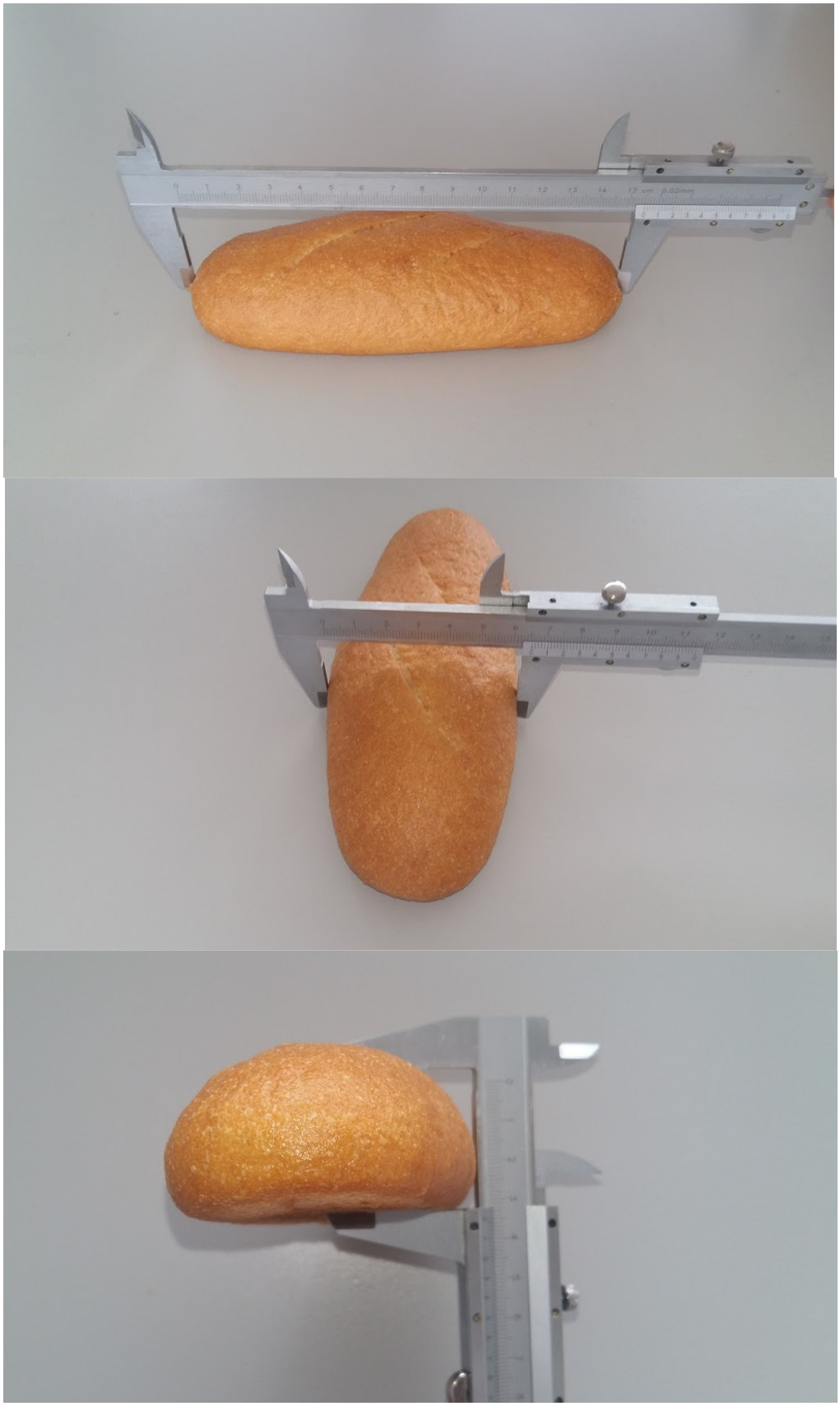


Figure 3-7. Photos of bread shape measurement.

All the baking and Rheofermentometer tests were replicated three times for each flour fraction and each improver treatment.

3.6. STATISTICAL ANALYSIS

One way analysis of variance was carried out using Excel (Office Excel version 2013, Microsoft, Redmond, USA) to determine significant differences in the measured properties between the samples. T-test analysis was carried out using Excel (Office Excel version 2013, Microsoft, Redmond, USA) to identify significant differences obtained from different improver treatments. In order to obtain an integrated view of relationship between flour physicochemical properties, dough rheology and breadmaking properties, PCA was executed using Unscrambler (Camo AS, Oslo, Norway) and Pearson's correlations between parameters were calculated using Excel (Office Excel version 2013, Microsoft, Redmond, USA)

CHAPTER 4. THE IMPACT OF PHYSICOCHEMICAL PROPERTIES AND OF IMPROVERS ON BREADMAKING PERFORMANCE

4.1. INTRODUCTION

A number of studies have shown that the physicochemical properties of durum wheat flour have a critical impact on breadmaking performance. The durum wheat kernel hardness is positive related with flour particle size and starch damage content. These properties have a major effect on flour water absorption capacity and dough tolerance during breadmaking. The influence of gluten content on baking quality have been widely studied. The majority of the studies have shown that the impact of gluten content is a critical but not the defining factor for bread volume. Considerable work has been undertaken over the years that has focused on the development of additives and formulas in order to improve the baking quality of bread products and to deal effectively with wheat quality inconsistency.

In this chapter data obtained fom the study of Durum wheat that has milled is presented. Samples obtained by the straight milling process (see section 3.3) and the resulting fractions obtained from the vibrosifting process were examined. These samples are defined in figure 4-1. These samples will be analysed for the relationship between the durum flour particle size and the gluten content, the Zeleny sedimentation volume, the starch damage content and the Falling number value. In addition it will be presented and discussed the impact of the particle size, the physicochemical properties and the improver treatment on the breadmaking performance.

4.2. RESULTS

4.2.1. Physicochemical properties

4.2.1.1. Particle size distribution

The figure 4-1 shows the sieving procedure and the particle size range of each fraction.

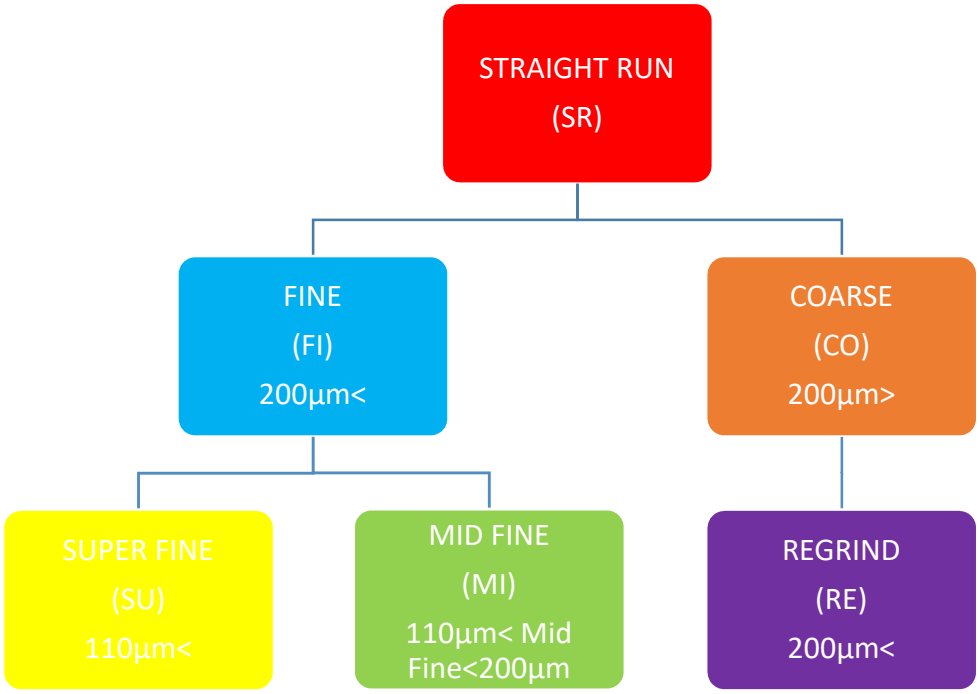


Figure 4-1. Particle size range and sieve fractioning procedure

A wide particle size distribution was observed in *Straight Run* flour (figure 4-2). Around 22% of the particles in *Straight Run* flour were smaller than 110µm, while 46%were larger than 200µm.

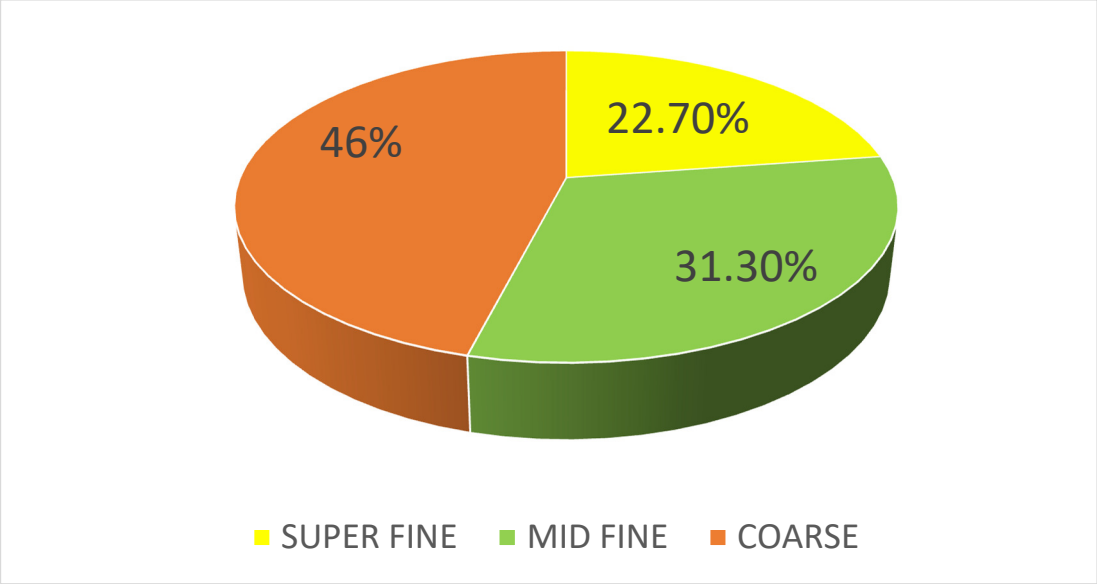


Figure 4-2. Straight run particle size partition

These samples were assessed for their properties using the methods analysed in section 3.4. A list of abbreviations is given on page xii.

4.2.1.2. Gluten content

ANOVA showed (figure 4-3) that *Super Fine* exhibited the lowest gluten content among all fractions, whereas *Course*, *Regrind* and *Mid Fine* exhibited the highest gluten content. The extreme fine particles i.e. lower than 110µm were responsible for the gluten variation. When they were sieved out as in case of *Mid Fine* the gluten content was increased substantially

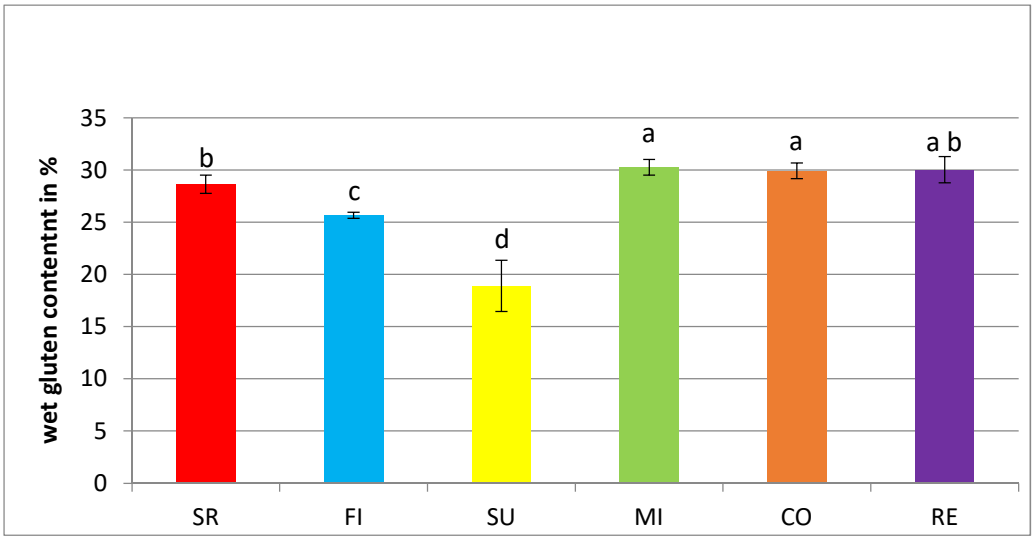


Figure 4-3. Gluten content. Each mean value was obtained from three replicates. Bonferroni corrections used to compare the mean values and the different letters in the bars show significant difference at $p<0.05$. Abbreviations of fractions: SR= Straight run, FI = Fine, SU = Super Fine, MI = Mid Fine, CO = Coarse, RE = Regrind

4.2.1.3. Starch Damage

Analysis showed (figure 4-4) a wide distribution of starch damage content among the fractions. It has been seen that *Coarse* exhibited the lowest starch damage content, whereas *Super Fine* the highest. *Regrind* exhibited nearly double starch damage content compared to *Coarse*. It can be observed that starch damage content was related with the flour particle size. The finer the particles the higher the starch damage.

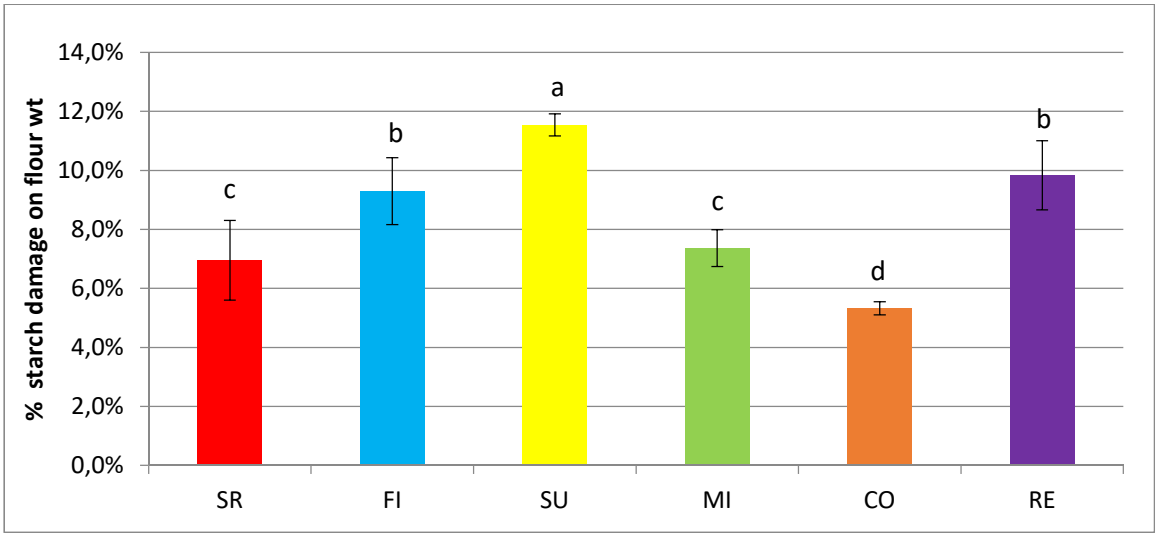


Figure 4-4. Starch damage content. Each mean value was obtained from three replicates. Bonferroni corrections used to compare the mean values and the different letters in the bars show significant difference at $p<0.05$

4.2.1.4. Falling Number

Results have shown extremely high Falling Number values for the samples tested. ANOVA showed (figure 4-5) that Falling Number values were related with the flour particle size. The finer the particles the lower the Falling Number. *Coarse* exhibited the highest Falling Number of all fractions. While the Falling Number of *Super Fine* was similar only to *Regrind*.

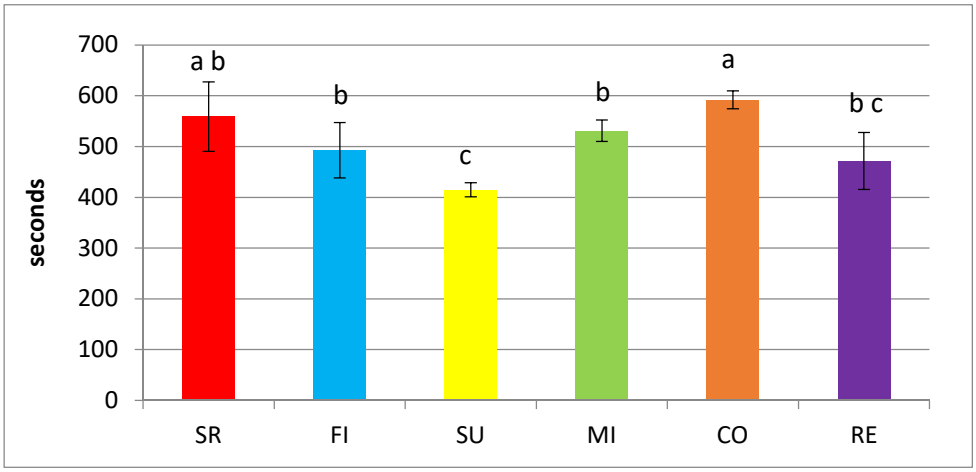


Figure 4-5. Falling Number values. Each mean value was obtained from three replicates. Bonferroni corrections used to compare the mean values and the different letters in the bars show significant difference at $p<0.05$

4.2.1.5. Zeleny Sedimentation volume

Anova showed (figure 4-6) that when the fractions were untreated *Super Fine* exhibited significant lower sedimentation volume compared to the rest fractions. It should be noted that the rest fractions exhibited similar volumes.

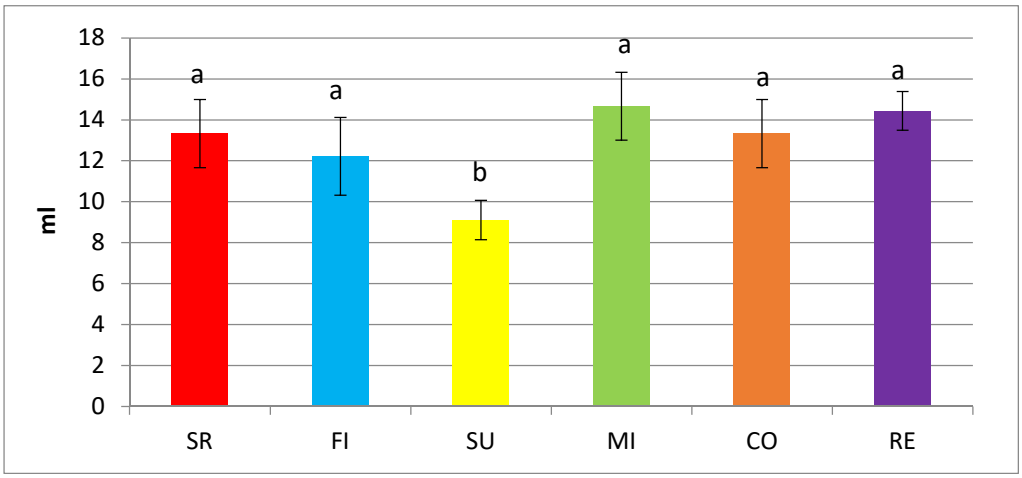


Figure 4-6. Zeleny sedimentation content. Each mean value was obtained from three replicates. Bonferroni corrections used to compare the mean values and the different letters in the bars show significant difference at $p<0.05$

4.2.2. Dough and bread performance

The durum flour fractions created by milling or sieve segregation (see section 3.3 and figure 4.1) were used to make bread doughs. Two different improver systems were used, A +B, and composition of these is given in table 3-1. The methods for manufacture are listed in section 3.5

4.2.2.1. Zeleny Sedimentation the impact of the improvers

When fractions treated with the improver A (table 4-1), analysis showed that the *Regrind* exhibited the highest sedimentation volume of all fractions while *Super Fine* the lowest. When fractions treated with improver B, ANOVA showed that the *Regrind* and *Mid Fine* fractions exhibited the highest sedimentation volume of all fractions while *Super Fine* the lowest. Interestingly the *Coarse* fraction exhibited significant lower sedimentation volume compared to *Regrind.*

Table 4-1. Zeleny sedimentation values expressed in ml for fractions treated with improvers. Each mean value obtained from three replicates. Bonferroni corrections used to compare the mean values and the different letters in the columns show significant difference at p<0.05 within each flour treatment i.e. A, B different improver treatments. T-test used to compare the effect of improvers for each fraction, significant different at p<0.05 =*, p<0.01=**, p<0.001=***, marks in raw for each value show significant difference.

SAMPLE	A (ml)	B
Straight run	12.22a	12.22a
Fine	11.55ab	12.44a
Super Fine	9.33b	9.33b
Mid Fine	14.66ac	15.33c
Coarse	12.22abc	13.55a
Regrind	15.33c	15.11c

4.2.2.2. The dough behavior during fermentation measured by Rheofermentometer

4.2.2.2.1. Dough development

4.2.2.2.1.1 Maximum dough volume during fermentation

ANOVA showed (figure 4-7) that when fractions treated with improver A, *Super Fine* exhibited significant lower maximum dough expansion i.e. Hm compared to *Mid Fine*. The rest fractions exhibited similar maximum dough volume during fermentation. When fractions treated with improver B *Super Fine* exhibited significant lower Hm compered to all fractions. In addition t-test analysis showed that only *Coarse* responded positive to improver B, whereas the response of the rest fractions was insignificant.

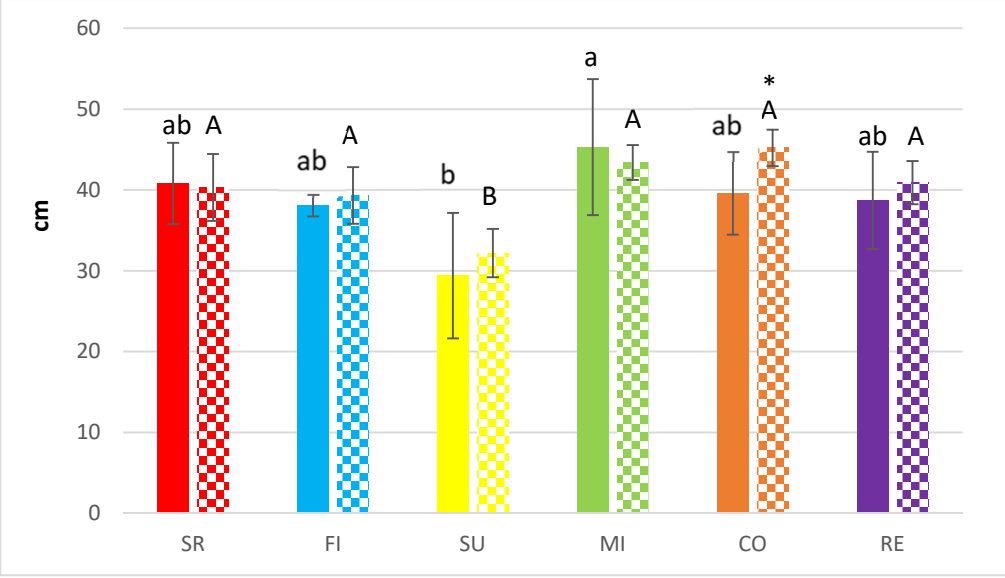


Figure 4-7. Maximum dough volume during fermentation expressed in cm. ■ improver A and ▩ improver B. Each mean value obtained from three replicates. Bonferroni corrections used to compare the mean values and the different letters in the bars show significant difference at p<0.05 within each flour treatment (a b c d improver A, A B C D improver B). T-test used to compare the effect of improvers for each fraction, significant different at p<0.05 =*, p<0.01=**, p<0.001=***.

4.2.2.2.1.2 Dough Volume at the End of Proving

Analysis showed (figure 4-8) that when fractions treated with improver A, *Super Fine* exhibited significant lower dough volume at the end of fermentation i.e. h compared to *Fine, Mid Fine* and to *Regrind*. Moreover *Mid Fine* exhibited significant ($p<0.05$) higher h value than *Fine*. When cysteine added (present in improver B) *Super Fine* exhibited significant lower h only compared to *Mid Fine* and to Coarse. T-test analysis showed that both improvers had similar effect in all fractions.

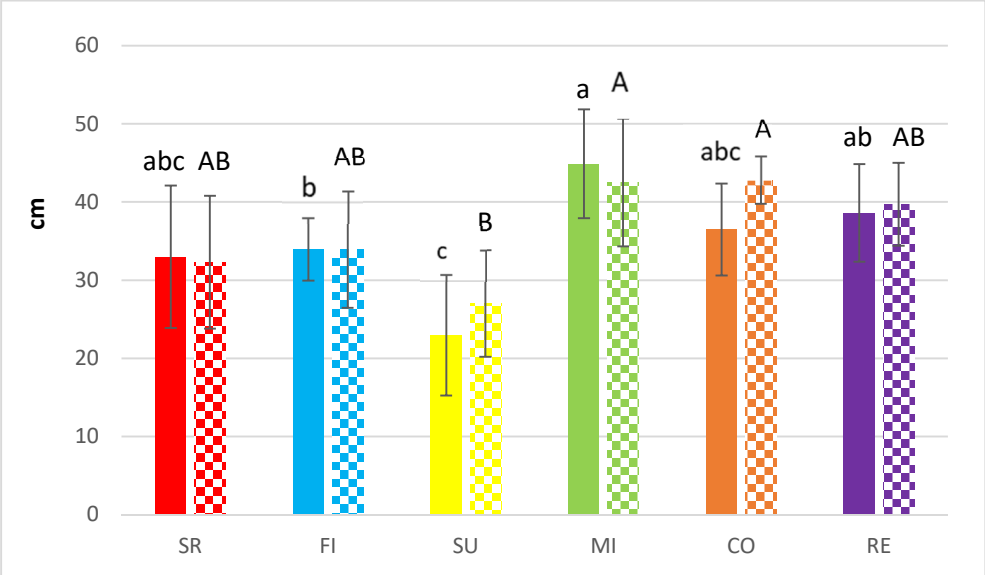


Figure 4-8. Dough volume at the end of proving expressed in cm. ■ improver A and ▩ improver B. Each mean value obtained from three replicates. Bonferroni corrections used to compare the mean values and the different letters in the bars show significant difference at $p<0.05$ within each flour treatment (a b c d improver A, A B C D improver B). T-test used to compare the effect of improvers for each fraction, significant different at $p<0.05$ =*, $p<0.01$=**, $p<0.001$=***.

4.2.2.2.1.3 Dough Tolerance and Expansion Rate

Analysis showed (table 4-2) that when fractions treated with improver A *Super Fine* was significant less tolerant than *Coarse*, *Regrind* and *Mid Fine*. While exhibited similar tolerance with *Straight Run* and *Fine*. It should be noticed that *Mid Fine* and *Regrind* exhibited extremely high tolerance during fermentation. When fractions treated with improver B all fractions exhibited statistical similar tolerance. Moreover t-test analysis showed that both improvers had a similar impact in all fractions.

Table 4-2. Dough Tolerance expressed as percentage of the difference between Hm and h and Expansion Rate expressed in minutes from Rheofermentometer for durum flour fractions. Each mean value obtained from three replicates. Bonferroni corrections used to compare the mean values and the different letters in the columns show significant difference at $p \leq 0.05$ within each flour treatment i.e. A, B different improver treatments.). T-test used to compare the effect of improvers for each fraction, significant different at $p<0.05$ =*, $p<0.01$=**, $p<0.001$=***, marks in raw for each value show significant difference.

DOUGH DEVELOPMENT				
	Hmd		T1	
SAMPLE	A	B	A	B
Straight run	19.1%abc	20.1%a	111a	113a
Fine	10.8%abc	13.9%a	134b	121ab
Super Fine	21.8%a	16.4%a	117ab	126ab
Mid Fine	0.8%b	1.9%a	160ab	154b
Coarse	8.0%c	5.4%a	108a	127ab
Regrind	0.4%b	3.0%a	171b	165b

Rheofermentometer parameters abbreviations: Hmd: difference between maximum dough volume achieved during fermentation and dough volume at the end of proving.T1: time in minutes required for maximum dough volume

Extremely time was needed by all fractions to achieve the highest dough volume during fermentation as it is shown in table 4-2, either treated with improver A or improver B. It worth to notice that *Fine* and *Regrind* achieved the highest dough volume towards the end of the test. When fractions treated with improver B *Straight Run* exhibited significant lower T1 than *Mid Fine* and *Regrind*. T-test analysis showed that both improvers had similar impact in all fractions.

4.2.2.2.2. Gas release

4.2.2.2.2.1 Maximum Point of Gas Production

Analysis showed (figure 4-9) that when fractions treated with improver A, *Fine* exhibited significant higher gas production rate than *Mid Fine* and *Regrind*. While when fractions treated with improver B, *Coarse* produced CO_2 at higher rates compared to *Mid Fine*, despite the fact that the latter was associated with higher starch damage and lower Falling Number. T-test analysis showed that the addition of improver B lead to higher maximum point of gas production only for *Coarse.*

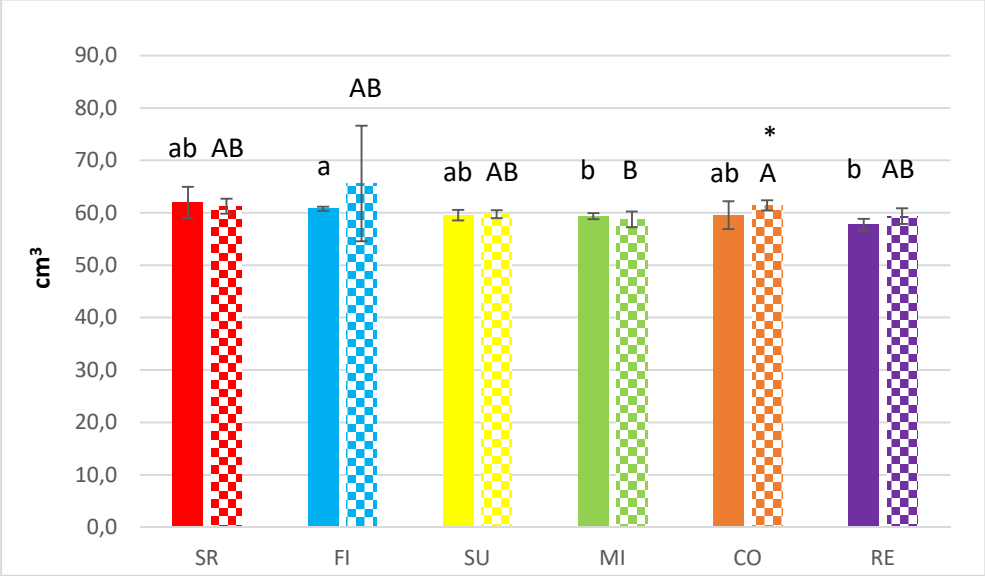


Figure 4-9. Maximum point of gas production expressed in cm^3. ■ improver A and ▩ improver B. Each mean value obtained from three replicates. Bonferroni corrections used to compare the mean values and the different letters in the bars show significant difference at $p<0.05$ within each flour treatment (a b c d improver A, A B C D improver B). T-test used to compare the effect of improvers for each fraction, significant different at $p<0.05$ =*, $p<0.01$=**, $p<0.001$=***.

4.2.2.2.2.2 Gas Production Rate

Extremely time was needed (figure 4-10) by all fractions to achieve the maximum point of gas production i.e. TG. In particular, when fractions treated with improver A, *Mid Fine* exhibited significant higher TG compered to all fractions except *Regrind*. Whereas when fractions treated with improver B, *Mid Fine* exhibited significant higher TG compered only to *Straight Run*. T-test analysis showed that only *Mid Fine* responded significantly to improver B addition. The TG reduced, in other words, the rate of gas production was increased. It can be seen that CO_2 production rate was closely related with dough development. To put it in other way, the low rate of gas production affected the dough development rate.

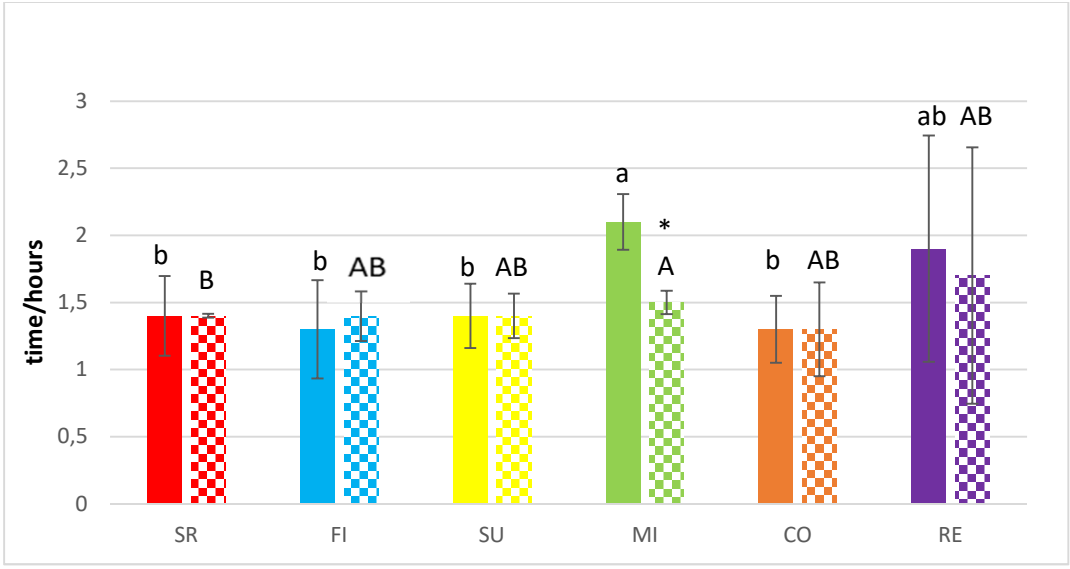


Figure 4-10. Time needed (hours) to achieve maximum gas production. ■ improver A and ▩ improver B. Each mean value obtained from three replicates. Bonferroni corrections used to compare the mean values and the different letters in the bars show significant difference at $p<0.05$ within each flour treatment (a b c d improver A, A B C D improver B). T-test used to compare the effect of improvers for each fraction, significant different at $p<0.05$ =*, $p<0.01$=**, $p<0.001$=***.

4.2.2.2.2.3. Dough Porosity, Total Gas Production and Gas Retention Capacity.

Analysis showed (table 4-3) that when fractions treated with improver A, started to give off air at similar time i.e. Tx. Whereas when fractions treated with improver B, all fractions exhibited significant lower Tx compared to *Mid Fine*. T-test analysis showed that cysteine addition did not have a significant impact in any fraction.

Table 4-3. Dough Porosity expressed in minutes, Total Gas Production expressed in ml and Gas Retention Capacity values expressed as percentage between the TV and final gas trapped by the dough. Each mean value obtained from three replicates. Bonferroni corrections used to compare the mean values and the different letters in the columns show significant difference at $p<0.05$ within each flour treatment i.e. A, B different improver treatments.). T-test used to compare the effect of improvers for each fraction, significant different at $p<0.05$ =*, $p<0.01$=**, $p<0.001$=***, marks in raw for each value show significant difference

GASEOUS RELEASE						
	Tx		TV		RET	
SAMPLE	A	B	A	B	A	B
Straight run	73a	74ab	1497ab	1452ab	85.7%ab	86.5%ab
Fine	65a	62ab	1500a	1604ab	86.3%ab	88.9%ab
Super Fine	61a	68a	1444ab	1444ab	83.8%ab	85.0%a
Mid Fine	74a	89b	1427ab	1425ab	88.9%b	88.7%b
Coarse	73a	79ab	1491ab	1518a	84.2%a	84.9%ab
Regrind	67a	74ab	1402b	1445b*	87.6%b	87.5%ab

Rheofermentometer parameters abbreviations: Tx: time in minutes when the dough starts to give off air, TV: total volume in ml of gas produced during the test, RET: volume of gas retained by the dough at the end of the test.

In case of total gas production i.e. TV, ANOVA showed (table 4-3) that when fractions treated with improver A, the only statistical significant difference occurred between *Fine* and *Regrind*. Where the former exhibited higher total gas production than the later. When fractions treated with improver B, *Coarse* exhibited significant higher TV value compared to *Regrind*. While both fractions were associated with similar TV value, as with the rest fractions. T-test analysis showed that cysteine addition favored the total gas production only in *Regrind* fraction. While in the rest fraction the impact was insignificant.

When fractions treated with improver A, analysis showed (table 4-3) that *Coarse* was associated with significant lower gas retention capacity i.e. RET compared to *Mid Fine* and *Regrind*. Whereas when fractions treated with improver B, *Mid Fine* exhibited significant higher retention capacity compared to *Super Fine*. Data findings showed that in general all fractions exhibited extremely high gas retention capacity. This might related with the low rates of gas production and dough development.

4.2.2.3 Geometrical properties

4.2.2.3.1. Dough Dimensions after Moulding

Analysis showed (figure 4-11) that when fractions treated with improver A, *Super Fine* exhibited significant lengthier dough compared to *Mid Fine*. While the rest fractions exhibited similar dough length. When fractions treated with improver B, *Super Fine* exhibited significant lengthier dough than *Straight Run*. Moreover t-test analysis identified that cysteine increased the dough length of *Mid Fine* and *Coarse*.

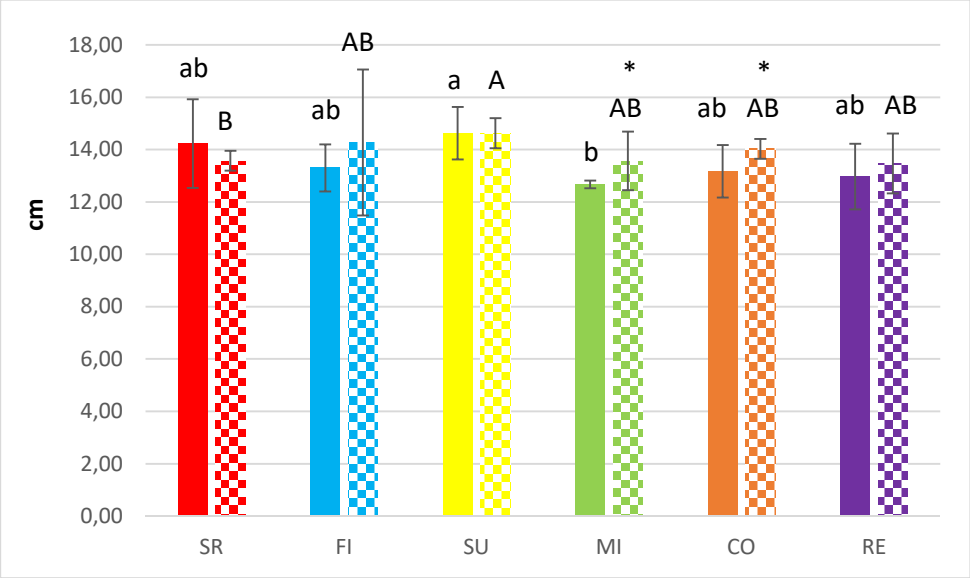


Figure 4-11. Dough length i.e. ML after moulding expressed in cm. . ■ improver A and ▩ improver B. Each mean value obtained from three replicates. Bonferroni corrections used to compare the mean values and the different letters in the bars show significant difference at $p<0.05$ within each flour treatment (a b c d improver A, A B C D improver B). T-test used to compare the effect of improvers for each fraction, significant different at $p<0.05$ =*, $p<0.01$=**, $p<0.001$=***.

It should be noticed that the dough width (figure 4-12) was similar for all fractions either treated with improver A or B treatments. T-test showed that the addition of cysteine did not have a significant impact on dough width in any fraction.

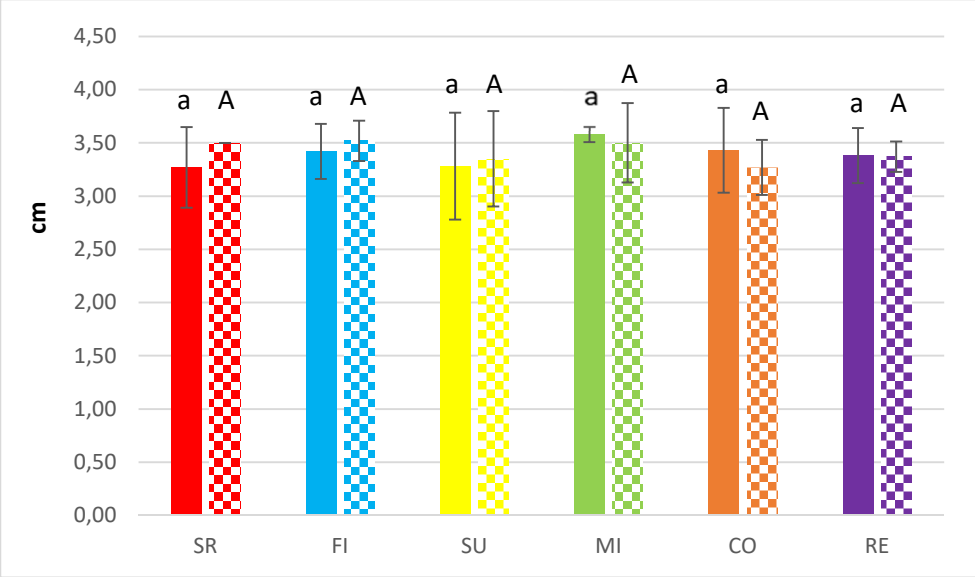


Figure 4-12. Dough width i.e. MW after moulding expressed in cm. ■ improver A and ▩ improver B. Each mean value obtained from three replicates. Bonferroni corrections used to compare the mean values and the different letters in the bars show significant difference at $p<0.05$ within each flour treatment (a b c d improver A, A B C D improver B). T-test used to compare the effect of improvers for each fraction, significant different at $p<0.05$ =*, $p<0.01$=**, $p<0.001$=***.

4.2.2.3.2. Dough Dimensions at the End of Proving

When fractions treated with improver A analysis showed (figure 4-13) that *Super Fine* and *Straight Run* exhibited lengthier dough compared to *Mid Fine*. When fractions treated with improver B, all fractions exhibited similar dough length. T-test analysis identified that cysteine addition increased the dough length of *Mid Fine* and *Coarse*.

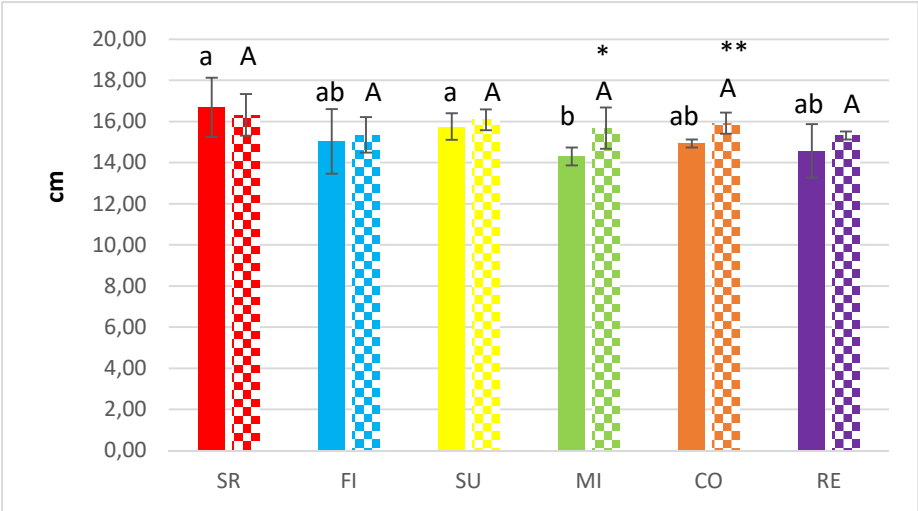


Figure 4-13. Dough length i.e. FL at the end of fermentation expressed in cm. ■ improver A and ▩ improver B. Each mean value obtained from three replicates. Bonferroni corrections used to compare the mean values and the different letters in the bars show significant difference at $p<0.05$ within each flour treatment (a b c d improver A, A B C D improver B). T-test used to compare the effect of improvers for each fraction, significant different at $p<0.05$ =*, $p<0.01$=**, $p<0.001$=***.

ANOVA showed (figure 4-14) again that the dough width was similar for all fractions either treated with improver A or B. T-test analysis showed that the addition of cysteine did not have a significant impact on dough width in any fraction.

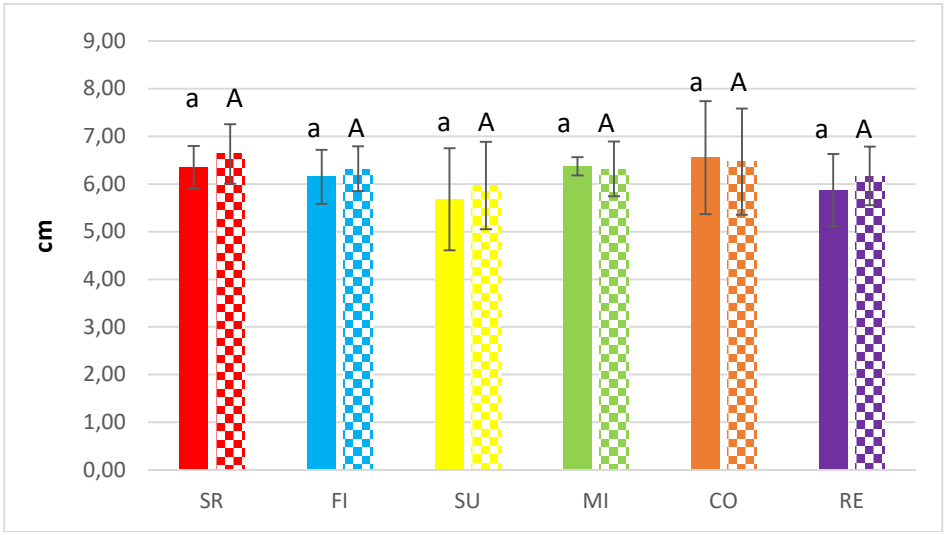


Figure 4-14. Dough width i.e. FW at the end of fermentation expressed in cm . ■ improver A and ▩ improver B. Each mean value obtained from three replicates. Bonferroni corrections used to compare the mean values and the different letters in the bars show significant difference at $p<0.05$ within each flour treatment (a b c d improver A, A B C D improver B). T-test used to compare the effect of improvers for each fraction, significant different at $p<0.05$ =*, $p<0.01$=**, $p<0.001$=***.

4.2.2.3.3. Loaf Dimensions

When fractions treated with improver A, results showed (table 4-4) again that high difference in gluten content was required in order significant difference to be obtained in dough loaf length. ANOVA showed that *Super Fine* exhibited lengthier loaf compared *Mid Fine*, *Coarse* and *Regrind*. When fractions treated with improver B, the loaves from *Coarse* and *Super Fine* were significant lengthier compared to *Fine*. T-test analysis identified that improver B, favored the loaf length of *Mid Fine*, *Coarse* and *Regrind*. Again analysis showed that the width of the loaf was similar foe all fractions either treated with improver A or B. in addition t-test analysis showed that the addition of cysteine did not have a significant impact on loaf width in any fraction.

Table 4-4. Loaf dimensions, Length, Width, Height and Height to Width Ratio expressed in cm. Each mean value obtained from three replicates. Bonferroni corrections used to compare the mean values and the different letters in the columns show significant difference at $p<0.05$ within each flour treatment i.e. A, B different improver treatments.). T-test used to compare the effect of improvers for each fraction, significant different at $p<0.05$ =*, $p<0.01$=**, $p<0.001$=***, marks in raw for each value show significant difference.

LOAF DIMENSIONS								
	BL		BW		BH		BH/BW	
SAMPLE	A	B	A	B	A	B	A	B
SR	15.72ab	15.90ab	6.37a	6.58a	2.82ab	2.97a	0.44ab	0.45a
FI	14.37ab	14.88a	6.18a	6.28a	3.05b	3.07a	0.49ab	0.49a
SU	15.48a	15.43bc	5.68a	6.07a	2.50a	2.83*a	0.44ab	0.47a
MI	13.92b	15.00*ab	6.33a	6.27a	3.40b	3.17a	0.53ab	0.50a
CO	14.58b	15.67**b	6.52a	6.63a	2.75ab	2.88a	0.42a	0.43a
RE	14.08b	14.77*ac	5.68a	5.98a	3.18b	3.08a	0.5b	0.52a

Loaf dimensions abbreviations: BL: loaf length, BW: loaf width, BH: loaf height, BH/BW: loaf width to height ratio

Again analysis (table 4-4) showed that the width of the loaf was similar for all fractions either treated with improver A or B. In addition t-test analysis showed that the addition of cysteine did not have a significant impact on loaf width in any fraction.

In case of loaf height i.e. BH it has been seen (table 4-4) that when fraction treated with improver A *Super Fine* exhibited significant lower loaf height compared to *Fine*, *Mid Fine* and *Regrind*. While when improver B was added all fractions exhibited similar BH. Probably because the height of *Super Fine* was favored by the cysteine addition, as it was shown by the t-test analysis.

In case of loaf width to height ratio i.e. BH/BW, when fractions treated with improver A, the ratio of *Regrind* was significant ($p<0.05$) higher compared to *Coarse*. All the other fractions exhibited similar ratios. When fractions treated with improver B all fractions exhibited similar BH/BW ratios. Moreover the addition of cysteine did not affected significant the ratios BH/BW ratio of any fractions as it was shown by t-test analysis.

4.2.2.4 Loaf Volume

ANOVA showed (figure 4-15) that when fractions treated either with improver A or B, the loaf volume of *Fine* and *Mid Fine* was significant ($p<0.05$) higher compared to *Super Fine*. While the rest fractions exhibited similar loaf volumes with *Super Fine, Fine* and *Mid Fine*. T-test analysis showed that the cysteine addition favored significant ($p<0.05$) the loaf volume of *Super Fine*, *Coarse* and *Regrind*.

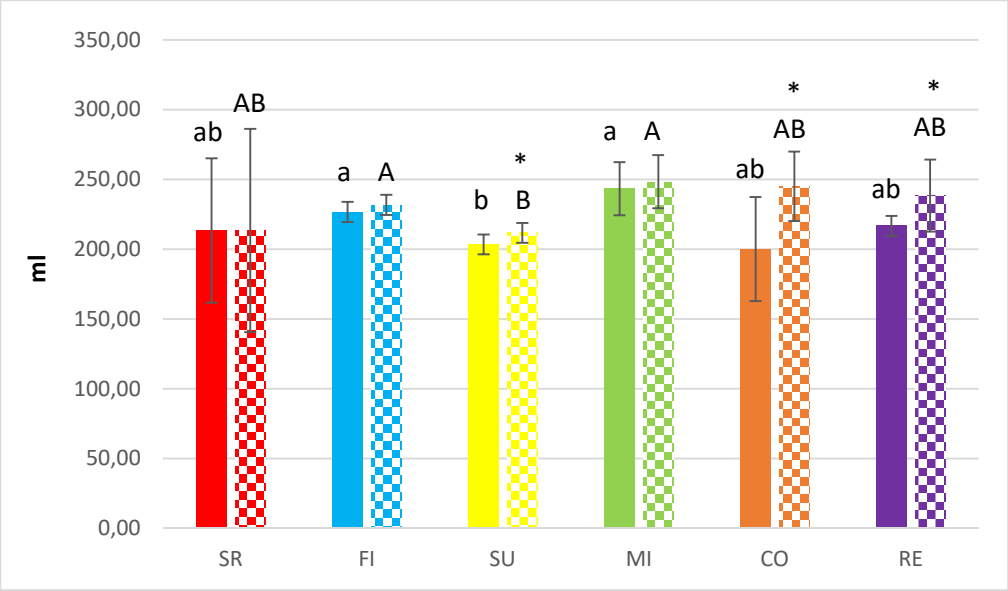


Figure 4-15. Loaf volume expressed in ml. ■ improver A and ▩ improver B. Each mean value obtained from three replicates. Bonferroni corrections used to compare the mean values and the different letters in the bars show significant difference at $p<0.05$ within each flour treatment (a b c d improver A, A B C D improver B). T-test used to compare the effect of improvers for each fraction, significant different at $p<0.05$ =*, $p<0.01$=**, $p<0.001$=***.

4.3 DISCUSSION

4.3.1. Physicochemical properties

4.3.1.1 Factors Which Affected the Particle Size Distribution

According to literature wheat hardness is positive related with flour particle size (Dexter, 1988 et al.; Pomeranz and Williams 1990; Eliasson and Larsson, 1993).The high variation of the particle size observed in the *Straight run* flour, could be explained by the presence of high proportion of starchy and non-fully vitreous kernels in the grist. In other words the irregularity of kernels hardness caused the irregularity of the flour particle size.

The extensive work on the milling performance undertaken by Campbell and his co-workers (2007) may explains further the wide particle size range of *Straight run* flour. According to their findings the particle size distribution produced by the 1st break (B1) determines the balance of flour streams through the rest of milling process. They have found that wheat hardness, rolls disposition and gap between the rolls have a critical impact on particle size distribution produced in 1st brake. By increasing the roll gap the particles become larger. Hard wheat produces narrower particle size, whereas soft wheat

produces a wider range of particles sizes. Moreover “Sharp to Sharp” disposition produces a narrower particle size compared to “Dull to Dull”, which produce a large proportion of fine and oversized particles. In addition they have concluded that the particle size distribution is increased substantially when “Dull to Dull” disposition is used to grind hard wheat. The roll disposition at 1st brake in Avlida mills was “Dull to Dull” (personal communication). According to them the “Sharp to Sharp” disposition will produce very fine bran particles which are difficult to be removed by the purifiers.

Thereby wheat hardness irregularity and roll pair disposition at the first break (B1) leaded to an imbalanced particle size distribution which affected the rest of the milling process. Based on that we can assume that this imbalance caused further pressure in the sieving and in the purification system. Specific sieving sections possibly were overloaded. Li et al (2002) found that when a specific sieving section is overloaded the small particles could not be segregated from the larger ones. The small soft particles do not pass freely through the sieve opening and adhered to sieve mesh (Hareland 1994, Posner and Hibbs 1997). Therefore a large proportion of these particles were rejected by the sieving screen and followed the same path as the larger particles and became even finer in the next reduction passage.

The existence of the large proportion (i.e.46%) of oversized particles (200μm) could not be explained only by the roll disposition in the breaking section and the variation of the kernels hardness. The desired flour granulometry and particle size distribution are mainly determined in the reduction section. Moreover other milling settings in this section like roll gap have an important influence on the particle size. It should be noted that in specific milling section the rolls are smooth which causes damage to starch (Campbell et al., 2007). An extended and well balanced reduction section produces flour with narrower granulometry. However the reduction section of a durum flour mill is less extended compared to common soft and hard wheat flow diagram. The reason is that starch damage will increased dramatically if the durum flour reduced several times. That’s why durum semolina and flour are reduced gradually five or three times (Gruber and Sarkar, 2012). Avlida mill owners verified (personal communication) that according to their flow diagram semolina and flour are gradually reduced three times. In addition, in order to limit the starch damage in reduction section the gap opening between the roll pairs is wider

compared to common wheat milling. However this is positive related with durum flour particle size and granulation variation.

4.3.1.2 Gluten Content

It has been seen that fractions of larger flour particle exhibited higher gluten content. In addition, in fraction where *Super Fine* was excluded like *Coarse* and *Mid Fine*, the gluten content was similar. This is in line with our previous hypothesis that Super Fine granulation is mirroring the proportion of starchy kernels in the grist. A further support to this hypothesis is derived from the work of Fortini et al (1975) who found that durum wheat vitreosity is positive correlated with protein content.

4.3.1.3 Zeleny sedimentation

In case of untreated fractions, results showed that only *Super Fine* exhibited lower sedimentation volume compared to the other fractions. According to literature (Moonen at al 1982, Eckert et al 1993), sedimentation volumes are affected only by glutenin content, since gliadins dissolved completely. Based on that two possible explanations can be given for the above result. First, the glutenin content was similar to all fractions except in *Super Fine* were it was lower. Second, the method is not very sensitive and high difference in glutenin content should occur in order to be identified. The latter was supported by Axford et al. (1979) who suggested that SDS sedimentation is more sensitive than Zeleny method on identifying differences in gluten strength in flours samples with similar properties. This was supported by the work of Eckert et al (1993) who they found that the swelling of the gluten was threefold when immersed in Zeleny solution while when immersed in SDS solution was fourfold. That is, is durum wheat is associated in general with low glutenin content therefore the moderate swelling power of Zeleny solution is incapable to produce results with statistical significance between samples with similar properties. This might be a reason which explains why so many workers in the field prefer SDS sedimentation over Zeleny.

In contrast to the above when the samples treated either with improver A or B the sensitivity of the method was increased. It was observed that lower difference in gluten content was required in order to obtain statistical significant different sedimentation values between the fractions. According to Adeyemi and Muller (1983) the addition of reducing agents such L-cysteine lower the sedimentation volume. Whereas the addition

of oxidizing agents such as ascorbic acid have no effect (Linko and Chin, 1962). However according to the findings of this work the sedimentation volume was not impacted negatively by the addition of the L-cysteine. Statistical analysis showed the when fractions treated with improver B *Regrind* was associated with higher sedimention volume compared to *Coarse.* Two possible explanations could be given for this finding. First, the degree of milling had an impact on the chemical properties of flour, severe grinding may lead to additional formation of SS bonds and the additioin of L-cysteien rebalanced the system and favored the sedimentation volume. Second, the particle size difference may be another reason. The time needed for a liquid to diffuse from the surface to the center of the particles is highly correlated with the size of particles (Hebrard et al., 2003). That is, the larger the particles the less time was available for gluten swelling and therefore the sedimentation volume was affected negatively. In addition the high specific weight of *Coarse* flour particles may cause further setting in Zeleny solution and thereby a lower sedimentation volume was obtained.

4.3.1.4 Falling Number

Data obtained from Falling Number (FN) tests showed a low level of α-amylase activity, with values ranging from 415 (i.e. *Super Fine*) to 592 sec (i.e. *Coarse*). This is line with previous works in the field .A study conducted by Boggini (1985) for Italian durum wheats showed FN values ranging from 264 to 526 sec, even higher values obtained for durum wheats originated from Cyprus where FN values ranging from 499 to 775 sec (Josephides, 1996). Holm (1985) identified significant difference between common and durum wheats in FN values with the former exhibiting lower values. According to Quaglia (1988) the high FN values obtained are typical for wheat cultivated in hot and dry conditions. As Josephides (1996) pointed out these extremely high FN values may be beneficial to pasta products but detrimental for breadmaking, leading to heavy underdeveloped, hard bread. Although it is safer for millers to have a low level of endogenous α-amylase and to add fungal α-amylase to the appropriate level (Kruger and Reed, 1988). Banu et al. (2010) suggested that the variation in FN values between fractions is due to the different damaged starch level and no to α-amylase activity. This is line with our findings since *Coarse* and *Regrind* exhibited significant different FN values.

4.3.2 The Dough Behavior during Fermentation measured by Rheofermentometer

4.3.2.1 Dough development

It is generally accepted that the four main factors affecting dough rheology and behavior during fermentation are protein content, protein composition, starch damage and flour particle size.

Analysis showed that in case of gluten content, fractions associated with higher values exhibited higher dough volume and dough tolerance. This is line with Dexter et al. (1994) who found that the gluten content is of paramount importance regarding with dough behavior of durum wheat flour during fermentation. However ANOVA analysis showed that high difference in gluten content should occur in order significant statistical results to be obtained in terms of maximum dough expansion during fermentation i.e. Hm and final dough volume at the end of proving i.e. h. This was more evident when fractions treated with improver A than with improver B. When fractions treated with improver A the only statistical difference occurred between *Super Fine* and *Mid Fine* with latter to be associated with superior performance during fermentation compared to the former. Although this result may be related with the high variation observed between the tests replications especially when fractions treated with improver A.

However the difference in gluten content cannot fully explain the behavior of fractions tested, this leads to the logical conclusion that is the gluten composition that may affects the dough properties during fermentation. It is generally accepted that the glutenin composition and its contribution to dough elastic properties is the main factor which determines the gluten strength (Boggini et al., 1994; Ammar et al 2000; Rao et al 2001; Edwards et al 2007). Although gliadins importance should not be underestimated since they contribute to viscosity and extensibility. An optimum gliadin to glutenin ratio is required for voluminous and stable dough during fermentation. Elasticity traps the CO_2 produced by yeast and thereby increase the gas retention capacity but also increase stiffness of the dough. Higher stiffness due to lower gliadin proportion leads to lower gas cell expansion (Hammer et al., 2009; Jayaram et al., 2014). Several studies have shown that durum wheat nonvitreous kernels are associated with lower proportion of gliadin (Fortini et al., 1975; Alessandroni et al., 1977; Dexter et al., 1989). Based on that we can assume that the *Super Fine* was associated with higher glutenin to gliadin ratio and thereby with stronger gluten properties than its gluten content implies. This may merely explains

why *Super Fine* demonstrated similar dough volume at the end of proving with *Straight run*, and *Coarse* when treated with improver A and similar final dough volume with *Straight run*, *Fine* and *Regrind* when treated with improver B. Also the increased gluten stiffness due to higher proportion of glutenins in the *Super Fine* fraction may explains why the said fraction exhibited similar dough expansion rate i.e. T1, with the most fractions either treated with improver A or B despite the high difference in gluten content. The importance of gluten composition of fractions tested and its impact on dough behavior during fermentation can be highlighted by the addition of L-cysteine. Cysteine reduces SS bonds between proteins (Bloksma, 1990a) and thereby reduces the molecular weight of glutenin polymer (Staufer, 1990). That is, a more balanced glutenin to gliadin ratio can be achieved. However the addition of cysteine did not differentiate the behavior of *Super Fine*. Although a positive trend can be observed, especially in case of dough volume at the end of fermentation.

Dough behavior during fermentation cannot solely be explained based on gluten content and composition. Starch damage has a strong positive effect on dough stiffness and density and negative to elasticity (Vinci et al., 2013). This effect is more severe on dough prepared from durum wheat flour. Since it is associated with inferior gluten properties compared to common wheat. Starch damage absorbs its own weight in water (Manley et al., 2011). During mixing damage starch granules compete with gluten for available water and thus prevents optimal gluten development. The negative effect of high starch damage content of durum flour on breadmaking performance have been demonstrated by (Dexter et al., 1994). In order to examine the effect of starch damage on fermentation properties we should focus only on *Coarse* and *Regrind* fractions since they were of the same origin and did not differ in gluten content and composition. The difference in starch damage between these fractions was almost double i.e. *Coarse* = 5.33%, *Regrind* = 9.83. In contrast to previous studies ANOVA showed that Regrind exhibited better tolerance during fermentation i.e. Hmd ($p \leq 0.01$) and lower rate of development T1 ($p \leq 0.01$) compared to *Coarse* when fractions treated with improver A. While when fractions treated with improver B no significant difference was identified between these two fractions. A possible explanation to this odd result can be based on dough firmness. We can assume that due to higher dough firmness of *Regrind* less air was incorporated in the dough (Campbell et al., 1993, 2001, Bellido et al., 2006). Chiotellis and Campbell (2003a, b) proposed that the rate of gas diffusion is dependent of air bubbles incorporated during

mixing which serve as nuclei for the expansion of CO_2 produced during fermentation. Moreover according to Verheyen et al (2015) the rate of dough development is negative related with the dough stability during fermentation. The above reasoning leads to a quite contradictory conclusion, the firmer the dough due to higher starch damage the more efficient to cope with starch damage destabilization effect. Since this assumption is hard to be plausible, a different dough stabilization mechanism than the above occurred. A possible explanation could be given based on the findings of Okada et al (1987). They found that excessive flour regrinding by roller milling cause oxidation of SH groups in the flour and thereby gluten becomes firmer and the dough stiffer. That is, the enhanced dough oxidation stabilised the dough during fermentation and counteracted the destabilization effect caused by the increased starch damage content.

T-test analysis showed that the addition of L-cysteine had a significant positive impact on maximum dough expansion i.e. Hm, on *Coarse* fraction. A number of previous studies have identified that cysteine addition reduces the mixing time and leads to earlier dough development (Pomeranz, 1988; Angiolini and Rosa 2007). Moreover mixing time is positive related with flour particle size since increased time is required for optimum dough hydration. Mixing time have been proven that is the most important factor affecting dough development (Ktenioudaki et al., 2010). In this study the mixing time was fixed. That is, large particles need more time to hydrate and longer mixing time is required, the addition of cysteine reduced the mixing time and the dough was fully developed. Thereby exhibited enhanced viscoelastic properties.

The effect of particle size distribution on dough development may explain why *Straight run* did not exhibit higher dough volume and tolerance during fermentation compared to *Fine*, despite the fact that it was associated with higher gluten content. *Straight run* particle polydispersity probably had a negative impact on flour components optimum hydration and viscosity, and thereby the dough was less tolerant during fermentation.

4.3.2.2 Gas Formation

Dough behavior during fermentation does not solely rely on its viscoelastic properties the rate and the total gas production have also a critical impact. The major factors affecting the CO_2 production are the presence and the level of fermentable sugars, dough temperature, yeast concentration, starch damage level and the α-amylase activity.

It is common belief that starch damage content is one of the most critical factors affecting the rate of CO_2 and the total gas production. However according to ANOVA this assumption holds only in case of comparing *Mid Fine* with *Super Fine*. The rate of gas production of the latter was significant higher compared to the former. Although the total gas production between these two fractions was similar. Furthermore ANOVA showed that in this work the effect of starch damage content on yeast fermentation was moderate or not so evident. Since the *Coarse* exhibited similar gas formation properties with fractions which were associated with significant higher starch damage content. A characteristic example is the similar rate of CO_2 formation i.e. TG and the total gas i.e. TV produced between *Coarse*, *Super Fine* and *Regrind*. These findings suggest that in this study other factors of equal importance to starch damage affected the rate and the total gas formed during fermentation.

The yeast will firstly consume the naturally present sugars and then will turn to maltose produced through starch hydrolysis from amylolytic enzymes (Chiotellis and Campbell 2003a, b). Durum wheat is associated with higher natural sugar content compared to bread wheat (Toepfer et al 1972, Holm 1985). This means that the importance of maltose fermentation might be limited in case of durum wheat flour. It has been found that different parts of the wheat kernel associated with different level of reducing sugars. The flour which contains high proportion of outer layers contain more sugar than that of clear endosperm (Mac Arthur and D'Appolonia 1976). Since bran contains more sugar than the endosperm does (Cerning and Guilbot, 1974). In addition it has been reported that vitreosity and reducing sugars content are positive related (Rharrabti et al., 2001). The above may explain the non-linear relationship between starch damage and gas production observed in this study.

Another reason which might explains the moderate effect of starch damage content on CO_2 and the total gas production is the dough temperature during fermentation. In this study the temperature in Rheofermentometer was set at 32^0C. According to literature the action of α- amylase is more intense in temperatures above 40^0C (Kulp, 1993). Therefore the maltose production through starch hydrolysis of damaged starch granules was limited by the dough temperature.

Another factor which affects yeast fermentation is the amino acids concentration and composition (Cruz et al 2002). Turkia et al. (2015) have found the aspartic acid, glutamine and glutamic acid are the most important essential amino acids for yeast growth. In a study contacted by Dexter et al. (1988) on durum wheat, it was found that vitreosity had a significant impact on the amino acid composition. According to their results durum wheat vitreosity was positive related with glutamic acid, proline and phenylalanine while it was negative related with lysine, arginine aspartic acid, threonine, glycine, alanine and methionine. This may be another factor which perplexed the yeast activity and the gas formation in each fraction.

It has been seen that the addition of L-cysteine had a significant positive impact on gas formation rate i.e. TG in *Mid Fine* fraction. One explanation may derives from Maw (1960) findings. He observed that L-cysteine at low dosages increased yeast growth in cases where low concentrations of sulphate occurred. Another possible explanation may be derived from the impact of L-cysteine on gluten proteins. A large proportion of β-amylases is being bound to glutenins through S-S bonds (Eliasson and Larsson, 1993). That is, L-cysteine addition reduced the protein macropolymer and freeing β-amylases and this favored the maltose production and the rate of gas production.

4.3.3 Geometrical Properties during Breadmaking

4.3.3.1 The Dough Geometrical Properties after Moulding and at the end of Proving

The aim of dough rounding is to cause the gluten hardening and to build up a more cohesive and thicker structure and thereby to stabilise the dough. (Kieffer and Stein, 1999).The action of dough rounding has a degassing effect and it depends of the mechanical action applied to the dough (Cauvain, 2012). In this work the dough degassing was limited since the dough was gently hand rounded. After ten minute of resting the dough was mechanical moulded. The aim of moulding is to create a uniform dough cylinder of the required length and width. This is achieved by the passage of a round dough piece through a set of parallel cylinders in order to be sheeted and then to be rolled up to "swiss roll". Therefore the resulting dough shape and length is affected or manipulated by: 1) the moulder type i.e. the number of roll pairs and the length of the moving and the static belt in which the dough is curled, 2) the moulder settings i.e. the gap between the rolls and the gap between the moving and static belt, (Ren et al 2008; Cauvain 2012).

The time span between dough mixing and dough moulding is quite critical since it affects the rheological properties of the dough. In particular several studies have dealt with the effect of resting time on dough properties. According to Belderock (2000) the gas retaining properties of dough are developed at this stage. The yeast starts to produce gas and the extent of CO_2 rate production depends on the length of resting time and the dough temperature. It could be assumed that in this work the rate of gas production at this stage was moderate since the temperature of the dough at end of mixing was 30oC, the cabinet temperature 22oC and the resting time in total was 20 minutes. The longer the resting time, the greater will the changes in dough rheology (Cauvain, 2012). Moreover the higher the gluten content and the strength the greater the dough recoil will be after moulding (Ren et al., 2008). This means that the length and the width of dough heavily depends on the gluten content and its elastic properties. According to ANOVA the gluten content of each fraction played a limited role on dough length after moulding, while the dough width was unaffected. The only statistical significant difference was between *Super Fine* and *Mid Fine* with the former to be lengthier than the latter, when fraction treated with improver A and between *Straight Run* and *Super Fine* when fractions treated with improver B

According to March and Cauvain (2007) an increased resting time reduces dough elastic properties and therefore reducing agents should be excluded from the dough formula otherwise gluten properties will be eliminated to a great extent. In other words the resting time could be reduced by using reducing agents like L-cysteine. However it has been seen that when fractions treated with improver B the only statistical difference in dough length occurred between *Straight run* and *Super Fine* fractions, where the former was shorter than the latter.

The above findings lead us to hypothesise the following. First all fractions were associated with similar gluten strength and the difference in gluten content among fractions did not had a significant impact. Second the level of cysteine was too low and thereby the impact on dough elastic properties was not significant. Although t-test analysis identified that the cysteine addition had a significant impact on dough length in *Coarse* and *Mid Fine* fractions. This may suggests that cysteine impact is positive related with gluten content and elasticity. This hypothesis is supported by previous works (Henika and Rogers, 1965; Chamberlain et al 1967; Calal et al 1978) which have shown that the

response to added cysteine is positive influenced by gluten content and strength. Third the resting time was too short and thus insufficient to exert differences on gluten properties between fractions. If that is true, then the impact of gluten content and strength should be better be discriminated at the end of fermentation. However, according to ANOVA the dough width between the fractions was similar either treated with improver A or B. The only statistical significant result obtained was that the length of *Mid Fine* was shorter compared to *Straight run* and *Super Fine* and that occurred only when fractions treated with improver A. While when fractions treated with improver B the dough length among fractions was similar. The cysteine added had again significant positive impact on dough length on *Mid Fine* and *Coarse*. The above results suggest that the differences in gluten properties between the fractions tested were not better discriminated at the end of fermentation.

4.3.3.2 Loaf Dimensions

It has been seen that when fractions treated with improver A, gluten content had a moderate impact on dough length. Whereas when treated with improver B the impact of gluten content on dough length was reduced. According to t-test analysis cysteine addition increased significant the loaf length of *Mid Fine*, *Coarse* and *Regrind* fractions. This is in the line with previous observations that cysteine is more active when the gluten content is increased. Again no significant difference observed for the loaf's width between different fractions either treated with improver A or B. The reason for that is unclear. Moreover the impact of gluten content was moderate regarding the height of theloafs. Since the height of the *Super fine* was significant lower only compared to *Fine*, *Mid Fine* and *Regrind* when fractions treated with improver A. While when improver B was added the loaf height of all fractions was similar. According to t-test analysis only *Super Fine* responded positively to cysteine addition.

In this study the baking experiment was the production of hearth bread, which is made without a tin. The reason for that is the bread made by durum wheat flour is usually hearth bread. However the most scientific work is based on pan bread production and little attention has been paid to hearth bread (Faergestad et al., 1999). Hearth bread is more complicated than pan bread, because the dough is not supported by the tin. Therefore both form and loaf volume are critical characteristics. Furthermore width to height ratio is of utmost importance (Faergestad et al., 1999). Faergestad and co- workers extensive work

on the relation of the protein content and strength of common wheat with hearth bread properties (Faergestad et al., 1999, 2000, 2004), showed that gluten strength is more important than gluten content on both loaf height and width to height ratio i.e. BH/BW. In particular gluten strength is positive related with loaf height and BH/BW ratio. However in this study fractions exhibited similar ratios either treated improver A or improver B. This leads to the following hypotheses. First, all fractions exhibited similar gluten strength irrespective the improver treatment. Second, the proving time was too short and thereby the discrimination of the gluten properties was limited. Third, the level of the added cysteine was too low.

4.3.4 Loaf Volume

According to ANOVA the gluten content had a moderate effect on loaf volume either the fractions treated with improver A or B. In other words the difference in gluten content cannot explain the loaf volume of the fractions. Since fractions with significant different gluten content exhibited similar loaf volume. A characteristic example is the similar loaf volume obtained between *Straight run*, *Super Fine*, *Coarse* and *Regrind* either treated with improver A or B.

In contrast to previous work (Dexter et al., 1994), the negative impact of high starch damage content on loaf volume was not evident in this study. Since *Regrind* and *Coarse* exhibited similar loaf volumes either treated with improver A or B. Moreover this finding suggests the durum wheat flour particle size had a minor impact on loaf properties. This result is in line with Sapirstein et al (2007) who found that both reduced and unreduced durum wheat flour particles exhibited similar loaf volume.

T-test analysis showed that the addition of L-cysteine had a positive impact on the loaf volume of *Super Fine*, *Coarse* and *Regrind*. As it was suggested earlier in the fermentation section, a different improving mechanism may be responsible for each of these fractions. It was suggested that *Super Fine* was associated with higher gliadin to glutenin ratio and the addition of L-cysteine balanced the ratio and favored dough extensibility and that leaded to higher loaf volume. In case of *Coarse* it is suggested that when was treated with improver A the dough was underdeveloped, the cysteine leaded to full dough development and thereby to higher loaf volume. While, in case of *Regrind*, cysteine reduced the dough stiffness and favored gas retention capacity and thus leaded to higher loaf volume.

However, these assumptions fail to explain why the rest fractions did not responded to cysteine addition.

According to Licciardello et al (2013) excessive protein oxidation and S-S bond formation in durum flour dough may be detrimental to loaf volume, since it increases dough stiffness and reduces extensibility. Durum wheat flours which exhibit high tenacity and low extensibility are strongly negative correlated with bread volume (Quaglia, 1988). Okada et al (1986) have found that excessive regrinding by roller milling cause oxidation of SH groups in the flour. A possible reason for that is the flour temperature increase. This could be more evident in durum wheat milling, since higher energy have to be applied to grind it especially in the reduction section. Climatic conditions have also an impact on flour temperature during milling. It should be noted that the flour samples were purchased in June, when normally the temperature in Greece is near or above 30^0C.

It was suggested earlier that *Super Fine* was subjected to excessive regrinding compared to the rest fractions expect to *Regrind*. Thereby these two fractions were oxidized into a greater extent than the rest. The addition of L-cysteine present in the improver B reduced the excessive protein oxidation of these two fractions caused by the regrinding and ascorbic acid addition. The dough became less stiff and more extensible and therefore expanded for longer time during baking.

The above reasoning reflects the belief that cysteine is the opponent of ascorbic acid. Since cysteine splits disulphide bonds and thus counteracts the effect of ascorbic acid if they used at the same time. However according to Kieffer et al. (1990) ascorbic acid and cysteine might have a synergistic effect. They have found that when cysteine was combined with ascorbic acid the latter became more active. This effect was more evident at low glutathione concentrations and became insignificant at higher concentrations. The levels of glutathione in flour are positive related with the extraction grade (Sarwin et al., 1992). Based on this it is tempting to assume that the different response of fractions to improver B might be related with the level of glutathione present in each fraction.

4.4 CONCLUSION

A wide particle size distribution was found in the *Straight run*. It was suggested that the reasons for that were the high percentage of starchy kernels in the grist and the mill settings. According to literature the flour obtained from starchy kernels is finer compared to this obtained from vitreous kernels. Moreover the roll disposition in the first break and the short reduction section in the mill further contributed to the wide size particle distributing. Based on these it is suggested that the severe grinding had greater impact than the kernel hardness on *Super Fine* starch damage content. In addition it was found that the gluten content and Zeleny sedimentation were affected by the particle size. The finer the particle size the lower the values of the said physicochemical properties. This finding strengthens further the belief that *Super Fine* was mirroring the starchy kernels in the grist. Zeleny sedimentation seems to be better correlated with gluten content rather than with gluten strength. Otherwise we should accept that all fractions had similar gluten strength. However, the sensitivity of the method was increased when fractions were treated with the improvers. The FN values found are typical for durum wheat cultivated in the Mediterranean basin. Also the degree of grinding was negative related with FN values.

The gluten content had a moderate impact on dough the behavior during fermentation. It was found that the gluten content effect on dough rheology was more evident at the end of proving. The addition of improver B impacted positively the maximum dough development of *Coarse*, whereas the rest of fractions did not affected significantly. It is suggested that the dough tolerance value i.e. Hmd is quite sensitive to gluten content differences. Moreover it is speculated that the gluten of *Super Fine* is much stronger than its gluten content implies. Evidence for this is the similar and h values of the said fraction with *Straight* run and *Coarse* when fractions treated with improver A and similar values with *Straight run*, *Fine* and *Regrind* when fractions treated with improver B. A possible explanation for this is derived from the fact that durum starch kernels are associated with lower gliadin content and therefore with higher gliadin to glutenin ratio and thereby with more elastic gluten.

It was found that the particle polydispersity affects negative the dough behavior during fermentation, since *Straight run* exhibited similar dough properties with *Fine* despite their difference in gluten content.

In contrast of what it was expected, the level of starch damage did not impacted negative the dough tolerance. A possible explanation may be derived from a previous work, where it was found the severe grinding which is responsible for high starch damage reduces the proteinase level and cause oxidation of SH groups in the flour. Thereby the gluten becomes stronger and capable to counteract the destabilization effect of starch damage.

The total and gas production rate could not be explained solely on starch damage content. A number of reasons may contributed to that. The content of natural sugars present in each fraction may were different. In addition according to literature the amino acids composition have an effect on yeast activity and may differ from fraction to fraction. Moreover it was found that in some cases cysteine promoted the gas production. The geometrical properties of the dough after moulding, proving and baking are of great importance especially in case of hearth bread. Gluten content had a moderate impact on these measurements. In addition it was found that cysteine effect was more evident in fractions with higher gluten content.

According the findings described in this chapter gluten content is not a great predictor of loaf volume. In addition it was found that flour particle polydispersity had a negative impact on loaf volume by reducing polydispersity a higher loaf volume may be obtained. Moreover reducing the particle size did not responded to higher loaf volume. The loaf volume obtained by *Coarse* was similar with *Regrind* either treated with improver A or B. This implies that the impact of starch damage in loaf volume was moderate. The addition of cysteine increased the loaf volume of *Super fine*, *Coarse* and *Regrind*. They have been proposed four hypotheses which may explain these findings. First the dough from *Coarse* fraction was not fully developed when treated with improver A due large particle size, the addition of cysteine (present in improver B) favored dough development and thereby the rheological properties were enhanced. Second, in case of *Super fine*, cysteine increased the extensibility of the dough by reducing the gliadin to glutenin ratio. Third, the excessive regrinding of *Super fine* and *Regrind* caused oxidation of SH groups in flour which was further induced by the addition of improver A. The cysteine added

reduced the excessive oxidation and the dough became softer and more extensible and this leaded to higher loaf volume. Fourth the three said fractions were associated with lower glutathione content and cysteine addition promoted the action of ascorbic acid.

With poor predictions from the analysis of the flour fractions and loaf quality a greater understanding of the rheological performance of the doughs was developed and analysed in the next chapter.

CHAPTER 5. THE RELATIONSHIP BETWEEN THE RHEOLOGICAL TESTS AND THE PROPERTIES OF THE DURUM WHEAT FLOUR

5.1 INTRODUCTION

It is generally accepted that the physicochemical properties determine the rheological behavior of the dough. Over the years a number of empirical rheology tests have developed and adopted in research and in industry. They are commonly divided in two categories to those describing the dough rheology during mixing and to those describing the extensional properties of the dough. However the relationship of these methods with the physicochemical properties of flour is often weak. Moreover the sensitivity on effect of improvers is often limited. This have led many workers in the field to propose some modifications on dough preparation and measuring procedure.

In this chapter it will be presented the impact of the physicochemical properties of the durum flour fractions on dough rheology during mixing. Therefore the findings of the Farinograph and Consistograph tests will be presented and analyzed. Also it will be presented and analyzed the relationship of the four Alveographic modifications with flour properties. In addition it will be presented and discussed the impact of the improvers on dough rheology and sensitivity of the above methods on improver treatments.

5.2 RESULTS

The samples used are the same durum wheat fractions described in the previous chapters (see section 3.3 and table 3.1). The methods used are given in section 3.4 and described in details in the Appendix.

5.2.1 Farinograph

Analysis showed (table 5-1) that *Regrind* fraction had the highest water absorption capacity (WA), followed by *Super Fine*. While *Coarse* exhibited the lowest water absorption capacity. The addition of improvers A and B did not change the order in water

absorption capacity between the fractions. *Super Fine* exhibited the lowest development time (DT) among all fractions. The addition of improver A did not change the order of development time between the fractions. However when improver B was added all fractions exhibited similar development time. *Regrind* and *Super Fine* exhibited the lowest mixing stability (CD) compared to all other fractions. Interestingly when improver A was added *Super Fine* exhibited the lowest CD. When improver B was added *Regrind* and *Super Fine* associated with lower CD ($p<0.05$) compared to only *Straight run* flour. *Super Fine* and *Regrind* exhibited the lowest mixing tolerance (MT) among all fractions, whereas *Coarse* the highest. The addition of improver A did not change the order in mixing tolerance behavior. The same is true when improver B was added with one exception, the *Fine* fraction exhibited similar MT to all fractions.

Table 5-1. Farinograph results for control, improver A and B treatments. Each mean value obtained from three replicates. Bonferroni corrections used to compare the mean values and the different letters (a, b, c, d) in the columns show significant difference at $p\leq0.05$ within each flour treatment, comparison for the improvers (control, A+B) are noted by A, B, C

	WA			DT			CD			MIX TOL		
Fraction	Control	A	B	Control	A	B	Control	A	B	Control	A	B
Straight	$64,5^{aA}$	$64,4^{aA}$	$64,7^{aA}$	$2,0^{aA}$	$2,1^{aA}$	$2,1^{aA}$	$2,8^{abA}$	$2,2^{acA}$	$2,9^{aA}$	$50,0^{acA}$	$66,7^{acA}$	$63,3^{aA}$
Fine	$64,1^{aA}$	$63,9^{aA}$	$64,0^{aA}$	$2,0^{abA}$	$2,0^{aA}$	$1,7^{aA}$	$2,0^{abA}$	$1,7^{abcA}$	$2,2^{abA}$	$71,7^{aA}$	$76,7^{aA}$	$96,7^{abcA}$
Superr Fine	$66,5^{bA}$	$65,5^{bB}$	$65,7^{bC}$	$1,5^{bA}$	$1,6^{bA}$	$1,6^{aA}$	$1,4^{aA}$	$1,3^{bA}$	$1,2^{bA}$	$100,0^{bA}$	$116,7^{bB}$	$120,0^{bB}$
Mid Fine	$62,7^{cA}$	$63,2^{cB}$	$63,1^{cC}$	$2,1^{aA}$	$2,1^{aA}$	$1,9^{aA}$	$2,1^{bA}$	$1,8^{abcA}$	$2,3^{abA}$	$63,3^{aA}$	$70,0^{aB}$	$70,0^{aAB}$
Coarse	$62,0^{dA}$	$62,0^{dA}$	$62,0^{dA}$	$2,6^{aA}$	$2,6^{aA}$	$2,3^{aA}$	$3,0^{bA}$	$3,1^{cA}$	$2,1^{ab}$	$46,7^{cA}$	$61,7^{cB}$	$66,7^{aB}$
Regrind	$69,0^{eA}$	$67,7^{eA}$	$67,7^{eA}$	$2,2^{aA}$	$2,1^{aA}$	$1,8^{aB}$	$1,5^{aA}$	$1,3^{abA}$	$1,5^{bA}$	$80,0^{dA}$	$106,7^{bB}$	$96,7^{cB}$

Abbreviations: WA = water absorbing capacity, DT = dough development time, CD = mixing stability and MIX TOL = mixing tolerance, Control = untreated, A = improver A, B = improver B

The impact of improvers A and B in each fraction is also presented in Table 5-1. As can be seen the addition of improvers had an impact on water absorption capacity only in *Super Fine* and *Mid Fine* fractions. In the former the water absorption capacity was decreased by approximately 1%, whereas in the latter it was increased by 0.5%. The only significant impact ($p<0.05$) in development time can be observed in *Regrind* fraction, where the addition of improver B lowered DT. In the case of mixing stability improver A and B did not have a significant impact in any fraction ($p>0.05$). The addition of both improvers decreased the mixing tolerance of *Super Fine*, *Coarse* and *Regrind* fractions ($p<0.05$), while in case of *Mid Fine* the MT was reduced significant only when treated with improver A

5.2.2 Consistograph

5.2.2.1 Consistograph constant hydration protocol

Table 5-2 shows, that the *Mid Fine* and *Coarse* exhibited the highest PrMaxs value among all fractions, followed by *Regrind*. Moreover *Straight run* flour, *Fine* and *Super Fine* exhibited similar PrMax values. The addition of improver A slightly changed the order, *Straight run* flour and *Super Fine* exhibited lower PrMax values compared to *Fine*. In addition *Regrind* exhibited similar PrMax values to all other fractions. *Mid Fine* exhibited higher PrMax compared to *Straight* grade flour and *Fine*, whereas similar values obtained for *Mid Fine*, *Fine*, *Regrind* and *Coarse.*When fractions treated with improver B *Mid Fine* and *Coarse* exbited the highest PrMax values compared to the rest fractions.

Table 5-2. Consistograph Constant hydration protocol results for control, improver A and B treatments. Each mean value obtained from three replicates. Bonferroni corrections used to compare the mean values and the different letters (a, b, c) in the columns show significant difference at $p<0.05$ within each flour treatment, comparison for the improvers (control, A+B) are noted by A, B, C

	PrMax			WA			HYDHA		
Fraction	Control	A	B	Control	A	B	Control	A	B
straight	2547^{aA}	2434^{aA}	2508^{aA}	55^{acA}	54^{aA}	55^{aA}	52^{acA}	52^{aA}	52^{aA}
fine	2605^{aA}	2598^{bdA}	2555^{aA}	55^{aA}	55^{aA}	55^{aA}	53^{aA}	52^{aA}	52^{aA}
super fine	2507^{aA}	2413^{aA}	2519^{abA}	55^{aA}	54^{aA}	55^{abA}	52^{aA}	52^{aA}	52^{abA}
mid fine	3001^{bA}	2792^{cdB}	2872^{bC}	57^{bA}	56^{bB}	56^{bB}	54^{bA}	53^{bB}	54^{bB}
coarse	2867^{bA}	2699^{dB}	2777^{bB}	56^{bA}	55^{abAB}	56^{bB}	54^{bA}	53^{abAB}	53^{bB}
regrind	2760^{cA}	2743^{abcdA}	2819^{abA}	56^{cA}	56^{abA}	56^{abA}	53^{cA}	53^{abA}	53^{abA}

Abbreviations: PrMax = maximum pressure value recorded, WA = 1700mb equivalent hydration rate based on 15% water, HYDHA= 2200mb equivalent hydration rate based on 15% water. Control = untreated, A = improver A, B = improver B.

The impact of improvers A and B in each fraction is also presented in Table 5-2. As can be seen the addition of improvers had significant impact on *Mid Fine* and *Coarse* fractions. In case of *Mid Fine* both improvers lowered PrMax. In particular the drop in PrMax was higher when *Mid Fine* treated with improver A rather than when treated with improver B. In case of *Coarse* both improvers lowered Prmax to the same extent.

5.2.2.2 Consistograph adopted hydration protocol

Table 5-3. Consistograph Adopted hydration protocol results for control, improver A and B treatments. Each mean value obtained from three replicates. Bonferroni corrections used to compare the mean values and the different letters (a, b, c, d) in the columns show significant difference at $p<0.05$ within each flour treatment, comparison for the improvers (control, A+B) are noted by A, B, C

	PrMax			TPrMax			D250			D450			WAC		
Fraction	Control	A	B	Control	A	B	Control	A	B	Control	A	B	Control	A	B
straight	$2380,3^{acA}$	$2387,7^{aA}$	$2352,7^{aA}$	$185,3^{acA}$	$200,7^{abcA}$	$165,7^{aA}$	$131,3^{abA}$	$82,7^{abcA}$	$203,3^{aA}$	$426,3^{abA}$	$437,7^{adA}$	$486,7^{aA}$	$57,7^{abA}$	$56,6^{abcdA}$	$56,8^{abA}$
fine	$2371,0^{aA}$	$2184,3^{bB}$	$2259,0^{aAB}$	$182,0^{acA}$	$182,0^{aA}$	$168,0^{aA}$	$133,3^{abAB}$	$80,3^{bA}$	$158,7^{aB}$	$486,3^{aA}$	$346,7^{abB}$	$425,0^{aC}$	$57,1^{aA}$	$55,5^{adB}$	$55,8^{aB}$
super fine	$2135,3^{bcA}$	$2107,7^{bcA}$	$2291,7^{aB}$	$248,0^{bA}$	$274,3^{bB}$	$228,0^{bcA}$	$1,5^{abA}$	$10,0^{aA}$	$14,3^{bA}$	$288,0^{bA}$	$251,7^{bcA}$	$412,7^{aB}$	$54,8^{bA}$	$54,2^{bB}$	$56,0^{aC}$
mid fine	$2152,0^{cA}$	$2244,0^{abcAB}$	$2299,0^{aB}$	$248,7^{aA}$	$262,0^{abcAB}$	$175,3^{aB}$	$72,0^{abA}$	$69,7^{abcA}$	$100,7^{abA}$	$243,7^{bcA}$	$288,0^{abcdAB}$	$392,7^{aB}$	$57,1^{aA}$	$56,6^{acdA}$	$57,4^{bA}$
coarse	$2350,0^{abcA}$	$2436,3^{aA}$	$2514,7^{bB}$	$155,7^{cA}$	$160,3^{acA}$	$170,3^{abA}$	$236,3^{aA}$	$196,7^{cA}$	$210,3^{abA}$	$526,7^{aA}$	$511,7^{dA}$	$563,7^{aA}$	$57,6^{aA}$	$58,3^{cAB}$	$59,8^{cB}$
Regrind	$2268,0^{acA}$	$2115,7^{cB}$	$2186,7^{aAB}$	$262,7^{bA}$	$261,0^{bA}$	$243,3^{cA}$	$8,3^{bA}$	$7,3^{aA}$	$1,7^{bA}$	$231,3^{cA}$	$220,3^{cA}$	$268,7^{aA}$	$56,6^{aA}$	$55,6^{dA}$	$56,4^{abA}$

Abbreviations: PrMax = maximum pressure value recorded, TPrMax = time in seconds needed for maximum pressure, D250 = drop in pressure after 250 seconds, D450 = drop in pressure after 450 seconds, WAC = WA fine-tuned value after adopted hydration test. Control = untreated, A = improver A, B = improver B

Analysis showed (table 5-3) that *Super Fine* and *Mid Fine* exhibited a lower PrMax ($p<0.05$) compared to *Fine*. When fractions treated with improver A, *Super Fine*, *Regrind* and *Fine* exhibited lower PrMax compared to *Straight run* and the *Coarse* fraction. When improver B was added all fractions exhibited lower PrMax values compared to *Coarse,* which exhibited lower TPrMax compared to *Super Fine*, *Mid Fine* and *Regrind*. The same hold true when fractions were treated with improver A, except *Coarse* that exhibited a similar TPrMax with *Mid Fine*. When fractions treated with improver B *Regrind* exhibited the highest TPrMax compared to other fractions except to *Super Fine*. In case of D250 *Regrind* exhibited a significantly lower value only compared to *Coarse*. When fractions were treated with improver A a better discrimination between fractions was achieved. *Regrind* and *Super Fine* exhibited a significantly lower D250 followed by *Fine*. When fractions treated with improver B, both *Regrind* and *Super Fine* exhibited significant lower D250 compared to Straight run. In case of D450 both *Regrind* and *Super Fine* exhibited significant lower values compared to *Fine* and *Coarse*. In case of improver A the *Coarse* fraction exhibited the highest D450 among all fractions except *Mid Fine*. Interestingly when fractions were treated with improver B analysis showed that all fractions exhibited similar values.

The impact of improvers A and B in each fraction is presented also in Table 5-3. As it can be observed the addition of the two improvers affected the PrMax of all fractions except the *Straight run*. In particular the case of the *Fine* flour with improver A reduced the PrMax. Whereas in *Super Fine* PrMax was significantly higher when improver B was added compared to control and improver A treatments. PrMax impacted positively when improver B was added in *Mid Fine* compared to untreated. The same can be observed for *Coarse*. Improver A addition lowered PrMax compared to untreated in the case of the *Regrind*. In addition the L-cysteine addition lowered the TPrMax only of *Mid Fine*. While improver A had a positive impact on TPrMax of *Super Fine*. The impact of improvers on the mixing profile i.e. D250 and D450 was insignificant for most fractions. However the results showed that D450 parameter was more sensitive than D250.

5.2.3 Alveograph Standard and modified methods

5.2.3.1 Alveograph Standard and modified methods for untreated fractions

5.2.3.1.1 Standard method

The Regrind fraction exhibited the highest tenacity P among all fractions, (table 5-4) followed by *Coarse*. While *Fine* fraction associated with lower P value compared to *Mid Fine* and *Coarse*. In addition the *Regrind* fraction exhibited the lowest extensibility i.e. L value, and the highest P/L ratio compared to all fractions .Whereas *Fine* exhibited higher extensibility and lower P/L ratio compared with *Straight run*. *Super Fine* exhibited the lowest deformation energy value i.e. W compared to all fractions. Whereas the *Coarse* exhibited the highest W compared to all fractions ($p < 0.05$) except to *Mid Fine*.

5.2.3.1.2 Interrupted method

The *Fine* and *Super Fine* fractions exhibited the lowest P values (table 5-4). In addition *Regrind* associated with the highest P value followed by *Coarse*. In case of extensibity the *Regrind* exhibited the lowest L value. Analysis showed that the rest fractions associated with similar L values ($p > 0.05$). *Super Fine* exhibited the lowest W among all fractions except to *Regrind*. It should be noted that all the other fractions exhibited similar W values. *Super Fine* and *Fine* characterized by lower P/L ratio compared to *Straight run*, *Coarse* and *Regrind.* Again as in Standard method *Regrind* exhibited extremely high P/L ratio.

Table 5-4. Alveograph results from all methods for untreated fractions. Each mean value obtained from three replicates. Bonferroni corrections used to compare the mean values and the different letters (a, b, c, d) in the columns show significant difference at $p<0.05$ within each flour treatment, comparison for the improvers on W and P/L (control, A+B) are noted by A, B, C

	STANDARD METHOD							
	P	L	W			P/L		
fraction	Control	Control	Control	A	B	Control	A	B
straight	149,3 ^{abc}	40,7 ^{a}	244,3^{aA}	251,7^{aA}	248,3^{aA}	3,7^{aA}	4,0^{aA}	3,4^{bA}
fine	133,3 ^{a}	44,3^{b}	228,0^{aA}	253,7^{aA}	234,3^{aA}	3,0^{bA}	3,3^{bB}	2,6^{cC}
super fine	122,6 ^{ab}	37,3^{ab}	185,0^{bA}	200,3^{aA}	201,3^{aA}	3,3^{abA}	4,2^{abAB}	2,9^{acAC}
mid fine	155 ^{bc}	40,3^{ab}	263,7^{acA}	274,3^{aA}	244,7^{aA}	3,9^{abA}	3,8^{aA}	3,6^{aA}
coarse	159 ^{c}	42,3^{ab}	275,3^{cA}	248,3^{abAB}	253,7^{bB}	3,8^{aA}	4,3^{bB}	3,8^{acA}
regrind	212,3 ^{d}	26,7^{c}	245,0^{aA}	231,3^{abAB}	213,3^{bB}	8,0^{cA}	8,0^{aA}	7,0^{bB}
	ADOPTED HYDRATED METHOD							
	P	L	W			P/L		
fraction	Control	Control	Control	A	B	Control	A	B
straight	135,7^{a}	44,3^{a}	239,3^{aA}	231,3^{aA}	226,3^{aA}	3,1^{abAB}	3,4^{aA}	2,7^{bB}
fine	113,3^{b}	46,3^{a}	203^{abA}	212,0^{aA}	203,7^{aA}	2,5^{aA}	3,1^{aA}	2,7^{aA}
super fine	102,7^{b}	40,7^{ab}	165,3^{bA}	174,0^{aA}	161,3^{aA}	2,5^{abA}	2,6^{aA}	2,2^{aA}
mid fine	119,3^{ab}	46,7^{a}	226,7^{abA}	216,7^{aA}	208,7^{aA}	2,6^{abA}	3,0^{aA}	2,3^{aA}
coarse	137,3^{a}	42^{a}	238,3^{aA}	212,7^{aA}	237,0^{aA}	3,3^{bA}	3,8^{bB}	2,4^{cC}
regrind	176^{c}	26^{b}	205,7^{abA}	191,0^{aA}	201,0^{aA}	6,8^{cAB}	7,1^{aA}	5,5^{bB}
	INTERRUPTED METHOD							
	P	L	W			P/L		
fraction	Control	Control	Control	A	B	Control	A	B
straight	137,7^{a}	44,0^{a}	234,7^{aA}	243^{aA}	156,1^{aA}	3,1^{aA}	3,1^{aA}	2,9^{aA}
fine	119,7^{b}	51,7^{a}	218,3^{aAB}	230,0^{aA}	208,0^{bB}	2,3^{bAB}	2,5^{aA}	2,1^{bB}
super fine	92,7^{c}	52,0^{a}	160,0^{bAB}	177,0aA	159,3^{bB}	1,8^{cbA}	2,1^{aA}	1,8^{aA}
mid fine	139,3^{ad}	47,3^{a}	262,3^{aA}	253,3^{aA}	228,0^{aA}	3,1^{abcA}	2,7^{aA}	2,3^{aA}
coarse	146,3^{d}	45,0^{a}	262,0^{aA}	260,3^{aA}	254,3^{aA}	3,2^{aB}	3,4^{aA}	2,9^{bB}
regrind	201^{e}	25,7^{b}	228,0^{abA}	206,3^{aA}	201,7^{aA}	7,8^{dA}	7,1^{aA}	6,6^{aA}
	ALVEO-FARINO METHOD							
	P	L	W			P/L		
fraction	Control	Control	Control	A	B	Control	A	B
straightn	84,3^{a}	53^{ac}	170,7^{abA}	189,0^{bB}	207,0^{cC}	1,6^{abA}	2,3^{bB}	1,7^{aA}
fine	87,7^{b}	60^{a}	190^{aA}	205,7^{aA}	181,7^{aA}	1,5^{aA}	2,0^{bB}	1,8^{cC}
super fine	85,3^{abc}	44^{b}	148,3^{bA}	164,3^{aA}	161,3^{aA}	1,93^{bA}	2,6^{aA}	2,2^{aA}
mid fine	102,3^{cd}	46,3^{bc}	197^{abA}	171,0^{aA}	194,3^{aA}	2,2^{cA}	3,2^{bB}	2,2^{aA}
coarse	105,7^{d}	47,7^{bc}	207^{cA}	186,3^{aA}	198,3^{aA}	2,2^{cA}	3,3^{bB}	2,4^{aA}
regrind	109,7^{d}	34,3^{d}	167,3^{abAB}	133,7^{aA}	160,0^{bB}	3,2^{dA}	4,5^{bB}	2,8^{cC}

Abbreviations: P = tenacity, L = extensibility, W = deformation energy, P/L = configuration ratio.

5.2.3.1.3 Adopted hydration method

Among all the fractions the *Regrind* exhibited the highest tenacity (table 5-4), followed by *Straight run* and *Coarse*. In case of extensibility all fractions exhibited similar statistical results except *Regrind*, which was again as in previous methods extremely inextensible. Analysis showed that *Super Fine* associated with lower W compared to *Straight run* and *Coarse*. *Regrind* again as in previous methods was associated with extremely high P/L ratio.

5.2.3.1.4 Alveo-Farino method

Regrind and *Coarse* exhibited the highest tenacity among all fractions (table 5-4). It should be underlined that both fractions in this method showed similar P values, whereas in the previous methods the P values of these two fractions were significant different. Analysis showed that the *Fine* was the most extensible, followed by *Straight run*. Whereas the *Regrind* exhibited again as in the previous methods was associated with the lowest L value. The highest P/L ratio achieved by *Regrind* while the lowest by *Fine*. In addition Coarse exhibited the highest W value.

5.2.3.2 The impact of improvers in Alveograph Standard and modified methods

5.2.3.2.1 Standard method

The impact of improvers A and B in each fraction is presented in Table 5-4. As it can be observed the addition of the two improvers affected the W value of *Coarse* and *Regrind*. Where in both cases the addition of the improvers reduced the W value compared to control ($p<0.05$). Moreover the addition of improver B reduced the P/L ratio in all fractions ($p<0.05$) except *Mid Fine*.

5.2.3.2.2 Interrupted method

In case of the Interrupted method analysis identified (table 5-4) that the W value of *Fine* and *Super Fine* was lowered significantly by the addition of improver B. Moreover analysis showed that the improver A had not a significant impact on P/L ratios. While the addition of improver B lowered the P/L ratio of *Coarse* and *Fine*. This is quite contradictory with the results of Standard method where except one fraction all the other fractions were affected by the addition of improver B.

5.2.3.2.3 Adopted hydration method treated fractions

As can be observed (table 5-4) neither improver A or B had a significant impact on W value in any fraction. However the addition of improver B lowered the P/L ratio ($p<0.05$) of *Straight run, Coarse* and *Regrind*.

5.2.3.2.4 Alveo-Farino method treated fractions

Analysis showed (table 5-8) that W values of *Straight run* flour and *Regrind* positively impacted by the addition of improver B. The addition of improver A increased the P/L ratio of all fractions, exept *Super Fine*. Whereas the addition of improver B reduced the P/L ratio compared to improver A, in all fractions, except in *Super Fine*. It should be noted that the control and the improver B treatment exhibited similar P/L ratios in all fractions , except in case of *Regrind* where improver B treatment exhibited lower P/L ratio compared to control ($p<0.05$).

5.2.4 PCA plot and Correlation coefficients between physicochemical properties and rheology tests

To obtain an integrated view of relationship between flour fractions and dough rheology parameters, PCA was executed and Pearson's correlations between parameters were calculated. In PCA plot, variables close to each other are positively correlated, whereas variables found in the opposite sides diagonal are negatively correlated. Variables found in the orthogonal direction are independent of each other. There are extensive samples and assays and the abbreviations are listed on page 89.

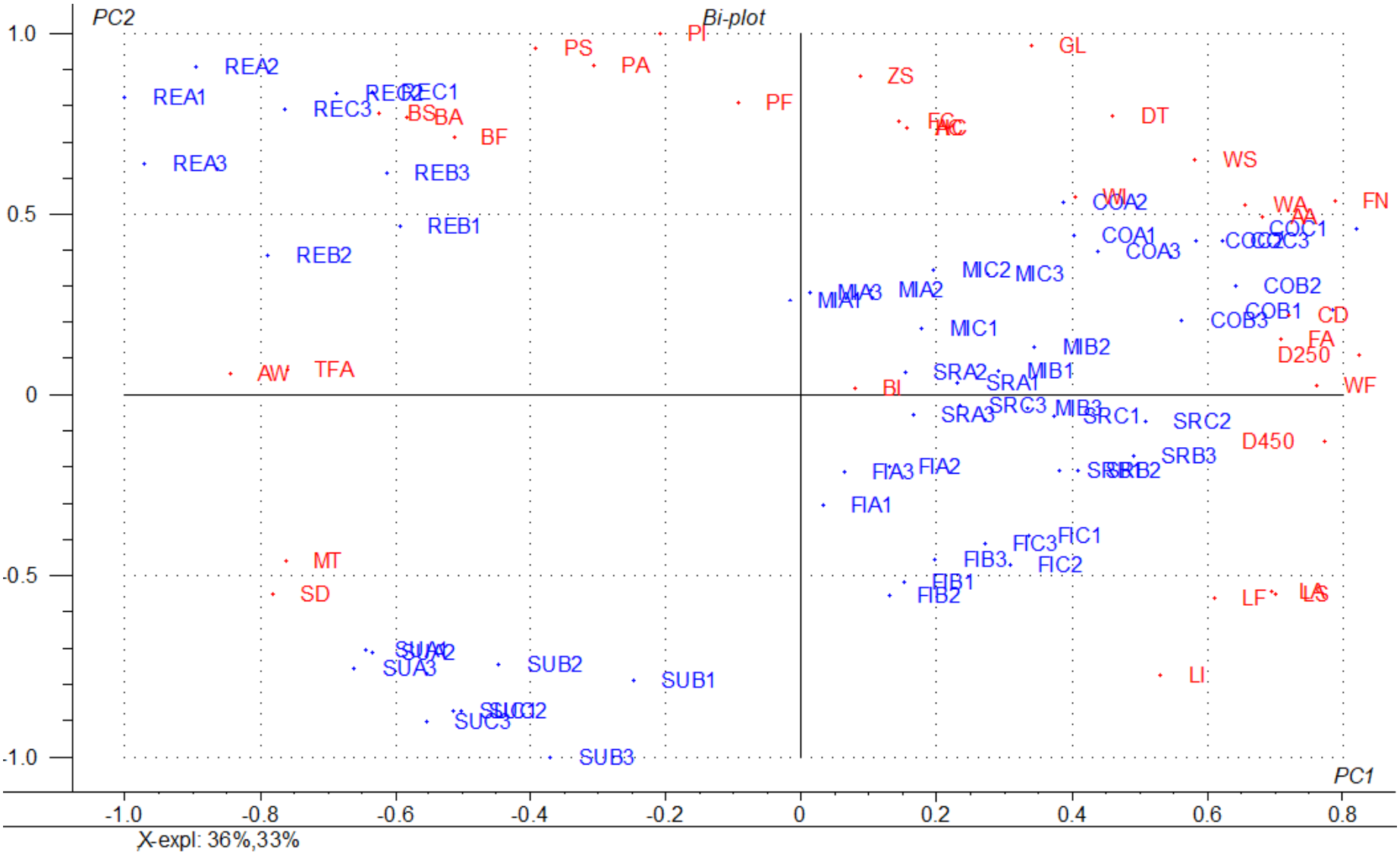


Figure 5-1. Principal Component Analysis for all flour fractions and all physicochemical and rheological tests

Fractions abbreviations:

- CO = Coarse untreated
- COA = Coarse treated with improver A
- COB = Coarse treated with improver B
- FI = Fine untreated
- FIA = Fine treated with improver A
- FIB = Fine treated with improver B
- MI = Mid fine untreated
- MIA = Mid fine treated with improver A
- MIB = Mid fine treated with improver B
- RE = Regrind untreated
- REA = Regrind treated with improver A
- REB = Regrind treated with improver B
- SR = Straight grade flour untreated
- SRA = Straight grade flour treated with improver A
- SRB = Straight grade flour treated with improver B
- SU = Super fine untreated
- SUA = Super fine treated with improver A,
- SUB = Super fine treated with improver B

Rheological and physicochemical Parameters abbreviations:
Alveograph

- AW = Water absorbing capacity, defined by Farinograph
- BA = P/L adopted, configuration ratio of the adopted method
- BF = P/L configuration ratio of the Alveograph Alveo- Farino method
- BI = P/L configuration ratio of the Alveograph Interupted method
- BS = P/L configuration ratio of the Alveograph standard method
- CD = Mixing stability, defined by Farinograph
- D250 = Pressure drop in mb after 250sec, defined by Consistograph
- D450 = Pressure drop in mb after 450sec, defined by Consistograph
- DT = development time, defined by Farinograph
- FA = PrMax maximum dough pressure recorded by Consistograph adopted hydration method
- FC = PrMax maximum dough pressure recorded by Consistograph constant hydration method
- GL = Wet gluten content
- LA = L, extensibilty defined by the Alveograph adopted method
- LF = L extensibilty defined by the Alveograph Alveo- Farino method
- LI = L extensibilty defined by the Alveograph interrupted method
- MT = mixing tolerance, defiend by the Farinograph
- PA = P tenacity defined by the Alveograph adopted method
- PF = P tenacity defined by the Alveograph adopted method
- LS = L extensibility defined by the Alveograph standard method
- PI = P tenacity defined by the Alveograph interrupted method
- PS = P tenacity defined by the Alveograph interrupted method
- TFA = TPrMax, time needed for dough maximum stiffness as defined by the Consistogarph
- WA = W deformation energy defined by the Alveograph adopted method
- WF = W deformation energy defined by the Alveograph the Alveo-Farino method
- WI = W deformation energy defined by the Alveograph interupted method
- WS = W deformation energy defined by the Alveograph interupted method
- ZS = Zeleny sedimentation

The loading plot of first two PCs explained the 69% of total variance in the flour properties measured. The PC1 accounted for 36% of the explained variance. PC1 was strongly positive determined by the following parameters: (1) Farinographic stability CD, (2) Alveo- Farino

method deformation energy value WF, (3) Adopted hydration Consistograph parameters PrMax (FA), D250, and D450. Farinograph stability exhibited strong positive correlation with Consistograph D250. While moderate positive correlation with FA and D450. Strong positive correlations obtained between FA and D250 and D450. Moreover in this PCA plot PC1 was determined negatively with the Farinograph water absorption AW and Consistograph TPrMax (TFA). Indeed these parameters were correlated to each other and negative to CD, FA, D250 and D450. In particular CD was negative correlated with AW and TFA. In addition FA, D250 and D450 exhibited very strong negative correlation with TPrMax.

The second PC, PC2 accounted for 33% explained variance and it positively determined the tenacity values P of Alveo –Farino and Interrupted methods and Zeleny sedimentation volume. Moreover Alveograph standard method P exhibited very strong correlations with P values obtained from Interrupted and Adopted hydration methods the relationship of these parameters can be easily identified in PC2 axis since they are localized very close. A quite interesting observation is that PC2 axis is mainly determined by tenacity and Zeleny sedimentation since in the negative side of PC2 neither rheological parameter is positioned. According to the PCA plot the factors showed low variance irrespective the treatment. However a trend can be identified. For example the addition of improver B increased in general the extensibility. To put it differently the addition of improver increased the tenacity and lowered the extensibility of the samples tested. A slight attraction to L parameter can be observed when samples treated improver B, whereas a slight attraction to P can be identified when treated with improver A.

Straight run flour, *Fine*, *Mid Fine* and *Coarse* are positioned in the positive side of PC1 axis. Which is determine d by Farinograph stability CD, Adopted Consistograph parameters TPrMax (TFA), D250 and D450 and W value obtained from the Alveo- Farino method. Indeed according to statistical analysis the said fractions exhibited higher stability than *Regrind* and *Super Fine*. The *Coarse* and *Mid Fine* exhibited significant difference in stability compared to these two fractions. Moreover *Straight run*, *Fine*, *Mid Fine* and *Coarse*, exhibited lower water absorbing capacity AW and TPrMax compared to *Regrind* and *Super Fine*.

Super Fine positioning in PCA plot indicated the strong influence of starch damage SD and mixing tolerance in the said fraction. This is supported by the statistical analysis previous presented. *Super Fine* exhibited the lowest mixing tolerance of all fractions, either treated with improvers or not, and the highest starch damage among all fractions.

Regrind exhibited very close positioning with P/L ratios of all Alveographic modifications except with the Interrupted method which was an outlier. This is confirmed by the previous statistical analysis in which the said fraction exhibited significant higher P/L ratios ($p<0.05$) compared to the rest, either treated with improvers A and B or not. The same applies for tenacity P, except in Alveo –Farino method where *Regrind* exhibited similar ($p>0.05$) P value with *Coarse*.

As it can be observed in the PCA plot the gluten content and Zeleny sedimentation are in close proximity with Farinograph's development time DT exhibiting positive correlation. In case of stability both physicochemical properties did not have strong influence on mixing stability CD. Whereas in case of Mixing tolerance MT the higher the gluten content and the Zeleny sedimentation volume the lower the drop. Moreover the higher the water absorbing capacity AW the higher the MT.

PrMax (FC) value derived from Consistograph constant hydration protocol did not correlate with PrMax (FA) derived from Consistograph adopted hydration protocol. However it was strong correlated with gluten content and Zeleny sedimentation. Moreover it exhibited positive moderate correlation with DT.

Observing the PCA plot we can identify that FA, D250 and D450 are high correlated to each other, since they are positioned very close to the positive side of PC1 axis.in addition both D250 and D450 were negative correlated with starch damage ($r=-0.71, p<0.01$; $r= -0.51$, $p<0.05$ respectively). While FA was weak correlated with starch damage. Furthermore FA, D250 and D450 did not correlated with either gluten content or Zeleny sedimentation.

Table 5-5. Correlation coefficients between physicochemical properties and rheology tests for all fractions, treatments: control, improver A and B treatments

	GL	*ZS*	*SD*	*FN*	*FC*	*AC*	*HC*	*FA*	*TFA*	*TL*	*D250*	*D450*	*AA*	*AW*	*DT*	*CD*
ZS	0,94***															
SD	-0,73***	-0,60**														
FN	0,73***	0,,60**	-0,94***													
FC	0,68**	0,69**	-0,54*													
AC	0,678**	0,68**	-0,55*													
HC	0,68**	0,68**	-0,55*													
FA				0,56*												
TFA			0,63**	-0,64**				-0,77***								
TL								-0,71*								
D250			-0,71**	0,76***				0,68**	-0,88***	-0,43*						
D450			-0,51*	0,58*				0,80***	-0,94***	-0,76*	0,88***					
AA	0,73***	0,59**	-0,71***	0,82***				0,71***	-0,57*		0,73***	0,56*				
AW			0,75***	-0,71**					0,64**	0,06*	-0,71***	-0,57*	-0,49*			
DT	0,78***	0,60**	-0,70**	0,68**	0,58*	0,57*	0,57*	0,53*			0,61**		0,67**			
CD			-0,76***	0,75***				0,52*	-0,67**		0,70***	0,59*	0,55*	-0,63**	0,50*	
MT	-0,74***	-0,57*	0,92***	-0,93***				-0,61**	0,67**		-0,77***	-0,56*	-0,81***	0,67**	-0,70**	-0,87***

	GL	*ZS*	*SD*	*FN*	*PS*	*LS*	*WS*	*BS*	*PI*	*LI*	*WI*	*PA*	*LA*	*WA*	*BA*	*PF*	*LF*
PS	0,66**	0,67**															
LS					-0,77***												
WS	0,91***	0,82***	-0,85***	0,84***	0,49*												
BS					0,95***	-0,92***											
PI	0,76***	0,76***			0,96***	-0,64**	0,57*	0,87***									
LI	-0,50*	-0,54*			-0,94***	0,79***		-0,93***	-0,90***								
WI	0,91***	0,83***	-0,84***	0,79***			0,92***		0,53*								
BI																	
PA	0,64**	0,61**			0,90***	-0,63**		0,84***	0,93***	-0,87***							
LA				0,32***	-0,74***	0,83***		-0,86***	-0,67**	0,79***		-0,74***					
WA	0,76***	0,65**	-0,80***				0,81***				0,83***						
BA					0,90***	-0,82***		0,94***	0,85***	-0,91***		0,91***	-0,93***				
PF	0,64**	0,63**			0,73***		0,64**	0,61**	0,75***	-0,59*	0,58*	0,68**	-0,51*		0,62**		
LF					-0,67**	0,84***		-0,77***	-0,56*	0,65**		-0,55*	0,76***		-0,71***	-0,59*	
WF	0,61**	0,50*	-0,70**	0,72***		0,52*	0,78***				0,76***			0,66**		0,49*	
BF					0,85***	-0,80***		0,88***	0,79***	-0,79***		0,75***	-0,82***		0,85***	0,82***	-0,92***

	PS	*LS*	*WS*	*BS*	*PI*	*LI*	*WI*	*BI*	*PA*	*LA*	*WA*	*BA*	*PF*
LS	-0,77***												
WS	0,49*												
BS	0,95***	-0,92***											
PI	0,96***	-0,64**	0,57*	0,87***									
LI	-0,94***	0,79***		-0,93***	-0,90***								
WI			0,92***		0,53*								
BI													
PA	0,90***	-0,63**		0,84***	0,93***	-0,87***							
LA	-0,74***	0,83***		-0,86***	-0,67**	0,79***			-0,74***				
WA			0,81***				0,83***						
BA	0,90***	-0,82***		0,94***	0,85***	-0,91***			0,91***	-0,93***			
PF	0,73***		0,64**	0,61**	0,75***	-0,59*	0,58*		0,68**	-0,51*		0,62**	
LF	-0,67**	0,84***		-0,77***	-0,56*	0,65**			-0,55*	0,76***		-0,71***	-0,59*
WF		0,52*	0,78***				0,76***				0,66**		0,49*
BF	0,85***	-0,80***		0,88***	0,79***	-0,79***			0,75***	-0,82***		0,85***	0,82***
FC			0,77***				0,74***						0,78***
AC			0,77***				0,74***						0,77***
HC			0,77***				0,73***						0,77***
FA													
TFA		-0,63**		0,50*									
D250		0,64**	0,50*				0,49*				0,50*		
D450		0,65**		-0,51*									
AA			0,74***				0,76***				0,72***		
AW	0,47*	-0,84***	-0,51*	0,72***		-0,60**	-0,55*			-0,79***	-0,51*	0,72***	
DT	0,53*		0,84***		0,61**		0,80***		0,57*		0,69**		0,67**
CD		0,50*	0,51*				0,55*	0,62**			0,65**		
MT			-0,81***				-0,80***				-0,85***		

	LF	*WF*	*BF*	*FC*	*AC*	*HC*	*FA*	*TFA*	*D250*	*D450*	*AA*	*AW*	*DT*	*CD*
BF	-0,92***													
FC		0,66**												
AC		0,67**		1,00***										
HC		0,67**		1,00***										
FA	0,49*													
TFA	-0,63**		0,54*				-0,77***							
D250	0,50*	0,62**					0,68**	-0,88***						
D450	0,68**		-0,57*				0,80***	-0,94***	0,88***					
AA		0,61**					0,71***	-0,57*	0,73***	0,56*				
AW	-0,61**	-0,72***	0,54*					0,64**	-0,71***	-0,57*	-0,49*			
DT		0,67**		0,58*	0,57*	0,57*	0,53*		0,61**		0,67**			
CD		0,50*					0,52*	-0,67**	0,67***	0,59*	0,55*	-0,63**	0,50*	
MT		-0,67**					-0,61**	0,67**	-0,77***	-0,56*	-0,81***	0,67**	-0,70**	-0,87***

p<0.05= *, p<0.01=**, p<0.001 =***
Notes: 1, the same abbreviations as in PCA plot, 2, insignificant correlations are not presented

It is quite interesting that P values obtained forum all Alveographic modifications exhibited from weak to very weak negative correlations with starch damage. In contrast they were strong correlated with gluten content and Zeleny sedimentation. Moreover there was a strong positive correlation with P/L ratios. Whereas they were strong negative correlated with L value, highlighting that tenacity was the main factor influencing the P/L ratio. Furthermore it is important to notice that the P values obtained were moderate correlated with corresponding W values.

W values obtained from Standard, Interrupted and Adopted Alveographic methods were positioned very close to each other in the PCA plot indicating a very strong correlation. Whereas W obtained from the Alveo-Farino method localized further from them indicating a weaker correlation. The W values obtained from Standard and Interrupted methods exhibited very strong correlation with gluten content and Zeleny sedimentation ($r=0.91$ <0.001; $r=0.91$, $p<0.001$; $r= 0.82$, $p<0.001$; $r=0.83$, $p<0.001$respectively).Whereas Adopted and Alveo- Farino methods exhibited strong correlations with said physicochemical properties ($r=0.76$, $p< 0.001$; $r=0.61$, $p<0.01$; $r=0.65$, $p<0.01$; $r=0.50$ $p<0.05$ respectively). Analysis showed a moderate correlation between W values and D250. Weak correlations were calculated between W values and FA, TPrMax and D450. W values were better correlated with Farinographic parameters. Where very strong correlations were observed between W and DT. In particular, Alveograph Standard and Interrupted methods exhibited very strong correlations with DT. While Adopted and Alveo-Farino methods exhibited less strong correlations with the specific Farinographic value. In contrast very strong negative correlations were calculated between W values and MT. Moderate negative correlations were calculated between W values and water absorbing capacity AW. Moderate positive correlations were obtained between W values and mixing stability CD.

5.3 DISCUSSION

5.3.1 Farinograph

Analysis showed that *Regrind* and *Super Fine* exhibited the highest water absorbing capacity among all fractions. According to correlations which were calculated starch damage content was the factor which contributed most. However statistical significant differences were observed in water absorbing capacity between fractions with similar starch damage. This suggests that apart from the starch damage content other properties may also have a significant impact on water absorbing capacity of each fraction (Muller, 1975; Rasper, 1993). For example the difference in AW between *Regrind* and *Super Fine* where the former absorbed approximately 2.5% more water than the latter can be explained by the difference in gluten content. Although gluten content exhibited weak correlation with AW. This is further supported by the fact both *Mid Fine* and *Coarse* exhibited lower AW compared to *Straight run* and *Fine* despite that the first two fractions accommodated by higher gluten content compared to the last two. It has been stated that the amount of α-amylase is negatively correlated with flour water absorbing capacity (Muller 1975). However our findings do not corroborate with this, since the *Coarse* fraction exhibited the lowest α-amylase activity among all fractions but also the lowest water absorbing capacity. The amount of Non-starch polysaccharides in each fraction might be the reason for this observation, since they contribute heavily on water absorbing capacity. According to Atwell (1998) they hold up one quarter of water present in the dough. However there is no data available to support this hypothesis.

Contrary to the above gluten content was the most important factor which determined the dough development time DT. Although statistical analysis showed that a high variance in gluten content should exist in order to consider it as an important factor for the specific Farinographic parameter. According to literature dough development time is related to protein content and gluten strength. In particular, glutenins require longer time from proper alignment during mixing than gliadins (D' Appolonia1984; Weipert, 2006). Based on this we should accept that all fractions except Super Fine were characterized by similar glutenin content and exhibited similar gliadin to glutenin ratio. There is no data available to reject or to accept this hypothesis. However it is hard to adopt it, since dough development is also influenced by flour particle size (Rasper, 1993). It is quite probable that these limitations of the method forced Schiraldi and Fessas (2012) to state that "Farinograph does not reveal the

mechanism of the process at molecular and supra-molecular level and it is therefore not particularly useful for the purposes of enhancing dough quality through recipe modifications, mechanical stress relaxation treatments, leavening and baking conditions"pp352.

Interestingly t-test analysis showed that the addition of improver B affected the DT only of Regrind fraction. This is quite contradictory to literature, since it is widely accepted that the addition of L-cysteine reduces the time needed for full dough development (Millar and Tucker, 2012; Wieser, 2012). A possible explanation is that the level of L-cysteine in improver B was too low and thereby incapable to exert significant influence on DT parameter. To put it differently higher sensitivity than of the present method is required in order the effect of very low cysteine dosage on gluten development to be detected.

Analysis showed that *Regrind* and *Super Fine* exhibited a lower mixing stability CD compared to *Mid Fine* and *Coarse*. Gluten content had little influence on this. On the other hand starch damage had a significant negative impact on CD. Moreover the addition of improvers did not have a significant influence. A possible explanation to that is the reaction time was limited i.e. approximately 3 minutes and thereby the influence of the improvers did not fully exerted. This is supported by the fact that mixing tolerance MT of all fractions except the *Straight run* was significant affected by the addition of the improvers. That is, the influence of the improvers was more evident with prolonged mixing time. It should be noted that both improvers had a similar negative impact on mixing properties in the said fractions. This leads to the following conclusions. First, the L- cysteine level was too low, which is why the impact was insignificant. Second ascorbic acid was not able to counter balance the softening effect of the added α-amylase and endo-xylanase. The influence of gluten content can be detected in prolonged mixing times, a strong negative correlation was observed between these two parameters. Although starch damage had the most significant impact on mixing tolerance. The effect of starch damage in mixing tolerance MT can be highlighted by the significant difference between *Regrind* and *Coarse* in MT, where the latter exhibited much more tolerant dough during mixing than the former.

5.3.2 Consistograph

It has been supported that Consistograph is highly correlated with Farinograph in terms of determining flour water absorbing capacity (Dreyfus et al., 2003; Dubois et al., 2008). However in this study weak or moderate negative correlations were calculated between

Farinograph AW and Consistograph FC and FA. The above results indicate that Consistograph was inappropriate for water absorption capacity determination. However this might not reduce the significance of this method since in this study it was identified significant positive correlations between FC and gluten content, Zeleny sedimentation and development time and moderate negative correlation with starch damage content. This is further supported by statistical analysis in which showed that *Coarse*, *Mid Fine* and *Regrind* were clearly discriminated from the weaker fractions i.e. *Straight run* flour, *Fine* and *Super Fine*. Although in case of Adopted hydration protocol FA (PrMax) parameter was insensitive to gluten content, Zeleny sedimentation and starch damage. Oddly TFA (TPrMax) had a strong positive correlation with the Farinograph water absorption parameter. It is difficult to propose a convincing hypothesis on how the time needed to for maximum stiffness is correlated to flour's water absorbing capacity. D250 and D450 were significant ($p<0.05$) positive correlated with CD and significant negative correlated with MT. These correlations show that by using the specific method valuable conclusions can be extracted on dough behavior during mixing.

5.3.3 Alveograph

P values from all methods exhibited strong correlations with gluten content, Zeleny sedimentation and development time. The ability of P value on discriminating gluten strength and elasticity has been supported by the findings of Edwards et al (2007) and Sapirstein et al (2007). Both authors found strong correlations between P value and gluten index, insoluble glutenins content, and unextractable polymeric protein. A low variance in P between the different Alveographic methods was observed in the PCA plot. However based on statistical analysis presented earlier a slight improved discrimination in P values between fractions was obtained by Interrupted method. During extended resting time the elastic properties of gluten are reduced (Ewart, 1979; Kim et al 2008). Thereby the discrimination of gluten elasticity is improved when the resting time is increased (Dexter 1994). Alveo – Farino method was associated with the lowest discrimination ability among all methods. Since, in this method, *Super Fine* exhibited similar P value with *Straight run*, *Fine* and *Mid Fine* despite the fact their high difference in gluten content.

It has been suggested that starch damage is a positive source of variation for P value. As at higher the starch damage the higher the water absorption capacity therefore the stiffer the dough and the higher the tenacity (Dexter, 1994; Martin and Gander 1994; Khattak et al.,

1974) .However according to PCA plot starch damage had a minimal effect on P value. With one exception, *Regrind* exhibited the highest tenacity among all fractions ($p<0.05$) and in particular with *Coarse* as well in Standard, Interrupted and Adopted methods. The first two were conducted at constant hydration. Therefore *Regrind* was less hydrated than *Coarse*. Thereby it was stiffer and more tenacious. In case of Adopted hydration method, *Regrind* exhibited higher P compared to *Coarse*. It was expected that the impact of starch damage on P value will be minimized in this method. But as we have seen earlier Consistograph did not correlated with flour water absorbing capacity and thereby both fractions were not optimum hydrated and the P value was heavily affected by the starch damage content. Results indicate that P values obtained from Alveo- Farino method were independent of the starch damage content and water absorbing capacity.

Deformation energy value W is considered to be closely related to the flour strength (Dubois et al., 2008). Its importance is highlighted by the fact that is accepted in internationally durum wheat trade as a primary gluten strength indicator (D'Egidio et al, 1990; Marchylo et al, 2001). Sapirstein et al, (2007) found that W value was very strongly correlated with durum wheat glutenin insoluble content. In an additional study conducted by Edwards et al (2007), the W value exhibited significant a positive correlation with gluten index, unextractable polymeric protein, Mixograph mixing time, Mixograph peak resistance and Mixograph band with at peak. Moreover in their work W value exhibited moderate to weak correlation with glutenin/gliadin ratio and HMW/LMW ratio. The results of this study are in line with the above. The W values obtained from the four Alveographic modifications exhibited significant ($p< 0.05$) correlation with gluten content, Zeleny sedimentation, Consistograph FC and with all Farinographic parameters. These results further strengthen the belief that the Alveograph W value can be regarded as an important indicator of durum wheat gluten strength.

A low variance in W values obtained by the different Alveographic values was observed in the PCA plot. Although it was identified that the W value obtained from the Alveo-Farino method was less correlated to the others. Moreover the absolute W values obtained from the said method were lower compared to the other three methods. One reason for that, is in this method the water which was added was significant higher and therefore lowered the P value and consequently the W value was decreased. Another contributing factor might be that mixing action of Farinograph was more severe than the Alveograph (Weipert, 2006).

In addition *Regrind* exhibited lower W value compared to *Coarse* ($p<0.05$) in the Alveo – Farino method. A possible reason for that is the high starch damage level of the two fractions. Whitworth (1999) based on the work of Farrand (1964, 1969) proposed a possible explanation on how gluten strength impacted by the starch damage. He suggested that the higher the starch damage the higher the surface of starch granules suspended in the gluten matrix. As the surface of granules increases the gluten becomes thinner in order to cover them and subsequently the dough is weakened. This explains the difference ($p<0.05$) in extensibility between *Regrind* and *Coarse* obtained by the Alveo – Farino method. The gluten was very thinly spread in order to cover all the starch granules and when exposed to stress caused by bubble inflation failed to maintain its structure and subsequently the bubble failed earlier. Therefore the difference in W is due to lower extensibility caused by the higher starch damage.

In the PCA plot we can identify the impact of the improvers. It was observed a low variance between control and improver treatments. Which means that the impact of both improvers on W values was moderate or weak. In some cases such as *Coarse* and *Fine* the control treatment was localized closer to the improver B than to the improver A. This indicates that the fractions did not respond in the same way or to the same extent when treated with the improvers. Moreover it was observed that neither fraction was impacted into that extent in order to change drastically its position in the PCA plot. Statistical analysis corroborates this observation, the impact of the improvers in W values in most cases was statistical insignificant ($p>0.05$). The interaction between enzymes added, ascorbic acid and L-cysteine have different effect on W and thereby a clear trend on the said value was omitted. For example ascorbic acid strengthens the gluten network and dough becomes stiffer and this leads to higher W value. On the other hand both α- amylase and endoxylanase enzymes hydrolyse starch and non-starch polysaccharides respectively and therefore the liberated water soften the dough and this leaded to lower W value (Rouau et al., 1994; Martinez-Anaya and Jimenez, 1997a; Courtin et al., 2001). All these perplexing the impact of improver A that's why we did not be able to diagnose a clear impact of the said improver on W. In case of improver B we can hypothesize that the level of L-cysteine added (12ppm) was too low in order to exert a clear impact on W value.

The extreme low L values obtained in this study are typical for durum wheat flour (Quaglia, 1988). Both durum wheat gluten properties and the high level of starch damage which usually accommodates durum flour contribute to this (Dexter, 1994). The severe effect of starch damage on Alveographic properties have been identified by a number of workers (Dexter, 1994; Chen and D'Appolonia, 1985). This is one of the main drawback of the Alveograph's constant hydration protocol. It is widely accepted that flours with different starch damage level exhibit different water absorbing capacity and this therefore may reduce the ability of the measured parameters to discriminate the rheological properties and more precisely the gluten properties of the flour (Whitworth, 1999). It was expected that if we get doughs of the same consistency irrespective the starch damage, as in case of Alveo-Farino method, the impact of starch damage on the L values will be insignificant. This hypothesis does not hold since the extensibility of the *Regrind* was significant ($p<0.05$) lower compared to *Coarse*. As we have seen starch damage and P value were moderate correlated. The same more or less apply for the L value, which exhibited weak or moderate insignificant ($p>0.05$) correlation with starch damage in all Alveographic modifications. However, the low variance in L values between fractions may contributed to this. This may explains the weak correlations which were obtained between L value and gluten content and Zeleny sedimentation. As was demonstrate by Interrupted method, prolonged resting time reduces the variance in extensibity.

P/L ratio is regarded as an indication of the geometry of the Alveogram (Chopin 1962). It is commonly used in durum wheat trade since it describes the balance between tenacity and extensibility. The P/L ratios obtained in this study were extremely high indicating that the flours tested were both too tenacious and inextensible. This is in line with Quaglia (1988) who stated that the alveograms of durum wheat flours indicate very high tenacity versus extensibility. According to Milatovic and Mondelli (1991) durum flour of good bread making quality should exhibit P/L values from 0.8 to 2.0. In this study the P/L ratios from all fractions and all Alveographic modifications were far out of this range, except in case of Alveo – Farino method. In PCA plot was observed that Regrind exhibited the highest P/L ratios, whereas Fine exhibited the lowest ratios. These PCA findings were further supported by the statistical analysis presented earlier. It is obvious that in this study P/L ratios were governed by P value variance while the contribution of L value was much less significant. Interestingly, it was expected that starch damage will have a significant effect on P/L ratio. Although their positioning in the PCA plot was orthogonal suggesting that these two

parameters were independent to each other. Moreover P/L ratio exhibited significant correlations ($p<0.05$) with flour's water absorbing capacity, except in case of Interrupted method. A possible explanation for this is that the extended resting time soften the dough and thereby tenacity was reduced and the extensibility was slight increased. Consequently this Alveographic modification was less dependent on dough hydration level.

Unlike W value P/L ratio was much more sensible to improver treatments. In particular statistical analysis showed that the most sensitive modification was the Alveo-Farino method. In which the improver A in most fractions increased the ratio. Whereas improver B lowered the ratio compared to improver A. This is an indication that L-cysteine has a buffering effect on ascorbic acid. *Super Fine* was the only fraction which did not respond to improver treatments. It is well known that the reaction of a catalyst depends heavily on the substrate concentration. The substrate for ascorbic acid and L-cysteine is gluten, when it is too low the effect of these two catalysts may be insignificant. This might explains why *Super Fine* did not responded to improver treatments. Alveo – Farino method and P/L ratio parameter were the most sensitive on detecting the effect of oxidizing and reducing agent in durum wheat flour dough. We speculate that Farinograph's mixing bowl geometry, temperature and intensity of mixing were responsible for that. According to literature ascorbic acid reaction is temperature dependent, warm conditions in a range of 25-35 °C favor the reaction (Millar and Tucker, 2012). The mixing temperature in Farinograph was set at 30 °C, in case of Alveograph it was at 24 °C. Moreover ascorbic acid reaction is oxygen dependent, therefore the intensity of mixing heavily affects the rate of air inclusion in the dough (Chamberlain and Collins, 1979). The intensity of mixing action is higher in Farinograph than in Alveograph and leading to a higher oxygen inclusion in the dough (Weipert, 2006).

It should be noted that protein level, gluten strength, starch properties and physical state are not the only factors that influence dough rheology. Non starch polysaccharides play an important role also in breadmaking and in dough rheology in particular (Goesaert et al., 2005). In general it can be said that they prevent optimal gluten development and dough stability is negative affected (Delcour and Hoseney, 2010). They are positive correlated with dough resistance to extension while they have negative impact on extensibility (Jelaca and Hlynka 1971).

5.4 CONCLUSION

It was found that durum flour water absorbing capacity was heavily impacted by starch damage content. This is why *Regrind* and *Super Fine* exhibited the highest water absorbing capacity among all fractions. Development time was affected by gluten content. However the sensitivity of this parameter is questionable. Since it was unable to detect the effect of the improvers. Mixing stability was also insensitive to improver treatments and to gluten content. On the other hand the mixing tolerance parameter was quite sensitive not only to improver treatments but also to gluten content and starch damage level of each fraction. In other words the impact of the different physicochemical properties and improver treatments was more easily detectable at prolonged mixing time. Based on this, *Coarse* exhibited the most tolerant behavior during mixing, whereas *Super Fine* and *Regrind* were the less tolerant among all fractions.

Results have shown that Consistograph was incapable to predict the water absorbing capacity of durum flour. However PrMax from Consistograph constant hydration protocol showed significant strong correlation with gluten content and Zeleny sedimentation. Moreover it was found that D250 and D450 parameters can describe quite precisely the dough mixing profile. It has been suggested that P value measures dough strength and elasticity. Our findings are in agreement with this. P value was significantly correlated with gluten content, Zeleny sedimentation and Farinographic parameters. Interestingly starch damage content was not related with P value in this study, which contradicts with previous work in the field. It was observed that by increasing dough resting time as in case of Interrupted method a better discrimination in P value can be achieved. Moreover it was found that doughs of the same consistency as in case of Alveo-Farino method minimize the impact of starch damage in P parameter. Although P value variance among fractions in this method was reduced at that extent at which the discrimination ability of this parameter was minimized.

W value is regarded by the industry as a primary parameter of durum flour strength. Our findings corroborate with this, since significant correlations were calculated between W value and gluten content, Zeleny sedimentation and Farinographic measured properties. In addition the impact of starch damage in W value has been identified. A low variance in W value has been observed between the four Alveographic modifications. It was found that W

value was quite insensitive to improver treatments. A possible answer which could be given is that the interaction of ingredients present in each improver is responsible for that.

All flour fractions tested in this work exhibited low extensibility. This is typical for durum wheat flours. This explains the extreme high P/L ratio found in this study. It was identified that the said parameter is much more sensitive to improver treatments compared to W. It was found that ratio was increased by the addition of improver A, while it was decreased by the improver B.

Concluding it can be said that starch damage and gluten content had strong influence in all rheological parameters. It would be said that the Farinograph is more sensitive than the Consistograph on defining durum wheat flour properties and the impact of improvers. The gluten strength of each fraction was slightly better discriminated by the Interrupted method of the Alveograph. However the Interupted Alveograph method would be comprised of different levels of starch damage are present. Therefore the recommendation is that in order to minimize the starch damage effect on measured properties the Alveo-Farino mehod should be used.

CHAPTER 6. THE RELATIONSHIP BETWEEN RHEOLOGY AND PHYSICOCHEMICAL TESTS WITH BREADMAKING PROPERTIES.

6.1. INTRODUCTION

It is generally accepted that the baking quality is heavily affected by the rheological properties of the dough. This motivated the scientific community to pay considerable attention on the relation between the empirical rheology tests and the breadmaking performance. In this chapter it will be presented and discussed the predictive power of the empirical methods on breadmaking performance. To obtain an integrated view of the relationship between flour physicochemical properties, dough rheology and breadmaking properties, PCA was executed and Pearson's correlation between parameters were calculated.

6.2. RESULTS FROM THE PCA PLOT AND PEARSON'S CORRELATION CALCULATIONS

Data from chapters 4 and 5 that are associated with dough and bread performance and with the rheological assesments are compared. There are extensive samples and assays and the abbreviations are listed also on page 109.The loading plot of the first two PCs explained the 68% (figure 6-1) of the total variance in the flour and in breadmaking properties measured. The PC1 accounted for the 35% of the variance explained. PC1 was strongly determined mainly by P/L ratios from the four Alveographic methods used in this study BS, BI, BA and BF and dough tenacity P value from the standard Alveographic method. All P/L ratios exhibited very strong ($p<0.001$) positive correlation to each other. Moreover as it can been seen by their positioning in the PCA plot they were strong correlated with the P values obtained by the four different Alveographic methods. Moreover in this PCA plot PC1 was strongly negative correlated with the dough extensibility L values obtained from all Alveographic methods. L values were strong positive correlated to each other. In addition L values was strong negative correlated with P/L ratios and P values.

The second PC, PC2 accounted for 33% explained variance and it was strong positive determined by dough maximum volume during fermentation i.e. Hm, dough development time i.e. DT and to a lesser extent by dough deformation values obtained from Alveographic standard and Interrupted methods i.e. WS and WI respectively. Indeed the correlation between these parameters was significant but not very strong. A quite interesting observation is that PC2 axis was mainly determined by the positioning of the most parameters in the positive side. However as it can been seen (table 6-1) starch damage was significant negative correlated with Hm, DT, WI and WS. Moreover mixing tolerance i.e. MT was significant negative correlated with Hm, DT, WI and WS.

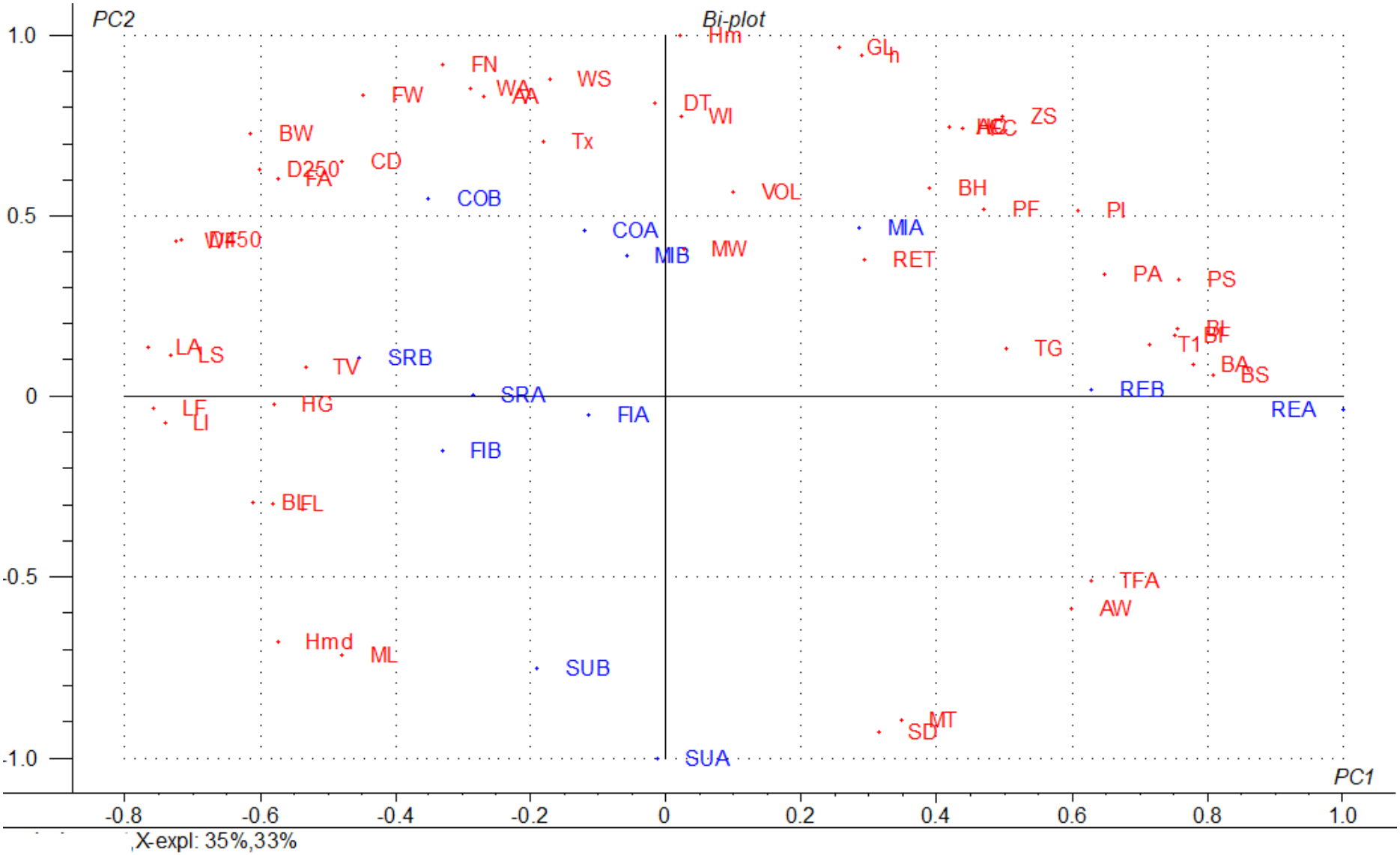


Figure 6-1. Principal Component Analysis for treated flour fractions, all physicochemical, tests rheological tests and breadmaking performance

Fractions abbreviations:

- CO = Coarse untreated
- COA = Coarse treated with improver A
- COB = Coarse treated with improver B
- FI = Fine untreated
- FIA = Fine treated with improver A
- FIB = Fine treated with improver B
- MI = Mid fine untreated
- MIA = Mid fine treated with improver A
- MIB = Mid fine treated with improver B
- RE = Regrind untreated
- REA = Regrind treated with improver A
- REB = Regrind treated with improver B
- SR = Straight grade flour untreated
- SRA = Straight grade flour treated with improver A
- SRB = Straight grade flour treated with improver B
- SU = Super fine untreated
- SUA = Super fine treated with improver A,
- SUB = Super fine treated with improver B

Rheological and physicochemical Parameters abbreviations: Alveograph

- AW = Water absorbing capacity, defined by Farinograph
- BA = P/L adopted, configuration ratio of the adopted method
- BF = P/L configuration ratio of the Alveograph Alveo- Farino method
- BI = P/L configuration ratio of the Alveograph Interupted method
- BS = P/L configuration ratio of the Alveograph standard method
- CD = Mixing stability, defined by Farinograph
- D250 = Pressure drop in mb after 250sec, defined by Consistograph
- D450 = Pressure drop in mb after 450sec, defined by Consistograph
- DT = development time, defined by Farinograph
- FA = PrMax maximum dough pressure recorded by Consistograph adopted hydration method
- FC = PrMax maximum dough pressure recorded by Consistograph constant hydration method
- GL = Wet gluten content
- LA = L, extensibilty defined by the Alveograph adopted method
- LF = L extensibilty defined by the Alveograph Alveo- Farino method
- LI = L extensibilty defined by the Alveograph interrupted method
- MT = mixing tolerance, defiend by the Farinograph
- PA = P tenacity defined by the Alveograph adopted method
- PF = P tenacity defined by the Alveograph adopted method
- LS = L extensibility defined by the Alveograph standard method
- PI = P tenacity defined by the Alveograph interrupted method
- PS = P tenacity defined by the Alveograph interrupted method
- TFA = TPrMax, time needed for dough maximum stiffness as defined by the Consistogarph
- WA = W deformation energy defined by the Alveograph adopted method
- WF = W deformation energy defined by the Alveograph the Alveo-Farino method
- WI = W deformation energy defined by the Alveograph interupted method
- WS = W deformation energy defined by the Alveograph interupted method
- ZS = Zeleny sedimentation

Rheofermentometer and Breadmaking Parameters abbreviations:

- Hm= Maximum development reached by the dough
- h = Dough volume at the of fermentation,
- Hmd = Difference in dough volume between maximum development and at the end of proving
- T1 = Time required for maximum development
- HG = H'm gas production curve
- TG = Time required to reach the maximum point of the HG curve
- Tx= Time when the dough begins to give off CO2
- RET = Gas still retained within the dough at the end of the test
- TV = Total volume of gas produced during the test
- ML = Dough length after moulding

- MW = Dough width after moulding
- FW = Dough length at the end of proving
- MW = Dough width at the end of proving
- BL = Loaf length
- BW = Loaf width
- BH = Loaf height
- VOL = Loaf volume

As it can be observed the positioning of the treated fractions was similar in this PCA plot (figure 6-1) as it was in the first PCA plot (figure 5-1), where the breadmaking parameters were excluded. The *Regrind* was positioned at the positive axis of PC1, close to P/L ratios from the four Alveographic methods and the rheofermentometer T1 reflecting the ANOVA results. *Straight Run* both treatments positioned on the opposite side of the PC1 but not near to the extreme of the axis. It can be seen that when *Straight Run* treated with the improver B was localized closer to extensibility than when treated with improver A.

The *Fine* was localized very close to the center of the PCA plot, especially when treated with improver A, showing that was equally attracted by the parameters placed in this PCA plot. *Super Fine* was localized towards to the extreme of the negative axis of PC2 especially when treated with improver A. This is in line with ANOVA analysis. It has been seen that *Super Fine* either treated with improver A or B exhibited the lowest DT and WI values compared to the rest fractions and lower Hm compared to *Mid Fine*. The *Mid Fine* when treated with improver A was localized close to Rheofermentometer parameter h and loaf volume. While it was localized opposite to the Rheofermentometer parameter Hmd. Indeed results previously presented have shown that when *Mid Fine* treated with improver A the difference between maximum dough expansion during fermentation and dough volume at the end of proving i.e. Hmd was extremely low. When *Mid Fine* treated with improver B it was localized in the middle of the positive PC2 axis, showing less attracting or repulsion from the said parameters. The Coarse when treated with improver A was also localized very close to the middle of the positive PC2 axis. Its positioning implies that its rheological characteristics and breadmaking properties were different with *Super Fine* when treated with improver A. Indeed ANOVA analysis have shown that these two fractions exhibited significant different results in most rheological tests. The same applies for *Mid Fine* either treated with improver A or B. *Coarse* when treated with improver B was localized close to those rheological parameters which describe the dough behavior during mixing.

Table 6-1. Correlation table between all rheology tests, physicochemical properties, Rheofermentometer parameters and breadma

	GL	*ZS*	*SD*	*FN*	*PS*	*LS*	*WS*	*BS*	*PI*	
ZS	0,89***									
SD	-0,73**									
FN	0,74**		-0,99***							
PS	0,61*	0,67*								
LS					-0,84***					
WS	0,69*		-0,780**	0,81**						
BS					0,95***	-0,94***				
PI	0,75*	0,71**			0,94***	-0,70*		0,85***		
LI					-0,92***	0,90***		-0,97***	-0,88***	
WI	0,61*		-0,68*	0,66*			0,71**			
BI		0,61*			0,94***	-0,85***		0,97***	0,92***	-0,
PA	0,63*	0,61*			0,93***	-0,70*		0,87***	0,96***	-0,
LA					-0,79**	0,80**		-0,87***	-0,72**	0,8
WA	0,74**		-0,88***	0,91***			0,84***			
BA					0,93***	-0,82**		0,95***	0,88***	-0,
PF					0,67				0,60*	
LF					-0,74**	0,78**		-0,77**		0,6
WF			-0,60*	0,63*		0,69*		-0,69*		0,6
BF					0,82**	-0,73**		0,79**	0,66*	-0,
FC	0,70*	0,84***								
FA			-0,82**	0,81**						
TFA			0,64*	-0,67*		-0,61*				

	GL	ZS	SD	FN	PS	LS	WS	BS	PI	LI	WI	BI
D250			-0,80**	0,82**								
D450			-0,670*	0,70*				-0,58*				
AW			0,74**	-0,71**		-0,67*	-0,65*	0,68*		-0,71**	-0,63*	0,66*
DT	0,69*		-0,85***	0,84***			0,68*				0,68*	
CD			-0,82**	0,83***								
MT	-0,71*		0,93***	-0,94***			-0,87***				-0,63*	
Hm	0,90***	0,80**	-0,78**	0,78**			0,81**				0,67*	
h	0,87***	0,90***	-0,60*				0,67*				0,67*	
Hmd	-0,68*	-0,85***			-0,60*							
T1		0,64*										
HG						0,67*						
Tx			-0,64*	0,60*								
TG												
TV						0,59*						
RET		0,69*										
ML	-0,74**	-0,70*			-0,61*		-0,62*	-0,42*	-0,64*			
MW												
FL												
FW	0,63*		-0,88***	0,89***			0,72**					
BL												
BW			-0,85***	0,86***		0,62*	0,69*					
BH	0,60*	0,77**										
BH/BW		0,64*										
VOL		0,67*										

	PA	LA	WA	BA	PF	LF	WF	BF	FC	FA	TFA	D250
LA	-0,83***											
BA	0,94***	-0,94***										
LF		0,74**		-0,71**	-0,76**							
WF		0,73**	0,67*	-0,66*		0,82**						
BF	0,68*	-0,75**		0,78**	0,84***	-0,95***	-0,73**					
FA			0,64*				0,61*					
TFA						-0,69*	-0,81**			-0,71**		
D250			0,70*				0,75**			0,79**	-0,85***	
D450		0,66*					0,71**			0,94***	-0,85***	0,87***
AW		-0,70*		0,66*			-0,72**			-0,72**	0,65*	-0,76**
DT			0,67*		0,74**					0,62*		
CD			0,66*				0,70*			0,70*	-0,79**	0,86***
MT			-0,91***				-0,75**			-0,68*	0,64*	-0,73**
Hm			0,82**						0,68*			
h			0,58*						0,89***			
Hmd					-0,60*			-0,59*	-0,96***			
T1									0,68*	-0,58*		
HG					-0,62*	0,68*		-0,66*				
Tx										0,61*		
TV											-0,61*	
ML	-0,59*				-0,69*				-0,66*			
FL					-0,61*	0,59*		-0,65*				
FW			0,82**				0,71*			0,79**	-0,76**	0,85***
BL								-0,63*				
BW		0,62*	0,78**				0,80**			0,89***	-0,79**	0,88***
BH									0,66*			
BH/BW										-0,64*		
VOL									0,71**			

	D450	AW	DT	CD	MT	Hm	h	Hmd	T1	HG	Tx	TG
AW	-0,71**											
CD	0,73**	-0,65*	0,63*									
MT	-0,59*	0,71**	-0,75**	-0,80**								
Hm			0,58*		-0,77**							
h						0,92****						
Hmd						-0,63*	-0,88***					
T1	-0,71**			-0,60*				-0,78**				
Tx					-0,68*	0,65*	0,58*					
TG									0,64*			
TV										0,92****		
RET							0,58*		0,63*			0,80*
ML						-0,59*	-0,71*	0,73**				
MW												0,59*
FL								0,70*	-0,66*			-0,64*
FW	0,75**	-0,65*	0,62*	0,88***	-0,88***	0,73**					0,62*	
BL								0,71**	-0,69*			-0,66*
BW	0,87***	-0,78**		0,81**	-0,84***	0,64*					0,62*	
BH						0,66*	0,76**	-0,72**	0,73**			0,73**
BH/BW	-0,72**							-0,67*	0,92****			0,79**
VOL						0,71**	0,77**	-0,64*	0,60*			

	TV	*RET*	*ML*	*MW*	*FL*	*FW*	*BL*	*BW*	*BH*	*BH/BW*
MW		0,72**								
FL			0,75**							
FW										
BL			0,76**		0,96****					
BW						0,95****				
BH		0,90****	-0,71*	0,69*			-0,64*			
BH/BW		0,79**			-0,65*		-0,74**		0,84***	
VOL		0,68*							0,70*	

p<0.05= *, p<0.01=**, p<0.001 =***, p<0.0001=****.
Notes: 1, abbreviations: BH/BW ratio i.e. bread height to bread width the rest as in PCA plot, 2, insignificant correlations are not presented

6.3. DISCUSSION

6.3.1. Wet gluten

The PCA plot have shown that the gluten content had a critical impact on dough behavior during fermentation. The level of the dough expansion during fermentation and the final dough volume at the end of proving were significant correlated with the amount of wet gluten. The higher the gluten content the higher the stability of gas cells walls during fermentation. Since Hmd i.e. the difference between Hm and h was negative correlated with the gluten content. The role of insoluble wheat protein has been extensively studied. The gas cells created during mixing are entrapped by the gluten starch matrix. The CO_2 produced by yeast fermentation diffuses in the gas cells and their size increase. Towards the end of proving the gas cells come in contact to each other and the smaller bubbles diffuse in the larger gas cells due to pressure difference. This leads to coalescence and to dough instability. Excessive coalescence may lead the dough to collapse. The insoluble wheat proteins adsorbed at the gas bubble interface, therefore the higher the gluten content the thicker and more elastic and thereby the stronger the gas cell will be and early coalescence will be prevented. However it will be inappropriate to state that the gluten content was the most critical factor for dough stability during fermentation. Since ANOVA have shown that fractions with different gluten content behaved similar during fermentation and high variation in gluten content was needed in order to be identified significant differences in dough properties during proving. Therefore the rheological properties and more precisely the gluten strength of each fraction characterized the dough behavior during fermentation. It has been seen that gluten content was poor related with loaf volume. The results of the present work are in agreement Edwards et al. (2007b) who found that the protein content was not the decisive factor for hearth bread volume made by durum wheat flour. A number of studies contacted on common wheat using fixed proving time have verified that the gluten quality and not the content was responsible for bread volume (Faergestad et al., 1999; Tronsmo et al., 2002; Uhlen et al 2004; Faergestad et al., 2004).

6.3.2. Zeleny sedimentation

ANOVA analysis have shown that Zeleny sedimentation test had a good discrimination ability, which was favored by the addition of the improvers. That means that the said method is quite sensitive on detecting the influence of improvers. In the previous chapter, we have seen that Zeleny sedimentation was significant correlated with most of rheological tests. The correlations and the PCA positioning of Zeleny sedimentation test in regard with the breadmaking properties have been already presented. Rheofermentometer properties like Hm, h and Hmd were highly correlated with the said test. Moreover the time needed for the highest dough volume during fermentation T1 and

the dough gas retention capacity RET were significant correlated with Zeleny sedimentation test. In addition it was negative correlated with dough length after molding ML. It has been suggested earlier that this measurement might resembles the dough elastic properties or extensibility or even both. Since the higher the dough strength the higher the elastic recoil and therefore the lower the length of the dough.

In addition it was significant correlated with bread height and bread width to height ratio. It has been previous discussed that these are critical properties for hearth bread and are highly rated both by bakers and consumers. It was found that found that gluten strength has a critical impact on BH/BW ratio(Faergestad et al., 2004).However a study conducted on common wheat Zeleny sedimentation was poorly correlated with BH/BW ratio (Magnus et al.,2000).

Our findings indicated a significant correlation between Zeleny sedimentation and loaf volume. This is in line with previous studies conducted on common wheat which they have identified good correlation between bread volume and Zeleny sedimentation (Magnus et al., 2000; Dobraszczyk and Salmanowicz, 2008). It has been suggested that only glutenins swell in the sedimentation solution while gliadins do not (Eckert et al 1993). This explains why Zeleny sedimentation test was significant correlated with durum wheat flour breadmaking properties. Glutenins impact on dough rheology cannot be further be overemphasized. They determine the elastic properties of the dough and therefore the dough strength (Mac Ritchie 1980, Hoseney, 1986).

However Zeleny sedimentation was also associated with shortcomings. ANOVA analysis showed that sedimentation volume was affected by the flour particle size. In addition it could not be regarded as dynamic method since it is a single point measurement.

The correlations calculated for treated fractions have shown that Zeleny sedimentation was weak correlated with Farinographic parameters and W values obtained from all Alveographic methods. Although it is not safe to state that for this observation, responsible is the Zeleny sedimentation test.

Despite the above shortcomings our findings suggest that Zeleny sedimentation can be valuable routine test in durum wheat flour milling. Since it is not time consuming method and does not requires highly technical skilled personnel. It can predicts with a relative good accuracy the durum wheat flour breadmaking properties.

6.3.3. Farinograph

Analysis showed that the relationship between Farinograph test parameters and breadmaking properties were poor. Mixing tolerance i.e. MT showed higher predictive power compared to the rest parameters. It has been seen that the said parameter was negative correlated ($p<0.01$) with dough maximum volume achieved during fermentation i.e. Hm and with the time that dough starts to release air i.e. Tx. Moreover it was found that MT was negative correlated with dough and bread width, while CD was positive correlated with these. This suggests that the stronger dough during mixing the more oval shape of the dough and bread the dough cylinder will be recoil. The significance of these correlations is limited by the ANOVA results, which have shown that dough and loaf width of all fractions were statistical similar.

Despite the above, Farinograph parameters did not related with loaf volume. A study conducted on durum wheat flour with durum wheat cultivars derived from ten countries, showed weak correlations for hearth bread volume and Farinograph parameters (Edwards et al 2007b). While a study conducted on Italian wheat cultivars, showed significant correlation for bread volume and Farinograph parameters. (Boggini and Pogna, 1989). According to Frazier et al. (1975), the standard Farinograph rate of work input does not fully develop the dough strength and higher rate of work input is required. Faergestad et al., (2000) and Uhlen et al., (2004) studies in common wheat flour further supported this. They have found that by mixing the dough at higher rates in the Farinograph the correlation between hearth bread volume and the said test parameters was improved. This can be explained by Tipples and Kilborn (1972, 1974, and 1975) studies. According to their work, dough mixed below the optimal intensity reverts to unmixed state faster than if it was simply rested. The loaf volume produced by undeveloped dough is significant lower compared to an optimal developed dough. The above suggest that dough mixing method for the baking tests and Alveo-Farino method followed in this study may produce undeveloped doughs and this leaded to misleading results. This might explains why the cysteine (present in improver B), favored the breadmaking properties of *Coarse*. However according to Oliver and Allen (1992) findings, the 1:5:2 Farinograph mixing method (1 min mixing, 5 minutes rest and 2 minutes mixing at 60 rpm) develops the dough to state similar to that of straight 5 minutes mixing. Since the extensograms obtained by the two different mixing procedures were similar. They concluded that the intermediate rest favored the dough development. Our tested samples showed a fast dough development ranging from 1.5 min to 2.6 min. this suggests that work input was above the critical limit and thereby the dough was fully developed.

6.3.4. Consistograph

The scientific community have been paid little attention to Chopin Consistograph. Few studies explored the relationship between Consistograph mixing parameters and breadmaking properties. According to our knowledge only Vinci and his co- workers (2013) have used Consistograph to measure key mixing variables of durum wheat flour and to relate them with dough properties and leavening performance. In brief they had built a model which predicted the effect of the hydration level and mixing time on durum wheat flour leavening performance. According to their calculations Consistograph can be a valuable alternative method to Farinograph in order to evaluate the mixing profile of durum wheat flour. However their methodology on dough preparation was different from the present and thereby the results of the two studies cannot compared directly.

6.3.4.1. Constant Hydration Consistograph Method

It worth noted that the Consistograph was introduced by Chopin in order to overcome the Alveograph shortcoming of constant hydration. For this purpose the dough first mixed in the Consistograph under constant hydration as in Alveograph test. At this stage the dough hydration properties are predicted in a fixed software which transfers the pressure applied to the sensor to the corresponding absorbing capacity. According to our knowledge Consistograph constant hydration PrMax i.e. FC value has never been used to correlate it with other rheological measurements and with flour breadmaking performance. It has been seen that it was significant correlated with gluten content and Zeleny sedimentation. Moreover when untreated fraction results were included in the correlation calculations, FC showed significant correlation with W value. However when the untreated fractions excluded from the correlation became weak. Also it has been seen that it was weak correlated with Farinographic parameters and starch damage. ANOVA analysis showed that according to FC value the untreated fractions can be divided into two groups. The first was consisted by the weakest fractions such as Straight Run, Fine and Super Fine and the second, by the rest fractions. Whereas the rest rheological tests failed to discriminate so clear the flour fractions. However according to ANOVA the fractions were better discriminated when treated with improver A rather when treated with improver B. FC parameter was significant correlated with breadmaking properties. The PCA plot and the Pearson correlations showed significant relationships between FC and dough behavior during fermentation. In some cases the correlations were extremely high, as in case of Hmd. Also it was significant correlated with dough length after molding and bread height. Furthermore it was significant correlated with loaf volume. The above results lead as to hypothesise that FC parameter is related with dough strength and

gluten elasticity. This hypothesis is further supported by the fact that starch damage and flour particle size had a minimal impact on this parameter. It is tempting to state that if dough stiffness at constant dough hydration is not related to starch damage and to water absorbing capacity, then it is governed by the gluten properties.

Due to absence of previous studies, we will attempt to explain the measuring mechanism. The Consistograph double arm mixer forces the dough to make repeatable contacts with the sensor which is placed in the side of the mixer bowl. The higher the force applied due to higher dough consistency the higher the FC value will be. When the dough forced by the revolving movement of the double arm mixer against the side of mixing bowl where the sensor is placed it spreads, the higher the spreading the lower force applied to the sensor. Since lower mass of dough will make contact with the sensor. The dough spreading is governed by the gluten elasticity. Therefore FC value is related to dough strength.

However further work is needed with wider range of durum flour samples in order to verify the above results. Also, it is needed a better explanation of the measuring mechanism and which property really represents the pressure to the sensor.

6.3.4.2. Adopted Hydration Consistograph Method

It has been seen that PrMax value from the constant hydration protocol was not related with PrMax value from adopted hydration protocol. The reason is that the optimum hydration level predicted by the former did not resembled the true absorbing capacity of each fraction. For example the defined water absorbing capacity for the *Regrind* was lower from the *Coarse*. Where the defined water absorbing capacity by Farinograph test for the *Regrind* was 69% and for the *Coarse* was 62%. The same more or less differences observed also for the rest fractions. Thereby the fractions were not optimum hydrated and thus leaded to poor correlation between FC and FA and to misleading results. A characteristic example is the significant negative correlation between FA and Farinograph water absorbing capacity. However despite its limitations which derived from the inappropriate hydration, Adopted Consistograph gave valuable information for the dough properties. Consistograph curve shape was similar with Farinograph indicating a strong correlation between these two methods. The strong relationship between these methods is an advantage for the Consistograph test since Farinograph method is highly regarded by the cereal industry and that shows that Consistograph has a potential on flour testing. It has been seen that the pressure measured during mixing was correlated with the dough and bread shape. The recorded pressure

was related positive with the dough and bread width. Both FA and D450 were significant correlated with the BH/BW ratio, while Farinograph test parameters were not. The pressure drop after 450 seconds of mixing i.e. D450 showed higher predictive power compared to the rest Consistographic parameters. For the dough behavior during fermentation, it has been seen that the said parameter was significant negative correlated with Rheofermentometer parameter T1. ANOVA results further supported the significance of the above correlations especially when fractions treated with improver A. This means that the softer the dough the higher the dough development rate. As in case of Farinograph, adopted Consistograph parameters exhibited pour correlation with loaf volume.

6.3.5. Alveograph

The PCA plot positioning and the correlation calculations have shown that the P values obtained from the four modifications were weak correlated with dough development properties during fermentation. The only significant ($p<0.05$) correlation observed was between PS, PF and Hmd, this means the higher the tenacity the higher the dough stability during fermentation. Also the L values and P/L ratios were not correlated with dough behavior during fermentation. Only the W values obtained from standard, Interrupted and Adopted methods were significant ($p<0.05$) related with Hm and h. The poor relation of the Alveo-Farino method with the Rheofermentometer values it was contrary to what it was expected. Since the dough hydration of Alveo-Farino method was same with the bread dough and both were mixed in Farinograph for exact the same time and work input. If we assume that the Rheofermentometer test represents accurately the dough properties during fermentation then we should accept that either dough tenacity or extensibility do not have a critical impact on dough behavior during fermentation or these properties were ill defined by this Alveographic modification.

It has been seen that P values obtained from the four Alveographic modifications were negative correlated with dough length after molding. Only the L value obtained from the Alveo-Farino method was positive correlated with the said dough property. Our results are in line with Sapirstein et al (2007) who found that P value from the standard Alveograph method was negative correlated with dough sheet length, while the L value was poor related with the said dough properties. Moreover it has been seen that W value was significant correlated with the dough width at the end of fermentation. P and L values obtained from the Alveo-Farino method were significant correlated with the dough length at end of fermentation. Moreover W values from all modifications except the Interupted Alveograhic method were significant positive correlated with loaf width. However

ANOVA have shown that the only significant difference in dough length during breadmaking was between *Super Fine* and *Mid Fine*, whereas the dough width was similar for all fractions. In case of bread length *Super Fine* exhibited significant lengthier loaf compared to *Coarse*, *Mid Fine* and *Regrind*, while again loaf width was again similar for all fractions. The above suggest that bubble inflation can predict in the dough and loaf shape into a moderate extent. The relation with said properties can be improved if the inflated dough will be in similar state with this of the baking test.

However despite the above correlations the four Alveograph methods followed in this study failed to predict the loaf volume. The correlations between the Alveographic parameters and the loaf volume were poor. The results of the present study disagree with Edwards et al (2007b) who reported that Alveograph length was highly correlated with loaf volume of hearth bread made by durum wheat flour. Also they found that Alveograph P, was poor correlated with loaf volume, while W had weaker predictive power on loaf volume than L value. They concluded that dough extensibility is the most critical factor for voluminous bread. Their results reflect the general belief that loaf volume of durum wheat flour is heavily affected by the dough extensibility (Quaglia 1988). ANOVA showed that flour fractions with significant different L values and similar gluten content exhibited similar loaf volume. A typical example is the loaf volume obtained from *Coarse* and *Regrind* where both exhibited significant ($p<0.05$) different extensibility but similar loaf volume either treated with improver A or B.

In Edwards et al (2007b) work the flour samples tested exhibited high variation in L value. In addition the absolute P values and P/L ratios were significant lower than of the present study. ANOVA analysis showed that the variation of extensibility between fractions was limited except in case of Regrind which was an outlier. Moreover P values were extremely high while L values were low. This means that P/L ratios and W values were affected by P variation while the impact of L was minimal. ANOVA analysis also showed that the variations in W values was limited. Bloksma work (1957b) on correlating Alveographic parameters with loaf volume implies that only greatly deviating samples could be distinguished from each other. This was further supported by the findings of Bettge et al., (1989). These works might explain the poor correlation between Alveographic parameters and loaf volume observed in the present study.

The standard Alveographic parameters have been heavily criticized, since the constant amount of water results dough of different consistency (Weipert 2006). Flours differing in protein content, starch damage, ash content or particle size show different water absorbing capacity. By adding

constantly the same amount of water i.e. 50%, irrespective the flour quality has been identified as the main limitation factor of the said method. This limitation might have severe effect in case of durum wheat flour evaluation were the water absorbing capacity is often well above 60%. In this study the water absorbing capacity range of the fractions tested in the Farinograph was in between 64% to 69%. This limitation motivate Chopin to introduce the Consistograph. However it has been seen at least for the present study that Consistograph was poor correlated with water absorbing capacity as it was determined by Farinograph. This suggest that doughs obtained from the different fractions were different in consistency. Therefore the poor correlation of the said method maybe reflects the limitation of the standard method. However by obtaining similar dough consistency as in case of Alveo-Farino method the correlation of the said bubble inflation method with loaf volume remained poor. In addition Alveo-Farino method showed poor correlation with Rheofermentometer parameters whereas the rest methods were shown significant ($p<0.05$) correlation with the said parameters. Interrupting the dough mixing favors the dough development (Oliver and Allen, 1992). Interrupting the dough mixing at 50% constant water hydration have shown that the fractions were better discriminated. But this methods also have shown poor correlation with loaf volume. The above suggest that other factors also contributed to weak correlation observed between loaf volume and Alveograph.

The resting time of dough in standard Alveograph method bubble inflation is approximately 20 minutes and is generally regarded as too short. Dough during mixing and sheeting absorb energy and the resistance to stretching immediately after mixing is very high. During resting the resistance to stretching is progressively lower as the rest time increases, a phenomenon which is called as structured relaxation. It is generally accepted that by increasing the resting time elasticity variation between different flour samples is more evident (Rasper and Preston 1991). In a study contacted by Weipert (1981) it was found that by increasing the resting times of the standard Alveograph procedure P and W values became more reliable predictors of loaf volume. In this study the resting time for all modifications was 20 minutes. This might contributed to poor relations between Alveograph parameters and loaf volume. The effect of resting time on predictive power of Alveograph in this study was evident by the significant ($p<0.05$) correlation between bubble inflation and dough length after moulding. The resting time between these two was similar.

The temperature of dough during mixing and resting might contributed to weak correlation between Alveograph parameters and breadmaking quality. The temperature during mixing at Alveograph was set at 24^0C, while for resting was set at 25^0C, except when the dough was mixed in the Farinograph bowl, where the temperature was set at 30^0C. Dough oxidation by ascorbic acid

is temperature depending (Millar and Tucker, 2012). This explains why the ascorbic acid effect was more evident when the dough kneaded in the Farinograph mixer.

Enzymes have a critical impact on dough rheology. Enzymes action and intensity is time and temperature dependent (Kornbrust and Matveeva, 2012). In the breadmaking process the temperature of the prover was set at 32 ^{0}C. The temperature optimum for most enzymes is above 40^{0}C (Kulp, 1993). According to Stauffer (1994) the increase of temperature by 10^{0}C until the optimum, increases the rate of reaction 1.5-2 fold. Thereby the enzymes were less active in Alveograph measurements than in breadmaking and thus contributed to poor relationship between Alveograph and breadmaking properties. If it is chosen to increase the resting time beyond the standard 20 minutes, the dough consistency in Farinograph should be set to meet the 600BU line. Otherwise the dough handling will be very difficult and the reproducibility of the tests will be limited. If it is chosen to increase the temperature during resting above 30^{0}C the dough will become too soft with poor handling properties.

Measuring the rheological properties of the dough outside the critical temperature range reduces the predictive power of the Alveograph. The dough samples in this study were inflated at room temperature. The rheological properties of the dough towards the end of fermentation and at the early stages of baking are critical for the final bread quality (Dobraszczyk, 2004). The gas cells at this stage are prone to rapture which may cause dough or bread collapsing. Baking causes a complex series of physical, chemical and biochemical transformation (Campbell and Martin, 2012). When gluten heated above 50^{0}C with a moisture content exceeding 20% the total SH content is decreased, the dough becomes less extensible and the gluten toughens (Schofield 1984, Wieser, 2012). These changes have a critical impact on gas stability and dough expansion. Studies from Dobraszczyk and his co-workers (Dobraszczyk, 2004, Dobraszczyk and Salmanowicz, 2008) have shown that the correlation between bubble inflation and bread volume is improved when bubble inflation is carried out at temperatures ranging from 50°C to 60^{0}C. That is, by increasing the temperature during dough resting and inflating the predictive power of Alveograph will be improved.

Another factor which influenced the Alveograph results and reduced the predictive power of the said method, it was the time needed for the dough to be extruded from the mixer. The extrusion time was positive related with dough stiffness. In cases like durum wheat flour where the dough is very tenacious the extrusion time is extremely long. In this work it has been seen that in some

cases the extrusion process lasted more than 6 minutes. Thereby the mixing energy put in each dough piece was different. It was observed a tendency for the first of the five dough pieces to relate with higher W compared to the rest, while the last related with higher P and lower L. Our observations are in agreement with Aitken et al (1944b) who found that the extraction process affected the inflation indices of the flour samples tested.

Another reason which contributed to the poor relation observed between Alveograph indices and loaf volume is the rate of dough deformation. The rates of expansion of the bubble walls during baking have been calculated in the range 10^{-2} s^{-1} to 10^{-3} s^{-1}, where Alveograph rate of deformation is several order of magnitude greater. The rate of deformation during molding is $30s^{-1}$ (Dobraszczyk and Roberts, 1994; Dobraszczyk and Schofield 2000). This explains the significant ($p<0.05$) correlation between P value and dough length after molding i.e. ML. The deformation rates during inflation and moulding were similar.

The action of yeast during the fermentation phase of breadmaking has been shown to bring about significant changes in dough properties (Nagao et al., 1981). During fermentation the dough development is continued and the dough becomes more elastic dryer and the gas relation properties are improved (Hoseney and Rogers, 1990). Yeast fermentation produces CO_2 and ethanol and the pH of dough drops, through the production of organic acids. Jayaram et al (2013) showed that succinic acid is the dominant organic acid produced is during fermentation. Jayaram et al. (2014a, b) found that both ethanol and succinic acid had an important impact on Alveograph indices. The P value and the P/L ratio were increased significant while the L value decreased. They concluded based on Alveograph measurements that succinic acid and ethanol make the dough stiffer and less extensible. This explains why the Alveo-Farino method was poor related with dough behavior during fermentation. The effect of yeast action on dough rheology was not taken into account. Also this may explain why Standard, Interrupted and Adopted methods were significant correlated with Rheofermentometer parameters. The doughs of the said methods were stiffer and less extensible compared to Alveo-Farino method due to lower water addition and therefore better reflecting the dough stiffening during fermentation.

It is generally accepted that the rheological properties of dough determine the breadmaking quality. The rheological dough properties might be better described by biaxial extension (Dobraszczyk and Morgestern, 2003) and in particular by bubble inflation, since it is related more close to the breadmaking process. However the relation between Alveograph indices and loaf volume is often

weak Khattack et al., (1974). The weak correlation between rheological measurements and loaf volume observed in this study might be explained into extent by the findings of Gan et al., (1990). Based on electron micrographs they observed that despite the gluten starch matrix became discontinuous the gas bubbles continued to expand. Their findings supported the liquid film hypothesis proposed by Mac Ritchie (1976). He suggested that at late stage of proving and early stage of baking a secondary mechanism enhances the gas retention properties of the dough. The gas bubbles coalescence is prevented by a thin film containing water soluble surface active components. However the gluten starch mechanism is the primary stabilizing mechanism. While the liquid lamellae is the secondary mechanism and its role is evident when gas bubbles become in contact Mac Ritchie (2016). Therefore the rheological properties as described by rheology tests cannot fully explain the dough behavior during proving and baking. The liquid film hypothesis might explains the weak correlation between Alveograph and loaf volume. However there is no data available in order to estimate the contribution of this mechanism to breadmaking properties of the durum samples tested in this study.

In this study P value obtained from Standard, Interrupted and Adopted hydration methods were significant correlated with Zeleny sedimentation and gluten content. Also, it has been seen that W was affected by P since the variation in extensibility was limited. P value have been received the most interest from the researchers and its relevance to dough rheology (Dubois et al., 2008). Over the years different researchers have related this value to different terms of empirical rheology. According to Aitken et al (1944a, b) P value describes dough stiffness, shortness and tightness. Ammos et al (1949) concluded that is an index of dough stability. Their views have been widely adopted by the industry and P value is regarded as measurement of dough tenacity. P value defined by ISO Alveograph method (ISO 2005) and AACC method (AACC 2003) as an indicator of dough resistance to deformation. According to Edwards (2007a, b) and Sapirstein (2007) P value indicates the dough elasticity and strength. However Hlynka and Barth (1955) supported that maximum height of the curve is related with thickness of the dough babble wall at the time measured. In other words at the beginning of the extension the thickness of bubble wall determines the P value. Therefore P value is insignificant in rheological terms. They suggested that the curve height should be measured at a chosen bubble volume instead of its maximum point. The insignificance of P value was further supported by Bloksma work (1957). Dobraszczyk and Roberts (1994) proved the insignificance of P value by transferring the data of bubble inflation on a true stress-strain curve. They found that the stress increase throughout inflation and showed no inflection at peak in pressure. This have shown that maximum height of the Alveograph curve is

only an artefact of the geometry and it is not related with dough rheology. These findings suggest that the typical pressure profile curve does not reveal the true rheological properties. This may explains why in this study, the Alveograph indices were weak correlated with loaf volume.

6.3.6. Rheofermentometer

Analysis have shown that starch damage had a negative impact on dough expansion during fermentation. Both maximum dough development i.e. Hm and dough volume of the end of fermentation h were significant negative correlated with starch damage. Moreover the negative impact of starch damage on dough properties during fermentation is evident from the significant ($p<0.05$) negative correlation between starch damage and the time when the dough starts to release gas i.e. Tx.

Our findings on the adverse effect of starch damage on breadmaking quality are in agreement with Chamberlain et al (1966). The destabilization mechanism and the impact on dough rheology has been presented earlier. It is generally accepted that damaged starch is more susceptible to enzymic hydrolysis (Hoseney, 1994) and therefore the higher the starch damage, the higher the gas production. However this general belief was not evident in this study. Starch damage was weak correlated with CO_2 production rate and total gas production volume. A number of reason have been proposed earlier such as the natural sugar content, the effect of cysteine addition and the amino acid composition of each fraction. The moderate effect of amylolytic hydrolysis is evident by the weak correlation of Falling Number with dough expansion and gas production. These findings further strengthen the belief that other factors of equal importance affected yeast metabolisation and gas production. It should be noted that starch damage content and Falling Number were weak correlated with loaf volume.

The maximum dough expansion during fermentation i.e. Hm was highly correlated with dough volume at the end of proving h indicating that the durum flour samples tested exhibited high tolerance during fermentation. The PCA plot and the correlation calculations have shown that the longer the time that dough porosity becomes evident Tx the higher the dough expansion will be during fermentation. According to Verheyen et al., (2014, 2016) Tx is related with CO_2 production rate however the results from this study are not in agreement with this, since the correlation between Tx and TG i.e. gas production rate was weak. It should be noted that Tx was also not correlated with the time needed for maximum dough expansion T1. That means that the dough continued to expand due to higher gas production rate. The rate of gas production was higher than

the rate of gas escaped from the dough until the maximum dough expansion Hm. This finding could be explained taking into account the considerations of Chiotellis and Campbell (2003a, b). They found that the decrease value of CO_2 entering the bubbles in late stages of proving was due to gas loss from the dough. Therefore Hm indicates the maximum volume of CO_2 which can be trapped by the dough. After that the gas bubbles rapture at greater rate and the dough becomes unstable and prone to collapse. It has been seen that h was significant ($p<0.05$) positive correlated with gas retention capacity RET. According to Verheyen et al (2014, 2015). The gas retention capacity is affected by the total volume of CO_2 produced and the dough rheology. The total gas volume produced by all fractions was similar according to ANOVA, therefore the gas retention capacity in this study reflects into extent the dough rheology.

The rate of dough expansion T1 was very low for all fractions. According to Chiotellis and Campbell (2003a,b) the rate of dough expansion is affected by the yeast concentration, the natural sugar present, the enzymic hydrolysis, the gas bubbles created during mixing and temperature. Their findings suggest that the CO_2 diffuses more rapidly in dough with lower density or to a less stiff dough and thereby the dough expansion rate is depend on dough rheology. If we accept that Alveograph, P value, measures dough stiffness then it should be negative correlated with dough expansion rate. This hypothesis was verified by a study contacted on common bread wheat flour. Ktenioudaki et al (2011), found that Alveograph P value was significant negative correlated with T1. However our results failed to verify the above hypothesis since the Alveograph P values obtained by the four methods adopted in this study were weak correlated with T1.

Analysis have shown that Rheofermentometer indices were significant correlated with durum flour loaf volume. Our results are in agreement with Ktenioudaki et al (2011) who found that Rheofermentometer measurements were significant related with bread volume. In particular in the present study Hm, h, T1 and gas retention capacity RET were related positive with loaf volume, linking the dough rheology during proving with dough rheology during baking. The dough expansion tolerance and gas retention capacity indicate the gas bubble integrity and stability. During the early stages of baking these properties are critical for high oven spring. When the dough enters at the oven the gas bubbles expand due gas thermal expansion and due to higher production rate production of CO_2 by yeast, therefore the gas bubbles should expand as much as possible and the coalescence should be retarded, in order to get voluminous bread. Later the dough expansion ceased due to gluten denaturation and starch gelatinization and the gas bubbles are interconnected and the trapped air diffused to the atmosphere. The foam structure transformed to sponge texture.

6.3.7. Geometrical properties

The PCA plot and the correlation calculations have shown that the dough flow and bread shape were affected by the gluten content. The gluten content was significant positive correlated with dough width at the end of fermentation and bread height. While it was negative correlated with dough length after molding. These results suggest that gluten has a critical impact on dough flow during breadmaking.

Alveographic measurements exhibited moderate predictive power on dough flow behavior during breadmaking. In brief, tenacity was negative related with dough length after moulding, W was positive related with dough and bread width while L was poor related with dough geometrical properties during fermentation. Faergestad et al (2004) reported that resistance to dough stretching was strongly correlated with dough flow and loaf shape. They have found that the higher the resistance the lower the dough flow during fermentation and the higher BH/BW ratio. It should be noted that in their study the dough properties were assessed by uniaxial stressing technique rather than biaxial as in the present work. The mixing properties as they were measured by Consistograph and Farinograph were not highly related with dough length after molding. However they were better correlated with dough flow properties at the end of proving and baked bread than biaxial extension measurements. In general it can be said that the softer the dough during mixing the higher the dough and bread width. In addition it should be highlighted that only D450 parameter was significant negative ($p<0.01$) correlated with BH/BW ratio. Zeleny sedimentation test have shown that had a predictive power on dough flow during breadmaking.

Among the tests and the properties measured in this study the Rheofermentometer test parameters had the closest relation with dough and bread geometrical properties. Both Hm and h were positioned diagonal opposite in the PCA plot with dough length after molding. Indicating that the dough elastic recoil is positive related with dough expansion during fermentation. The dough length after molding is an indication of dough strength and gluten elastic properties. Therefore the lower the deformation the higher dough expansion during fermentation due to stronger gluten. This explains the significant ($p<0.01$) positive correlation between Hmd and ML. The dough volume of the end of proving was positive correlated with bread height. While Hmd was significant negative correlated with bread height and BH/BW ratio. This links the dough stability with loaf shape. The less tolerant dough will flow and during baking will expand to all directions, while tolerant dough will have more cylindrical shape.

The dough expansion rate T1 was significant ($p<0.05$) related with dough shape during fermentation. The lower the rate of dough expansion the lower the dough flow during proving. Dough development is affected by yeast concentration, pH, temperature and dough strength (Chiotellis and Campbell 2003a, b; Cauvain 2012). Flour with higher protein quality needs more time for expansion (Faergestad et al 2004). That is the higher gluten elasticity the lower the dough flow. This explains why T1 was significant correlated with loaf height and BH/BW ratio, since these geometrical properties are positive related with protein quality (Faergestad 2004). The dough density was significant related with dough shape during proving and baking. The higher the dough density caused by slow gas production rate TG the lower the dough flow during fermentation and baking. The significant ($p<0.01$) positive correlation between TG with bread height and BH/BW ratio lead as to suggest that the lower the gas rate during proving the higher the oven spring. The yeast was not depleted during proving and high amount of leavening was available at the early stages of baking. The CO_2 production rate was accelerated by the temperature increase and thereby the oven rise was increased significantly. The gas retention capacity RET was significant correlated with bread height and BH/BW ratio ($r=0.90$ $p<0.001$ and $r=0.79$ $p<0.01$ respectively) At the early stage of baking the increase of vapor pressure and the accelerated rate of CO_2 production induces considerable stress to gluten-starch matrix. The gas retention capacity is critical at this stage, because early gas cell rupturing before structure setting will cause bread collapsing and the hearth loaf shape will become flat due to gravity. Experienced bakers are well aware of this phenomenon and the proving time is set according to the flour protein strength. The proving time of hearth bread is usually shorter compared to tin bread because the dough during proving and baking is not supported by the tin. This explains why it is very common the hearth breads to have more crust opening than to tin breads.

The dough length after moulding was significant ($p<0.01$) positive related with dough length at the end of proving and with final bread. This shows that the pattern of the dough flow in length did not change during the breadmaking process. The dough length after molding and the bread height were positioned opposite in the PCA plot. It was suggested earlier that the ML was related with the dough elastic recoil and therefore with gluten strength. That means that the higher the gluten elasticity the higher the bread height will be. This is supported from the work of Faergestad et al (2004) who found that the hearth loaf height was positive related with protein quality. The width of the dough after molding was related ($p<0.05$) with loaf height. Since the higher the elastic recoil after molding the more oval the shape of the dough will be. Therefore dough width after moulding reflects the dough strength. However ANOVA have shown that the width of all fractions

and in all stages of breadmaking was similar. Bonferroni correction might contributed to this since it is regarded as very conservative post hoc test. The dough length after fermentation was significant ($p<0.05$) negative related with BH/BW ratio while dough width was poor related with the said ratio. Similar trend was observed for the baked loaf geometrical properties. The length was significant negative related with bread height and BH/BW ratio while the bread width was poor correlated with the said parameters. This means that the impact of dough and bread in length had more significant impact on bread height BH/BW ratio. In addition it has been seen that the length and width were not related with loaf volume, whereas bread height was significant related with BH/BW ratio and loaf volume. Our results are in agreement with Faergestad et al (2004) who found that loaf height had greater impact than width on loaf hearth bread volume.

6.4. CONCLUSION

Analysis have shown that the Farinograph test parameters were poorly correlated with loaf volume. However mixing tolerance and stability were significant correlated with dough and loaf width. Moreover it has been seen that mixing tolerance was significantly related with dough maximum expansion during fermentation and with the time that dough gives off air. Adopted Consistograph test parameters were significant related with Farinograph parameters. As in case of Farinograph Adopted Consistograph had a limited predictive power on loaf volume. The parameters obtained from the pressure curve of the said method were significant related with the dough and loaf shape. Constant hydration Consistograph is used in order to determine the water absorbing capacity of flour. In this study results have shown that the Consistograph was poorly related with the flour water adsorbing capacity as it is defined by Farinograph. Although constant hydration Consistograph method was significantly correlated with bread volume. In addition it was significant related with the dough behavior during fermentation and dough and loaf shape during the breadmaking process. These findings suggest that more attention should be paid on this Consistograph method with constant hydration and further work is needed to evaluate the results of these tests.

Zeleny sedimentation was significantly related with breadmaking properties of durum flour tested in this work. In particular it was significantly related with dough behavior during fermentation, the dough and loaf shape with bread volume. These results suggest that Zeleny sedimentation could be a very valuable method for the milling industry since it is fast and does not required high

technical skilled personnel. The gluten content was significantly related with fermentation parameters and dough and loaf shape. However it was poorly related with loaf volume the results indicate the protein quality will have the most significant impact in loaf volume. Starch damage was negatively related with dough volume during proving reflecting destabilizing impact on the gluten starch matrix. In addition it was poorly related with gas production rate indicating that other factors also affected the CO_2 production rate. Results have shown the amylase activity as it was determined by the falling number method had a minimal impact on breadmaking properties.

Analysis showed that the Alveograph modification methods were significant correlated with dough behavior during proving and with dough and loaf shape. In particular W value obtained from standard, interrupted and adopted methods were significant correlated with dough maximum expansion during fermentation and final dough volume at the end of proving. Whereas Alveo-Farino method was poorly related with the said breadmaking properties. In addition it has been seen that Alveograph indices from the four modifications were moderately related with dough and loaf shape. Results have shown that all Alveographic modifications adopted in this work were poorly correlated with bread volume. A number of reasons may contributed to that such as the bubble deformation rate, the resting time and the temperature during resting and bubble inflation.

However the Rheofermentometer test showed high predictive power on the dough breadmaking properties. It was significantly related with dough and loaf geometrical properties and with loaf volume. Rheofermentometer could be regarded as very valuable test linking the proving stage with the baking. It can describe quite accurately the dough behavior during fermentation. However the significance of the high correlations obtained between Rheofermentometer and physicochemical properties, rheology tests and dough behavior during breadmaking is limited as shown by the ANOVA results. It has been shown that high variation in these properties should occur and thus impact on the statistical results to be identified by the ANOVA. It was suggested earlier that Bonferroni corrections might contributed to this since it is regarded as very conservative post hoc test.

It has been seen that the geometrical properties of the dough during breadmaking were heavily affected by the dough rheology. The dough flow during moulding and proving were highly correlated with gluten quality. The shape of the dough and bread are very important especially in case of hearth loaf breadmaking. It has been found that the loaf length was negatively related with the BH/BW ratio which is the most important geometrical loaf property. Moreover it was found

that BH/BW ratio was not significant correlated with loaf volume. However as in the case of Rheofermentometer the significance of these correlations is limited by the ANOVA results, probably for the same reasons as above. Concluding it could be said that hearth bread shape reflects the dough rheology, the highest correlation occurred with the Consistograph constant water method and the breadmaking process followed.

CHAPTER 7. GENERAL CONCLUSION

Durum wheat is the raw material of preference for pasta making, also it is very popular for breadmaking especially in the Mediterranean countries. Where in some of them more than 70% of the durum wheat produced is used for breadmaking. Its use as a raw material for traditional bakery products is spreading also in other countries outside the Mediterranean basin. The bread made from durum wheat is usually characterized by low loaf volume and by uniform crumb structure which has a yellowish color. Moreover it has a characteristic nutty taste and increased shelf life. It is produced mostly at artisanal level in a variety of forms and shapes and the processing methods are varied from place to place and from baker to baker.

A number of studies have shown that the physicochemical properties of the durum wheat have a critical impact on the breadmaking performance. Durum is the hardest of all wheats and this dictates the milling process and has a major impact on flour particle size and starch damage content. It is generally accepted that the gluten of the durum wheat is stiff, inelastic and with low elasticity. A number of researchers have concluded that these properties are responsible for the inferior loaf volume of bread made from durum wheat. A significant amount of work has been done on altering these properties. This is possible either by genetic improvement or by the application of specialized additives which are able to alter the breadmaking performance of durum wheat flour. Despite the efforts that have been made durum wheat flour is still associated with inferior loaf volume compared to common wheat.

A number of empirical rheology methods have developed in order to assess the physicochemical properties of wheat. The majority of them are both used in common and durum wheat. Despite their wide acceptance their predictive power on breadmaking properties is still debatable. It has been suggested that many reasons are responsible for that such as dough consistency, resting time, temperature during resting and dough deformation rate.

In this study it was attempted to assess the impact of the durum flour properties on the breadmaking performance. How these properties are affected by the addition of different improvers. In addition it was examined the relationship of commonly used tests with durum flour physicochemical properties and breadmaking performance.

Flour particle size

Much of the work discussed in this thesis was designed to establish whether there was a relationship between the flour particle size and the gluten content, the starch damage and the Falling number values. To this end significant quantities of durum flour samples were produced of differing particles size or similar size but with additional milling were examined. Moreover the impact of flour particle size on the breadmaking properties was examined. Sieve analysis showed a wide particle size distribution in the Straight run flour. It was suggested that the main reasons for that were the high percentage of starchy kernels in the grist and the milling settings. Starchy kernels are softer and therefore the flour produced is consisted from smaller particles. In addition the fine flour particles produced at the mill breaking section were probably adhered to the larger particles and further grinded in the reduction section and thereby the starch damage was increased. The results showed that durum flour is characterized by high water absorbing capacity and starch damage content had a critical impact on that. The high Falling Number value of the Straight run is typical for wheat cultivated in dry and hot environment. The difference in Falling Number values between the flour fractions probably reflects the starch damage content and not the α-amylase activity. This suggestion is supported by the significant statistical difference in Falling Number values between *Coarse* and *Regrind*. It was found that the larger particles were associated with higher gluten content. This finding supported the hypothesis that the fine particles were reflecting the starchy kernels in the grist. Since durum starchy kernels are associated with lower protein content. ANOVA showed that the flour particle size had an impact on dough behavior during fermentation but the impact on the loaf volume was not critical. In case of reducing the particle size, analysis showed that both *Coarse* and *Regrind* were associated with similar loaf volume, therefore regrinding the durum flour granulars does not offer any advantage at least in terms of loaf volume. Our results are in line with Sapirstein et al (2007).

The effect of improvers and L-cysteine on breadmaking performance

Another aim for the work was to examine the impact of two improver formulations on the durum flour breadmaking performance. The only difference in these two improvers called Improver A and improver B, was that to the latter was added 12ppm of L-cysteine on top of the additives in improver A. The idea behind this was to examine if the added cysteine would help to reduce the stiffness and to increase the extensibility of the dough and thereby to favor the dough expansion during fermentation and to increase the loaf volume. L-cysteine is often added to common wheat strong flours used for breadmaking which exhibit tenacious and inextensible dough. In some

preliminary tests (data not shown) it was found that by adding 24 ppm of L-cysteine on top of improver A the breadmaking performance was negatively impacted and made the dough collapse

T-test analysis showed that L-cysteine had a significant impact on dough expansion during fermentation only on the *Coarse* fraction. While the impact of L-cysteine on dough behavior during fermentation was not significant in the rest of the fractions. One possible reason for that may be the level of L-cysteine addition, at higher levels the impact of L-cysteine would be more evident. In addition it was found that L-cysteine had a positive impact on gas formation rate on *Mid Fine* fraction and on the total gas production on *Regrind*. A possible explanation is that a proportion of β-amylase is entrapped in the glutenin polymer, L-cysteine reduced the size of the polymer and thereby a higher amount of β-amylase was available for maltose production.

The addition of L-cysteine favored the loaf volume of *Super Fine*, *Regrind* and *Coarse*, while the loaf volume of the rest fractions were not affected by the addition of the said reducing agent. In this study the dough mixing time was fixed for all fractions and for both improver treatments therefore the dough obtained from *Coarse* fraction might be underdeveloped when treated with improver A. This hypothesis is based on the general belief that the larger the particle size the longer the development time. It was proposed that the cysteine addition favored the dough development of the *Coarse* fraction and that lead to higher dough expansion during fermentation and to higher loaf volume.

Two hypotheses have been proposed in order to explain the positive effect of L-cysteine on *Super Fine* fraction. The first is that the said fraction was characterized by higher gluten strength than its gluten content implies and the addition of cysteine reduced the dough stiffness. Previous studies have shown that starchy durum kernels are associated with higher glutenin content and lower gliadin content or in other words with higher glutenin/ gliadin ratio. This might explain why *Super Fine* fraction exhibited similar loaf volume with *Straight run*, *Coarse* and *Regrind* despite its significant lower gluten content. The addition of cysteine reduced the ratio and favored dough extensibility and reduced dough stiffness and that lead to higher dough expansion during the early stages of baking.

The second hypothesis which has been proposed was based on the findings of Okada et al (1986). They have found that excessive regrinding causes new disulphide bond formation which results in tough gluten. It was suggested that *Super Fine* was excessive reground and therefore the addition

of cysteine reduced the SS bonds and thereby the gluten became softer and more extensible and that leaded to higher loaf volume . This hypothesis also explains the positive effect of added cysteine on the loaf volume of the *Regrind* fraction. This hypothesis might also explain why the rest of the fractions were not responded to cysteine addition. Since these fractions were not excessive reground

Kieffer et al (1990) suggested that ascorbic acid and cysteine have a synergistic effect. They have found that when cysteine was combined with ascorbic acid the latter became more active. However the results from the rheological tests of this study failed to verify these findings. The W values and P/L ratios of all fractions tested either reduced or remained unchanged by the addition of cysteine. The results from the Farinograph and Consistograph tests have shown that in most cases the impact of L-cysteine was not significant. Although it has been observed a tendency that cysteine reduced the dough viscosity during mixing.

The relationship between rheological tests and durum flour physicochemical properties and bread making performance

Considerable attention has been paid over the years by the scientific community and the cereal industry on empirical rheology tests. The main interest is to assess the relationship of these tests with the wheat physicochemical properties and the breadmaking performance. Many reports have shown high correlations between these tests and the flour breadmaking properties, while other have shown weak correlation. In this study much of the work undertaken was examine how commonly used tests are related with durum flour quality characteristics and the predictive power of them on breadmaking performance. In addition it was examined if the relationship between Alveograph and baking quality can be improved by modifying the mixing procedure, the mixer type and the dough consistency.

The results showed that Farinograph is related with gluten content, but high variation should occur in order significance difference to be identified. In contrast Farinograph was significant correlated with starch damage content. In addition analysis showed that the said test was not very sensitive on discriminating the fractions tested and on identifying the impact of the improvers. Moreover the relationship between Farinograph and the breadmaking performance was relatively weak.

The Consistograph test is not as popular as the Farinograph is. In fact little attention have be paid in the said test by the scientific community. The results showed that it was incapable on defining the water absorbing capacity. The adopted hydration Consistograph protocol parameters which describe the mixing behavior were related with those of Farinograph, but in general they were poor correlated with the breadmaking properties. In contrast constant hydration Consistograph method was significant correlated with dough behavior during fermentation and with loaf volume.

The standard Alveograph method and its modifications have shown a limited discrimination ability on durum flour fractions physicochemical properties. It was expected that by obtaining similar dough consistency as in case of Alveo-Farino method the discrimination ability of the said bubble inflation method would be improved, however this was not verified by ANOVA. Although the Alveo –Farino method was more sensitive than the rest modifications on detecting the effect of the improvers added. In particular P/L ratio was affected more than the W value by the improvers. However the said modification was less related with dough expansion during fermentation than the other modifications. Results have shown that all Alveographic modifications which adopted in this study were poor related with loaf volume. Therefore the predictive power of the Alveograph on breadmaking performance it is affected by the mixing procedure, the mixer type and the dough consistency. Other factors as well have a critical impact such as dough resting time, temperature during dough resting and during bubble inflation and deformation rate.

The results showed that the Rheofermentometer parameters were significant correlated with the breadmaking performance and in particular with loaf volume. Therefore it could be said that Rheofermentometer is a very useful test on measuring the dough expansion and the gas production during fermentation and relating them with final bread volume. However the significance of the high correlation of the said test with the baking quality is limited by ANOVA results. It has been seen that high variation was occurred between the test replications and that has a negative impact on the Rheofermentometer results reliability.

Measuring the dough shape during breadmaking cannot be regarded as a true rheological test. However bakers pay much attention on the dough flow during breadmaking since it has a critical impact on final loaf shape of hearth bread. The gluten content was negative related with the dough length after dough moulding and at the end of fermentation. Reports have shown that the gluten elasticity has a critical impact on dough shape. Although the relationship between dough shape and the Alveographic measurements was relative weak, while Consistograph and Farinograph tests

were better correlated with dough geometrical properties. Also Rheofermentometer properties were related with the dough shape during breadmaking, this shows that the rate of dough expansion influences the dough geometrical shape. However ANOVA identified high variation between test replications.

The studies reported in this dissertation provide evidence on how physicochemical properties are related with durum wheat flour particle size and breadmaking performance and how they affected by the improver treatments. In addition how empirical rheology is related with these physicochemical properties and with the baking quality. Further studies are needed to investigate how the gluten composition is related with the flour particle size the impact of the improvers on the gluten properties. Also further studies are needed in to investigate the inter-relationship between particle size, gluten composition, improver effect, empirical rheology and breadmaking performance, so that compensatory mechanisms can be devised to improve the tolerance and the quality of bread made from durum wheat.

Future work

Extend the modifications of the bubble inflation technique

- Resting time
- Resting temperature
- Dough preparation
- Deformation rate

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Appendix supporting information for Chapter 2

Dough assessing methods

1. Dough Kneading Methods

Kneading is one of the defining steps during breadmaking. At this stage water and flour are mixed in order to form the dough. There are two primary goals for kneading, first to create a viscoelastic network and second to incorporate air to the dough (Campbell and Shah, 1999). Flours from different origin and composition differ heavily on water absorption capacity and optimum work input needed for a desired dough development and consistency. Therefore, is very important to define these properties in order to achieve dough with the desired texture. Several laboratory mixers have been developed for this assesment such as the Farinograph and the Consistograph. Bellow these methods are presented in more details.

1.1.Farinograph

Farinograph is the most widely conducted method used to determine the dough physical properties at the kneading stage (figures 1-1 and 1-2). It records and measures the mechanical resistance – torque of the dough during mixing and kneading.



Figure 1-1. Farinograph AT



Figure 1-2. Farinograph bowl close up- kneading the dough

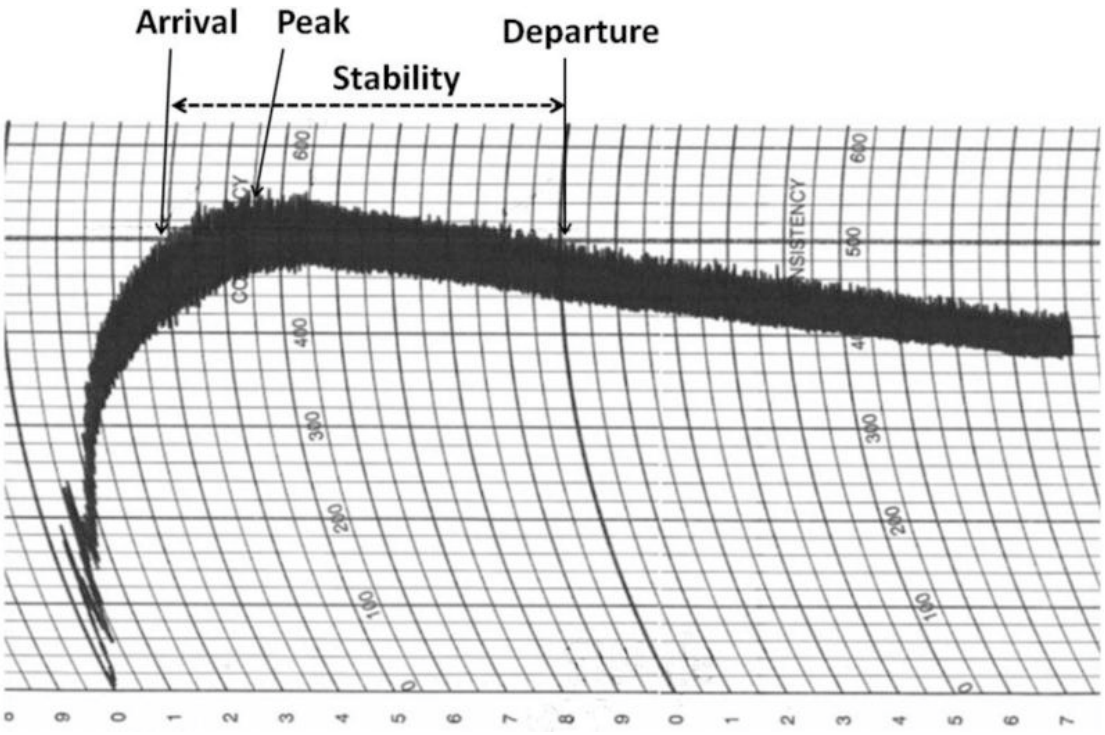


Figure 1-3. Typical Farinograph curve

The basic readings which can be interpreted from the Farinograph curve (figure 1-3) are:
Arrival time: is the time required for the top of the curve to reach the 500 (BU) line after the mixer has been started and the water introduced
Dough development: is the time needed for dough's maximum consistency
Departure time: is the time required to leave the 500 BU line
Stability: is the time difference between arrival time and departure time
Tolerance index (MIT): is the difference in BU from the top of the curve at the peak to the top of the curve measured 5 min after the peak

People in industry consider water absorption as the most significant parameter because it is directly related to the yield of final product. Water absorption capacity is positive correlated with protein content, starch damage and non-starch polysaccharides (Whitworth, 1999). While it is negative correlated with flour moisture, starch and protein degrading enzymes. Focusing only on water absorption capacity it may lead to false conclusions (Bloksma, 1990b). A correct interpretation of the results requires attention to be paid to the degree of softening and mixing tolerance because they are highly correlated with gluten properties (Weipert, 2006). Despite its good correlation with protein content several researchers found poor correlation with bread volume (Edwards et al., 2007; Ktenioudaki et al.; 2010a,). This may be explained by the limitations that the method

associated with. The shear rates during Farinograph mixing are significant lower compared to those of mechanical dough development (Nagao, 1986). In addition dough stickiness contributes to higher resistance and thus to misleading results (Witworth, 1999).

1.2.Consistograph

In contrast to the previous torque measurement methods the principle of Consistograph is based on the measurement of the pressure applied by the dough to a pressure sensor. The pressure expressed in millibars (mb). A stiff under hydrated dough will apply higher force to the sensor while a soft over hydrated dough will apply less force. The force applied to the sensor is translated to apparent viscosity.

Consistograph is composed of an Alveograph modified mixer (figure 1-4). A double mixer arm is used to increase the intensity of mixing. A static rod is positioned between the two arms in order to prevent dough balling and to direct the dough to the pressure sensor placed in the side of the mixing bowl.



Figure 1-4. Consistograph mixing bowl

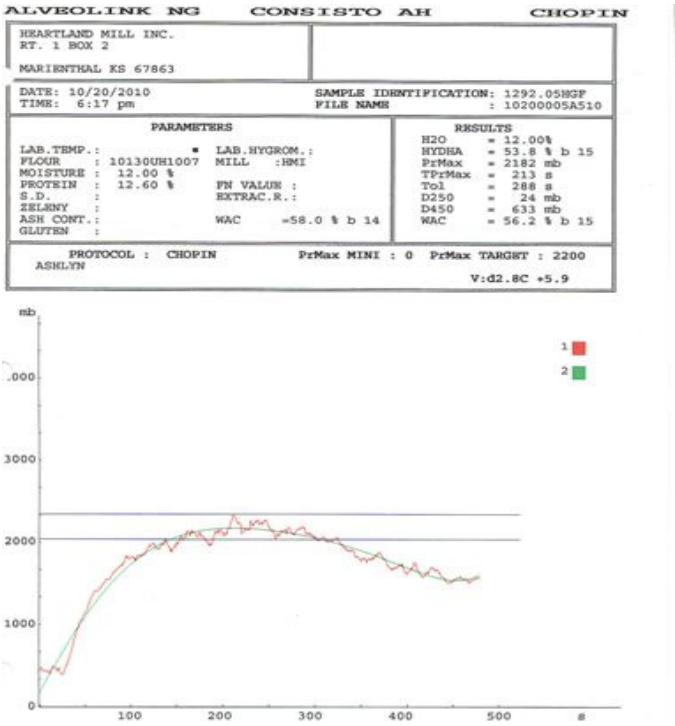


Figure 1-5. Typical Consistograph curve

The basic readings which can be interpreted from the Consistograph curve (figure 1-5) are:

1. PrMax : maximum pressure reached
2. TPrMax : time to reach PrMax
3. Tol : tolerance, time which the pressure exceeds PrMax -20%
4. D250 : pressure drop from PrMax after 250 sec
5. D450 : pressure drop from PrMax after 450 sec
6. WA : optimum water absorption to reach the target of 1700 mb (it is calculated automatically based on the PrMax value)

Consistograph water absorption capacity prediction is highly correlated with Farinograph (Dreyfus et al., 2003; Dubois et al., 2008). It should be mentioned that because its protocol and principle Consistograph always gives lower values than Farinograph (Dubois et al., 2008). According to Dubat (2000) in Consistograph method stickiness does not appear to be a factor leading to better tolerance as in case of Farinograph. This is further supported by Whitworth (1999) were he found that water absorption capacity was better discriminated in case of sticky doughs by Consistograph rather than by Farinograph. Dubois et al. (2008) proposed an explanation for this, sticky dough will stick around the static rod, and as a result less dough is available to apply pressure in the sensor. Geoffroy and Dubat (2003) findings support that Consistograph reacts very sensitively to the changes of ingredient formulation.

2. Alveograph

Extensibility represents the most unique property of wheat dough which enables getting characteristic structure and volume of baked products (Kieffer, 2006; Young 2012). There are several methods which are used to measure the rheological properties of dough in extension. The two most common are: simple uniaxial extension, where dough is stretched in one direction; and biaxial extension, where the dough is stretched in two opposing directions, which can be achieved by bubble inflation (Dobraszczyk and Morgenstern, 2003). The most common device used to define dough uniaxial extensional properties is the Extensograph while for biaxial it is the Alveograph.

The Alveograph method is widely accepted in the milling and baking industry. It is commonly used in wheat trading because it has the ability to classify the quality parameters of bread wheat (Bordes et al., 2008; Aldovrandi and Vitali, 1995). This is done by measuring the force required to inflate and blow a dough sheet at constant rate (figure 1-6). Stronger dough requires more force to blow and break a bubble; the volume of the bubble at the breaking point is translated to extensibility.



Figure 1-6. Alveograph close up-bubble inflation

Each dough patty is inflated at constant rate and its rheological properties are measured in a graph named Alveogram (figure 1-7).

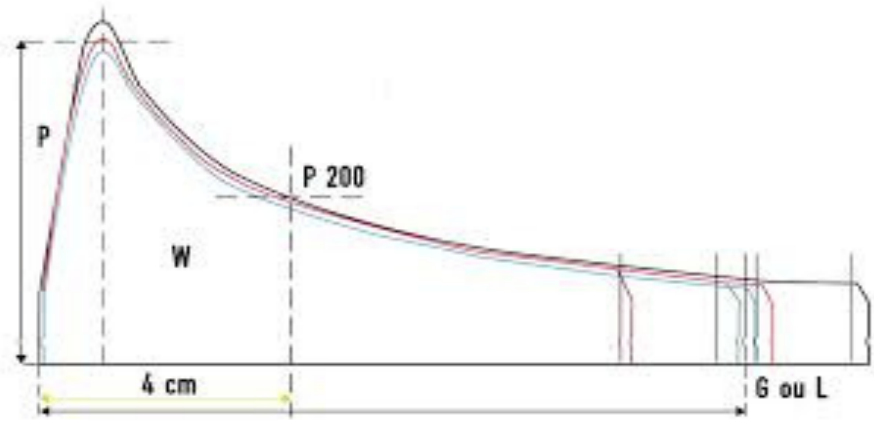


Figure 1-7. Typical Alveograph curve

The basic readings which can be interpreted from the Alveograph are:

P: is the dough tenacity- maximum pressure achieved

L: is the length of the curve up to the breaking point which related to extensibility

W: is the surface area under the curve and represents the energy required to inflate the dough until rupture.

Ie: elasticity index (Ie: pressure at 4 c m from the beginning of the curve)

P/L: configuration ratio

In general strong flours are characterized by high P and W values, while soft wheat flours by higher L, lower P and W values. Alveograph is sensitive to the changes of ingredient formulation (Dubois et al., 2008). There has been reasonable success in correlating these parameters with flour types and loaf volumes. Addo et al. (1990) found high correlation (R2=0.94) between W and loaf volume. In addition L has good correlation with loaf volume (Ktenioudaki et al, 2010a; Jansen et al 1996). P is the most contradictory value. Scott Blair and Potel (1937) found that P is correlated with dough viscosity and thus with water absorption capacity. Starch damage has good correlation with P (Chen and D'Appolonia, 1985; Rasper et al., 1985) and this leading again to the conclusion that P is correlated with water absorption, since starch damage increase the hydration capacity of flour (Farrand, 1964). In contrast Bloksma (1957) point out that P value is not significant. He found that P decreased as relaxation time increased while viscosity remained constant and thus the theory of Scott Blair and Potel (1937) should be rejected.

Constant water addition is the major drawback of Alveograph (standard method) because this may lead to either over hydrated or under hydrated dough and thus to misleading results. For this reason Chopin Technologies developed Consistograph (discussed earlier) in order to get doughs of

constant consistency. Several other modifications have been proposed (Chen and D'Appolonia, 1985; Rasper et al., 1985). Results of these modifications have shown that help in differentiating flours with different properties.

Despite the success of correlating Alveograph's parameters with dough properties and loaf volume, it is thought that more fundamental measured property will better distinguish the differences between doughs (Campbell and Martin, 2012). Based on Bloksma work (1957) bubble inflation rheology can be presented in the form of strain – stress curve. The significance of strain –hardening to gas retention and to bread volume have been presented by van Vliet et al (1992). The correlation between dough strain hardening and breadmaking has proved (Dobraszczyk and Roberts, 1994; Kokelaar et al., 1996; Dobraszczyk and Morgenstern, 2003).

3. Rheofermentometer

Fermentation is a critical step in the breadmaking process. The CO_2 produced by yeast fermentation diffuses into the gas cells which have been created during mixing making them expand. Dough tolerance and overall behavior during fermentation is a critical factor for bread final volume and appearance. A number of instruments have been developed which measure the dough fermentation properties, such as National Risograph, Chopin Rheofermentometer and Brabender Maturograph. Among them the most popular is Chopin Rheofermentometer Weipert (2006). It measures the dough volume change and also the gas production and retention during fermentation. The Rheofermentometer (figure 1-8) has been used widely in the cereal industry in order to examine the impact of additives on doughs as well as to study the dough behavior during fermentation of different flours (Ktenioudaki et al., 2011; Verheyen et al., 2014, 2015).



Figure 1-8. Rheofermentometer F3 device

According to Rheofermentometer F3 instruction manual the test procedure can be described as follows : the dough sample is placed at the bottom of the test bowl and will be fermented under the chosen parameters such as dough mass, test duration time, piston weight and temperature. The dough development curve and gas release curve are presented simultaneously (figure 1-9).

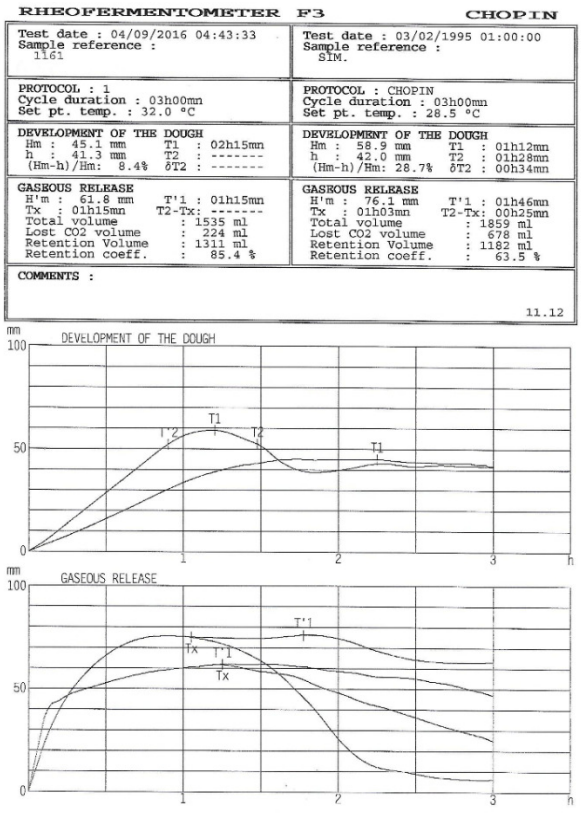


Figure 1-9. Typical Rheofermentometer curves

The basic readings which can be interpreted by the Rheofermentometer test are

1. Dough development curve:
    - Hm: maximum dough volume
    - h: dough volume at the end of test
    - T1: time required for maximum dough volume
2. Gas release curve
    - H'm: maximum point of gas production
    - T'1: time required for maximum gas production
    - Tx: time when dough starts to release gas
    - Total volume: total volume of gas produced
    - Retention Coefficient: gas retention capacity of the dough

4. Zeleny sedimentation test.

Sedimentation tests have long history in cereal science. They have been proved very useful for predicting the gluten quantity (Eckert et al., 1993). The most popular of these is the Zeleny sedimentation test (Preston et al., 1982). The original test procedure designed by Zeleny (1947) was modified by Pickney et al. (1957) into its present form. It measures the sedimentation volume of flour in dilute lactic acid. The tests is based on the known facts that the gluten swells enormously in lactic acid, the degree of swelling depends on the strength of the gluten (Zeleny, 1947, Anderson, 1956).

Zeleny sedimentation test is attractive to breeders since it requires on a few grams of flour. It is also attractive to millers because it is simple, fast and does not requires highly technically skilled personnel. According to Fraud and Kim (2006) the said method can predict the dough breadmaking properties such as resting time, gas retention and bread volume.

5. Falling Number

The Falling number method is used to determine the level of α- amylase activity in flour. It is perhaps one of the most widely conducted tests in the cereal industry (figure 1-10). The reason is that it is simple, robust and fast. The basic idea behind the method is that α-amylase activity can be measured based on its impact on the viscosity of hot flour slurry.



Figure 1-10. Falling Number device

In the Falling Number, test flour/water slurry is heated in a water bath at 100 °C. The slurry is stirred for 60 seconds and then the stirrer is left to free fall from the top position of the tube. The time needed for the stirrer to reach the bottom of the tube is measured in seconds and named Falling Number. Flour for breadmaking typically ranges between 250sec to 350sec.Flour or wheat batches with Falling number values lower than 200 sec usually is unaccepted by the industry. Because, it is associated with excessive levels of dextrins leading to high dough stickiness, poor crumb texture, low bread volume and excessive crust browning. In contrast extremely high Falling number may lead to low bread volume and poor crust color. Different wheat species may show different Falling Number patterns. Common wheat is generally associated with normal Falling number values ranging typically from 200sec to 400sec.In contrast Durum wheat is characterized by high Falling number, usually above 400sec which is typical for wheat cultivated in dry and hot conditions (Quaglia 1988).

Despite its wide acceptance, Falling Number test is associated with heavy criticism. It is regarded as a single point measurement which does not provide useful information such as the pasting profile of the flour. It is highly affected by the level of the starch damage since α-amylase hydrolyse only the ruptured starch granules (Eliasson, 2012). Moreover the viscosity of flour slurry may relate to other factors than enzymatic degradation (Wong and Lelievre, 1981). In addition in standard method the effect of the addition of fungal α-amylase cannot be detected since the enzyme is inactivated at temperatures approximately 70°C. According to AACC (1983a) the Falling number is an indirect measurement, based on viscosity, of α-amylase activity.