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Quality analysis in winter wheat varieties grown in Norway: Investigating quality differences among winter wheat cultivars and impact of environmental factors

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Finally, I would like to dedicate this master thesis work to my late sister Ms. Mershaye Beyene.

Yohannes Beyene Mekonnen
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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
daa	Decare
DMT	Daily Mean air Temperature
DON	Deoxynivalenol
Ext	Extensibility
FAO	Food and Agricultural Organization
FN	Falling Number
g	Gram
ha	Hectare
HMW-GS	High Molecular Glutenin subunit
Ib/bu	Pound per bushel
kDa	Kilo Dalton
Kg/hl	Kilogram per hectoliter
Kg	Kilogram
Km^2	Square kilometre
LMW-GS	Low Molecular Glutenin subunit
min	Minute/s
ml	Milliliter
mm	Millimeter
NMBU	Norges Miljø-og Biovitenskapelige Universitet/Norwegian University of life Science
NPK	Nitrogen, Phosphorus, Potassium
°C	Degree Celsius
°N	Degree North
PHS	Pre-harvest Sprouting
R_{max}	Gluten resistance
R_{max}/Ext	Ratio between gluten resistance and Extensibility
P	Precipitation
s	Second
SDS	Sodium Dodecyl Sulphate
SSDS	Specific Sodium Dodecyl Sulphate

LIST OF CODES

APV … ………..Apelsvoll

Busk ….….….…Buskerud

Fol…..................Follo

Gra…………….Graminor

Gra/Bjø……..…Graminor/Bjørke

Gra/Rød……….Graminor Rød

Rom ……..……Romerike

Sør/Fol ………..Sørøst/Follo

Sør………........Sørøst

Telem ……..….Telemark

Vest…………...Vestfold

Østa…………...Østafjells

Opp…………...Oppland

SUMMARY

Bread making quality is one the desirable goals to be met by wheat breeders and growers; however, this bread making quality is the determined by both genetic and environmental factors. Quality variation occurs in winter wheat cultivars due to high and frequent precipitation (P) and fluctuating daily mean temperature (DMT) during the grain-filling period, which leads to huge economic loss by downgrading of wheat from food to feed as well as yield losses. In the last few years wheat production in Norway has been greatly affected due to loss of quality because of wet and persistent rainy weather conditions as well as fluctuating temperature during the grain-filling periods. In Norway, spring wheat is the main wheat production, but winter wheat counts for a substantial proportion in some seasons, and are often favored due to higher yield potential. While there are many studies conducted on Norwegian spring wheat, studies on winter wheat are scarce.

The objectives of this study is thus to investigate genetic variation between winter wheat cultivars and to study the influence of weather conditions during grain-filling period on quality parameters. The study used two kinds of materials: Material 1 includes data obtained from field trials included in the official variety-testing program performed by Bioforsk; The Norwegian Institute for Agricultural and Environment Research and Arable Crop Division. These data were analyzed for quality by IPV-NMBU (Norges Miljø-og Biovitenskapelige Universitet/Norwegian University of life Science- Department of Plant Science) and Norwegian Institute of Food, Fisheries and Aquaculture Research (Nofima) from 2005 to 2013.

Material 2 includes data collected from Østfold and Vollebekk experimental field trials in 2013 where new promising varieties were included. These data were analyzed for quality at Vollebekk and Nofima. Weather data obtained from Bioforsk (*http://lmt.bioforsk.no/*) was collected and used for calculations of daily mean temperature and precipitation during the 4 sub-phases during grain filling. These data were used to study environmental influences on variations among cultivars and locations.

This study found significant variations among cultivars in material 1. The study revealed that Bjørke was the best in all the quality parameters used, the data further showed that Olivin exhibited higher gluten strength compared to Magnifik and Mjølner. Temperature during sub-phase 2 and 3 explained 23.6 % to 27.9 % variation in gluten strength among cultivars. Besides, significant

negative correlation was also detected between falling number (FN) and precipitation during sub-phase 4 of the grain-filling period. Higher SDS sedimentation volume and SSDS values among the newer varieties in material 2, Skagen, Akratos and Matrix, revealed values suggesting higher gluten strength. Olivin have also showed higher protein content as well as strong gluten strength in material 2 as well.

1 INTRODUCTION

1.1 History of wheat in brief

Wheat is among the most important grains in the world, as it is the third most cultivated crop next to maize and rice (FAO, 2013, Shewry, 2009). Usually wheat is used as human food as whole-grain products or as flour, and the bran is used as animal feed (Harlan, 1981a). Food and Agriculture Organization (FAO) records show that 65 % of wheat is used as food, 17 % is used as animal feed and 12 % is used as industrial inputs including biofuel (FAO, 2013).

Wheat have been cultivated since from the time of the discovery of agriculture and since from the time of domestication of crops by humans. The discovery of agriculture changes the people's lifestyle in many ways; it leads people to live more closely and somehow in stable conditions and forming society. According to Salamini et al. (2002) agriculture is believed to became in practice at about 12,000 years ago in the so called 'Fertile crescent'-a region which in today's map includes Jordan, Israel, Syria, Lebanon and southeast of Turkey. It is at this place where human beings turned from gatherers to farmers. However, some literatures put the time of domestication and the beginning of agriculture at about 10,000 years ago (Özkan et al., 2002, Zohary et al., 2012, Dubcovsky and Dvorak, 2007, Shewry, 2009).

Archeological findings have shown that during the period of domestication, people have domesticated the three important crops which are einkorn, emmer and barley from their wild relatives and the first wheat cultivation is believed to be happened at about 10,000 years ago in the 'Fertile crescent' (Dubcovsky and Dvorak, 2007, Zohary et al., 2012). Phylogenetic studies have showed that the origin of wheat is most likely to be southeast of Turkey. Moreover, the diploid einkorn (genome AA) and tetraploid emmer (genome AABB) were the first cultivated wheat in this area (Dubcovsky and Dvorak, 2007, Heun et al., 1997, Shewry, 2009). Through a long and an interesting evolutionary processes today's form of common wheat (*Triticum aestivum* L*)* having the genome AABBDD is believed to be appeared at about 6000 BC in the Iranian highlands (Belderok et al., 2000).

Currently, wheat is grown almost everywhere in the world, from north in Russia to the south in Argentina. It is the most produced, used and traded crop throughout the world. Perhaps it might be the only crop which is widely used in all human society in diversified ways like many types of breads, cakes and other types of baked foods as well as pasta, macaroni, porridges and different break-fast cereals (Belderok et al., 2000). More than 90 % of today's wheat production is common wheat *(Triticum aestivum L)* and about 5 % is durum wheat *(Triticum turgidum).*

1.2 Structure of the wheat kernel

When processing wheat into flour, three major parts of the wheat kernel distinguished. These are – the bran, endosperm and the germ. The bran consists of the pericarp (the fruit coat that is made of several kinds of cell layers), the testa (the seed coat that is a thin layer next to the pericarp, including the nucellar tissues) and aleurone call layer. The aleurone layer is botanically part of endosperm, but it is considered as part of the bran since it is mostly removed together with the bran in the processing of sifted flour. The endosperm contains starch and proteins in different proportions. An average endosperm protein is about 12.5 % and the starch reaches about 63 % (given as percentage of dry matter) (Osborne and Mendel, 1919). Of course, these figures can vary depending on the type of cultivars used, agricultural inputs and climatic conditions during the growing season within the range of 8 to 20 % protein and 60 to 70% starch varying inversely with the protein content. The germ is the embryonic plant within the seed. The detailed structures of the typical wheat kernel are shown below (Fig. 1).

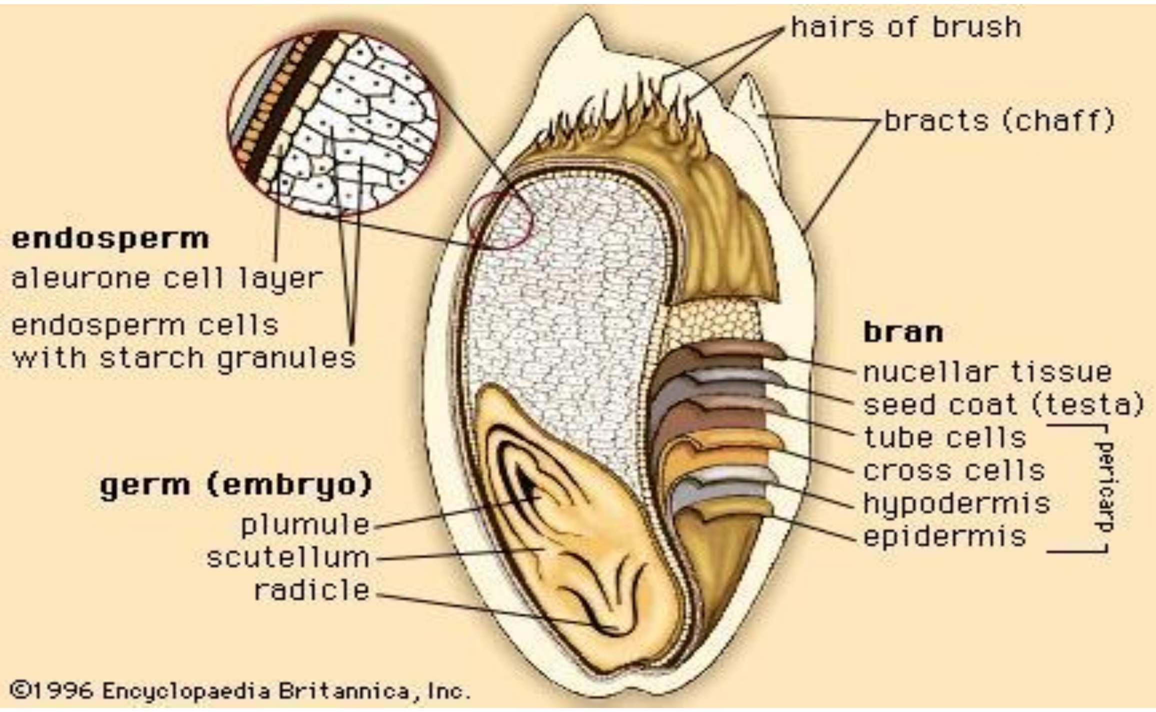

Figure 1. Detailed structure of wheat kernel. Adapted from (Encyclopædia Britanica**)**

1.3 History of wheat in Norway

1.3.1 A brief introduction about the land of Norway

Norway is located between the latitudes 57°58' and 71°10'N in western Scandinavian region with a total land area of approximately 324,000 km^2 excluding Svalbard and Jan Mayen. Only 3 %, which is about 1 mill ha, of the total land is arable land, the rest is mountainous, forest lands, lakes and wet lands (William et al., 2011, Statistics Norway, 2013). Half of the total arable land is situated in the southeast of the country (Fig. 2), where the climatic conditions are favorable for wheat production. This is mainly because of the climatic condition in these regions, which is giving a higher temperatures and a longer growth season with suitable proportions of precipitation. In addition to this, the topography of these regions being relatively flat and of larger units of farming land make them optimal for a mechanized grain production. The role of the mountains which divide the country in to two halves providing suitable temperature and rainfall for the growing seasons should not be discredited (William et al., 2011).

	County	arable land 1000 ha	% of wheat area
1	Østfold	77	36
2	Akershus	81	19
3	Oslo	-	-
4	Hedmark	109	11
5	Oppland	103	4
6	Buskerud	52	9
7	Vestfold	44	18
8	Telemark	26	2
9	Aust-Agder	12	-
10	Vest-Agder	20	-
11	Rogaland	97	-
12	Hordaland	47	-
13	Sogn og Fjordane	48	-
14	Møre og Romsdal	62	-
15	Sør-Trøndelag	76	-
16	Nord-Trøndelag	89	1
17	Nordland	58	-
18	Troms	27	-
19	Finnmark	11	-

Figure 2. County share of arable areas in Norway. The major agricultural areas are indicated by circle. Wheat area (%) is the percent of total cultivable area in the county. Adapted from (William et al., 2011).

1.3.2 Wheat production in Norway

Agricultural practices in Norway is believed to have begun at about 4000 BC during the early Neolithic period, the history of wheat cultivation in Norway dates back to 2500 BC with an evidence of an imprint of emmer grain wheat (William et al., 2011). And some put this time a bit higher like as 3000 BC mentioning the introduction of wheat into Scandinavia (Harlan, 1981b).

Both winter and spring wheat have been cultivated for generations in Norway. Since winter wheat cultivation is highly dependent on the weather conditions during sowing, the amount of winter wheat produced also varies from time to time. The agricultural practice in Norway is adapted to this very long winter and short summer; so that winter hardiness for winter wheat and early maturity or ripening for spring wheat are important for the production. Besides, a lot of effort is also put on improving quality, breeders and researchers have been doing a lot to improve winter hardiness and early ripening in winter and spring wheat respectively (Belderok et al., 2000).

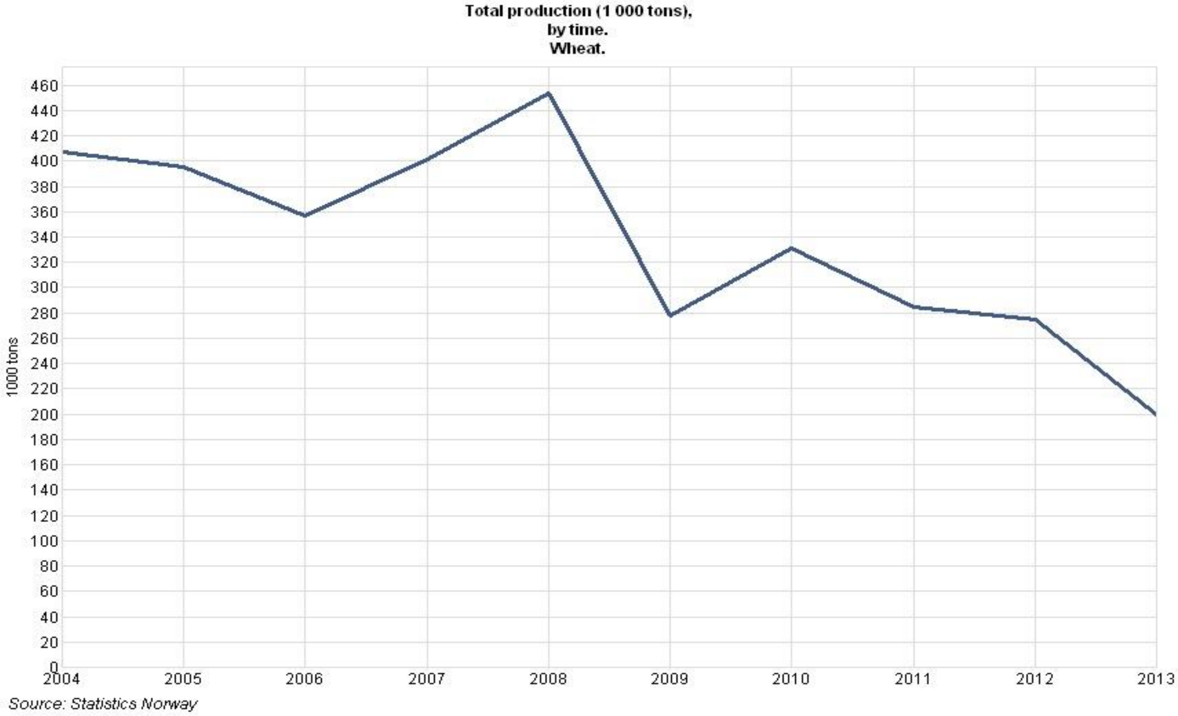

Figure 3. Total wheat production in Norway from the year 2004-2013 (Statistics Norway, 2013).

Wheat production in Norway increased sharply from the 1970`s to 2000. However, the recent trend in Norwegian wheat production is declining (Fig. 3) since 2008. According preliminary data from Statistics Norway, the total wheat production in 2013 is 199, 400 tons and that is less than by 75, 300 tons (27.4 %) from the total production in 2012. In 2013 growing season, the total cultivated land dropped down from 669.8 km^2 to 547.3 km^2 and this could be one of the reasons for the reduction of the total wheat production. Out of this 547.3 km^2 area 91.2 km^2 was covered with winter wheat and the remaining 456.2 km^2 was covered with spring wheat (Statistics Norway, 2013).

Table below (Table 1) shows the dramatic decrease in winter wheat production in Norway for the period 2008-2011 compared to 2006 and 2008. The decrease in winter wheat production could have an impact on the decrease in total wheat production. The weather conditions in autumn when the winter wheat sowing took place could be the main reason for the decrease in winter wheat production. Furthermore, the amounts of winter wheat used for food also vary with the quality found, and in some seasons, large amounts have had quality defects due to pre-harvest sprouting. Sowing should be done during September and the presence of high and frequent precipitation at this period in 2007-2012 could have made sowing not possible in many farm fields. However, in 2013, the autumn was dry and larger area is expected to be covered with winter wheat for 2014 harvesting season.

The total yearly production of winter wheat in class 4 was higher than production in class 5, but still the decrease was observed in both classes generally. Although the total wheat area used in the years 2007 was lower than in 2008, the proportion of winter wheat dropped to very low values. This dramatic decrease could be because of many reasons; but the weather variation could be the major cause. Highly fluctuating weather conditions during sowing periods for could play a great role in determining the quantity and quality of winter wheat. Sowing is done during September, and the presence of persistent rainy weather conditions hampered the process of sowing. In addition to this, due to high and persistent rainy weather condition could also affect soil temperature, which will have an impact on the survival of the plant later on.

Table 1. Winter wheat production grouped as class 4 and class 5 during 2006-2011 harvesting season.

Winter wheat production in tons			
Growing seasons	**Class 4**	**Class 5**	**Total production**
2006	34395	10308	44703
2007	47515	13313	60828
2008	7603	759	8362
2009	7169	1775	8944
2010	17033	3305	20338
2011	13855	2038	15893

In 2006/07, higher amount of winter wheat was obtained, and this production sharply decreased to the lowest for class 4 (winter wheat with strong gluten) in 2007 and for class 5 (winter wheat with weaker gluten) the lowest was in 2008 (Table 2). This is mainly because of the weather condition in winter wheat producing areas and at the same time, there seem to be stagnations or even decreases in the yield per hectare. In the years 2004-2008, the industry wanted a higher wheat production to be used for both food and feed. However, in the later seasons, there have been challenges to obtain good quality of wheat, and the area of winter wheat was highly reduced in some of these seasons because of poor conditions for sowing in autumn because of much precipitation. In general, both the area for wheat cultivation in Norway, and the production seem to vary quite a lot from season to seasons and particularly for the winter wheat (Table 2).

Table 2. Total cultivated area in Norway for spring and winter wheat from 2004 to 2013 in 1000 daa.

	Cultivated land during 2004-2013		
Growing seasons	**Spring wheat**	**Winter wheat**	**Total area**
2004	519.8	333.6	853.4
2005	536.7	271.4	808.1
2006	561.7	295.8	857.5
2007	530.3	381.9	912.2
2008	564.6	367.1	931.7
2009	559.2	256.8	816.0
2010	535.0	185.9	720.9
2011	597.4	141.5	738.9
2012	650.1	19.7	669.8
2013	456.2	91.2	547.4

1.3.3 Wheat classification in Norway

Wheat is grouped in two general groups as winter and spring wheat depending on the season when it is sown. Winter wheat is usually sown in fall/autumn and harvested during late summer or early autumn depending on the weather. The other one is spring wheat, which is sown in spring and will be harvested during summer. Wheat can further be classified based on the kernel hardness as hard and soft, and based on the presence or absence of the red pigment gene it can also be classified as red and white wheat.

Generally, there are six recognized wheat classes where several hundreds of wheat varieties produced worldwide categorized. These are hard red winter wheat, hard red spring wheat, soft red winter wheat, hard white wheat, soft white wheat and durum wheat. These classifications are determined not only by the season they are planted and harvested, but by their kernel hardness, grain color and the shape. Each class of wheat has its own similar family characteristics, especially as related to milling and baking processes. However, different countries have their own criteria for milling and baking qualities that can lead to develop their own classifications based on qualities desired by milling and baking industries as well as with respect to the countries climatic and weather conditions.

Table 3. Norwegian wheat classification based on gluten quality (strength).

Class 1 Strong	Class 2 Strong	Class 3 Strong	Class 4 Strong	Class 5 Weak
Bastian (SW)	Bjarne (SW)	Zebra (SW)	Bjørke (WW)	Mjølner (WW)
	Berserk (SW)	Demonstrant (SW)	Magnifik (WW)	Finans (WW)
	Quarna (SW)	Krabat (SW)	Olivin (WW)	Anthus (WW)
	Scirocco (SW)	Aino (SW)	Kuban (WW)	
		Amaretto (SW)	Ellvis (WW)	
			Skagen (WW)	

SW- spring wheat
WW- winter wheat

In Norway, based on the gluten quality (strength), wheat is categorized in to five classes. Form this five classes four of which are recognized as strong wheat and the remaining class is as weak wheat (Felleskjøpet, 2013/14). According to this classification, the winter wheat is categorized in class 4 and 5 and spring wheat is grouped into the first three classes. Strong winter wheat is categorized in class 4 and the weaker ones are into class 5. This Norwegian classification of wheat is summarized in the Table above (Table 3).

1.3.4 Challenges in wheat production in Norway

There are several challenges in the Norwegian wheat production because of unstable weather conditions during sowing and harvesting seasons. Pre-harvest sprouting (PHS) is the major quality challenge, which can be caused by either rainy weather, or high and frequent precipitation during and before harvesting. PHS could lead to the downgrading of wheat grade from food to animal feed and cause major economic losses. Stability in gluten quality is also another challenge in the Norwegian wheat production. The other major challenges in wheat production are fungal diseases caused by *Fusarium* spp. (mycotoxins from this infestation), mildew and septoria species (William et al., 2011, McCrate et al., 1981). Breeding companies are trying to develop new varieties with strong and desirable gluten quality for baking and other end use purposes which are resistant to fungal infestations. Here in Norway, Graminor is one of the responsible company for wheat breeding and Felleskjøpet and Strand Unikorn for distributing these seeds to farmers.

1.4 Thesis goal

Because of higher variability of weather conditions in Norway, the yield and quality of wheat are also expected to be more variable from one growing season to another. Variable weather conditions were perceived in different wheat growing locations and it is believed to be the major cause for the variation between cultivars within the same growing season in different locations. For the past 4 years (2010, 2011, 2012 and 2013), there has been a dramatic decrease in domestic wheat production due to downgrading in quality of wheat from food to feed (Fig. 3).

This thesis work focused on quality analysis of winter wheat. High and frequent precipitation in September that are experienced in recent years make sowing of winter wheat difficult and hamper the area covered with winter wheat. Another major problem related to wheat quality is pre-harvest sprouting due to wet weather and frequent precipitation starting from yellow ripening to harvesting. In addition to this, highly fluctuating daily mean temperature can also be a major cause for variation among cultivars by affecting gluten strength.

The global climate change could have an effect in the Norwegian weather conditions, thus, quality variation and effect of PHS most likely induce yield losses and downgrading of wheat from food to feed to be severe in the future. Therefore, understanding the connection between weather conditions especially temperature and rainfall during the grain-filling period with gluten strength and PHS will be necessary. Furthermore, using PHS resistant cultivars could help to curb the adverse effect of wet weather conditions during maturation.

Tremendous efforts have been made to improve cultivars in breeding programs all over the world. Here in Norway, Graminor is the responsible company for conducting such breeding researches on domestic wheat cultivars as well as testing and integrating foreign origin cultivars to the Norwegian climate and growing conditions. New cultivars are continuously being introduced into the production line and are being tested for quality parameters. Depending on their quality records, these new cultivars are grouped into the different quality classes.

Therefore, the main objectives of this study were (i) to assess quality variation between cultivars of winter wheat, (ii) to assess quality variations between different locations and seasons using the historic data collected from 2005-2013, and iii) to investigate relationships between weather parameters and the variations in quality during this time period (material 1). Moreover, in material 2, (i) to assess quality differences between the newly released cultivars and compare with the old ones, and (ii) to see environmental influence on cultivars collected from Østfold and Vollebekk.

2 LITERATURE REVIEW

2.1 Bread-making quality

Bread making quality is a difficult term to define using a single statement. Rather, it is a result of several quality characteristics that makes the given wheat kernel best properties for making bread of a defined type and process. In fact, not all wheat cultivars are useful for making quality bread; some criteria that must be met to say that one wheat cultivar is suitable for making bread and the other one is not. What are these qualities? The criteria used to assess the bread-making qualities of wheat include the possession of higher kernel and test weight, falling number (FN) above a certain level (threshold level of 200 sec are often used), higher sodium-dodecyl sulphate (SDS) sedimentation volume, optimal mixing properties and gluten strength, as can be recorded from farinograph, mixograph and extensograph analysis. Therefore, the term bread-making quality refers to acquiring all these qualities.

There may be some differences in the grading scale from country to country, or between different milling industries. Therefore, it is always a big challenge for wheat growers to maintain the qualities desired by the milling industries. The major quality challenges in wheat production are pre-harvest sprouting (PHS), gluten quality variation, physical grain qualities such as having low test weight and several fungal diseases (McCrate et al., 1981). Bread making quality is the key issue for wheat breeding programs, milling industries and wheat growers. But there is always a big challenge in maintaining this bread making quality from year to year and even between batches within a year (Peterson et al., 1998), as quality variations may appear due to the variation in growth environment. Moreover, this is a challenge for growers, traders and for baking industries.

There may be several reasons for the differences in quality to occur but the major causes for this are believed to be the genotype of the cultivars, amount and qualities of agricultural inputs, environmental and climatic conditions during sowing, growing and harvest season (Peterson et al., 1998, Sofield et al., 1977). As it is known, too much precipitations during yellow ripening and even closer to harvest period may lead to PHS and this is a major cause for downgrading the products. Variations in the quality and quantity of nitrogen fertilization may also cause differences in protein content. Hence, it may cause variations in gluten quality and quantity, since the gluten itself is influenced by the amount of protein to some extent.

The two most influential traits for bread-making quality of wheat are the quantity and quality of gluten. Quantity of gluten is dependent on the amount and availability of nitrogen in the soil and the density of grains per a given area during sowing. There may be a lot of competition for available nitrogen between seedlings if they are sown densely in a given area and on the other hand, if seeds are sown below the standard density, they will leave much of the nutrients in the soil for weeds and then poorly compete with weeds and leads to extra expense for chemicals (Olsen et al., 2005). Therefore, this competition for nitrogen will lead to minimal allocation of nitrogen for protein synthesis, and hence this will affect the gluten quality.

It is possible to increase the amount of gluten by increasing nitrogen fertilization, especially by practicing split fertilization. For winter wheat, it is good to give the first round in spring to promote good vegetative growth and the second and third rounds during stem elongation to heading with some times difference in between. Nitrogen fertilization during heading/anthesis stages mainly goes to maximizing the amount of gluten (Belderok et al., 2000).

2.2 Test weight and Kernel weight

Test weight is the weight of a measured volume of grain expressed in either Ib/bu (in the United States) or kg/hl (in most countries). It has been used for quality measurement since 19th century, but standardized during 20th century (Protic et al., 2007). Kernel weight is a measurement of kernel size, commonly expressed as the weight of a thousand kernels in gram. It is measured using the common laboratory balance. Usually test weight is dependent on grain size, shape and density.

According to Protic et al. (2007) test weight can vary from 60 kg hl^{-1} to 84 kg hl^{-1}, but a wheat above 76 kg hl^{-1} is acceptable in the world market as sound wheat these days. A wheat with good bread making qualities should have higher test weight than 60 kg hl^{-1}, and if it less than this it is considered as wheat with poor quality. However, the above grading scale for test weight may not be applicable to all wheat growing countries, for example, here in Norway, the recommended value for test weight is 79 kg hl^{-1} according to Felleskjøpet (2013/14).The higher the test weight, the more the flour yield capacity of the seed. There has been positive and significant correlations between test weight and flour yield (Marshall et al., 1986, Troccoli et al., 2000, Schuler et al., 1995).

2.3 Pre-harvest sprouting (PHS)

Pre-harvest sprouting (PHS) is an early germination of wheat kernel while it is on the ear before or during harvest (Groos et al., 2002). It usually happens when rainy, moist or humid weather conditions persist for some period than needed right before or during harvest. PHS is common in non-dormant seeds and it is also highly influenced by the presence and amount of abscisic acid (Walker-Simmons, 1987). It is well understood that abscisic acid involves in induction and maintenance of seed dormancy. Seed dormancy is an innate property of seeds which is defined as it is a block to the completion of germination of an intact viable seed under favorable conditions (Finch-Savage and Leubner-Metzger, 2006). The lack of dormancy or its early breakage can result in PHS under moist weather conditions because of early degradation of starch, protein, and lipids stored in the endosperm (Groos et al., 2002).

The activities of α-amylase and other enzymes in the seed should decrease during the period of grain ripening. However, wet or moist weather conditions during these periods could initiate germination. The onset of germination triggers the activation of many genes and giving a new and strong signal for the synthesis of α-amylase and other enzymes as well, and as a result of this the activities of these enzymes remain high. Therefore, this situation leads to degradation of stored starch by α-amylase; proteinases and some lipases will also be active and degrade stored protein and lipids respectively. This is a normal process when the seed intends to germinate when it gets enough moisture, air and temperature in order to make the stored food available for the growing embryo. This whole phenomenon results in pre-harvest sprouting when it happens before harvest.

Sprouted wheat has low bread-making qualities compared with the non-sprouted ones. Since much of its stored starch is degraded and still the enzymes, remain active and efficiently act on the starch when the flour is mixing with water. Sprouted wheat will lose most of the end-use qualities than the non-sprouted ones, and therefore, such wheat cannot be used as human food. PHS will also affect other quality parameters like test weight, milling and baking properties negatively not only because of the degradation of the starch but also affects the quality of protein (Simsek et al., 2014, Groos et al., 2002).

PHS could result a great disaster in the production, milling industries and bakeries since it reduces the quality of wheat grains. Due to unstable and highly rainy weather in autumn, PHS is a major challenge for the Norwegian wheat growers. Especially for the past three-four years, PHS resulted in the downgrading of winter wheat as feed because of low bread-making quality parameters.

Resistance to PHS is one of the desirable assets of sound wheat cultivars. It is well agreed that both the genotype and environment plays a great role in determining the bread-making quality of wheat. Resistant to sprouting is usually affected by the genotype of the cultivars as well as the environmental factors during and before harvest. One of the major genotypic factor associated with resistance to PHS is grain color, and this is maybe due to the genes controlling the red-testa pigmentation (*R*) or the relationship between these genes; genes controlling the pigmentation and genes affecting pre-harvest sprouting (Groos et al., 2002, Gfeller and Svejda, 1960). White-grained wheat are more susceptible for PHS than red grained ones (Kottearachchi et al., 2006, PAUW and McCaig, 1983).

The dominant alleles of the *R* genes are located on the chromosomes 3A, 3B and 3D (1 in each chromosome) of hexaploid dormant wheat. Non-dormant wheat which are susceptible to PHS have one or two dominant alleles of the *R* genes on the chromosomes of 3A, 3B and 3D (Bassoi and Flintham, 2005, Groos et al., 2002). It might be possible to develop seeds that are resistant to PHS.by manipulating the number (dosage) of the dominant alleles of the *R* genes on these chromosomes.

There are ongoing researches to identify QTLs for PHS and dormancy. Several studies identified the location of major QTL on chromosome 4A (Kato et al., 2001, Noda et al., 2002) and another study indicated that one major QTL on chromosome 3A and two minor QTLs on chromosome 4A and 4B, respectively (Osa et al., 2003). Many studies have also showed different locations for QTLs governing PHS resistance and seed dormancy using molecular mapping. However, there was inconsistency with these locations. According to Roy et al. (1999) there are two genes located on chromosome 6B and 7D controlling PHS resistance. The four QTLs associated with grain color and PHS resistance mentioned by Groos et al. (2002) are located on the groups of 3 chromosome. Kulwal et al. (2005) recently reported that a major QTL for PHS resistance on chromosome 3A. Therefore, it is unclear that whether PHS resistance and seed dormancy are controlled by same or different QTLs. Although many studies are being carried out focusing to locate the QTLs for PHS resistance and seed dormancy, still it needs more research on this area in order to be sure about it.

Determination of falling number (FN) is the easiest and simplest way of detecting PHS. Falling number is a viscometric assay that involves a rapid gelatinization of starch flour suspension in water, by immersing in a boiling water bath, with a subsequent measure of its liquidification by α-amylase (Mares and Mrva, 2008). Different countries might have different threshold values for falling number depending on the classes of wheat and for what purpose the wheat is needed. In Norway, the minimum threshold for bread-making wheat is 200 (Felleskjøpet, 2013/14).

2.4 Wheat proteins and gluten quality

The bread-making quality of wheat flour is highly dependent on the quantity and quality of proteins in the wheat flour. There is commonly described a linear relationship between bread-making quality measured with in terms of loaf volumes and flour protein content (Schofield, 1994, Johansson and Svensson, 1998). Usually those wheat cultivars with higher protein content tends to have strong gluten with compared to those which have lower protein content (Aamodt et al., 2005) Nonetheless, this may not always be true since protein content and strength of gluten vary independently. However, in most breeding companies high protein content with strong gluten are the desirable goal.

Gluten is the rubbery mass the remains when a wheat flour dough is kneaded and washed with water. This solid mass may contain 75-85 % protein, 5-10 % lipid depending on the degree of washing. The gluten protein plays a great role in determining the baking quality of wheat (Wieser, 2007, Song and Zheng, 2007). Gluten proteins are responsible for the formation of a unique viscoelastic property of dough by conferring water absorption capacity and cohesivity (Wieser, 2007).

Gluten protein can be divided roughly into two equal fractions according to their solubility in water-alcohol solution: the soluble gliadins and the insoluble glutenins. The unique viscoelastic property of wheat gluten is because of its two protein fractions the gliadins and glutenins. In addition to this, gliadin/glutenin ratio and HMW-GS/LMW-GS ratio plays an important part in the viscoelastic property of gluten (Popineau et al., 1994, Song and Zheng, 2007). The monomeric gliadins are responsible for the viscous property since they are sticky but non-elastic, whereas, the polymorphic glutenin are responsible for the strength and elastic nature of wheat gluten (Wieser, 2007, Hoseney, 2010, Shewry et al., 1986).

Gliadins, which are a single polypeptide proteins (monomers), mainly weighing about 30–80 kDa are classified into four groups (α, β, γ and ω-gliadins in decreasing mobility) based on their mobility at low pH gel electrophoresis. Unlike ω-gliadins, the α, β, and γ-gliadins have less amount of proline, glutamine and phenylalanine, but 2-3 mol.% cysteine and methionine (Shewry et al., 1986). The ω-gliadins are known to have large proportion of glutamine, proline and phenylalanine, but they are sulphur poor molecules since they have less or no cysteine and methionine (Wieser, 2007).

However, later studies revealed that this type of classification does not always show the protein relationship. Therefore, in modern classification [as two-dimensional electrophoresis or reversed-phase high-performance liquid chromatography (RP-HPL)], gliadins are classified in to four different types: ω5-, ω1,2-, α/β-type and γ-gliadins (Wieser, 1996). The two former groups of gliadins that are α and β gliadins now put together in one group as α/β- type.

Glutenins are polymeric proteins with a molecular weight ranging from 500,000 to 11 million, and they belong to the largest protein in nature (Wieser, 2007). They are composed of two groups of subunits: the low molecular weight glutenin subunits (LMW-GS) and high molecular weight glutenin subunits (HMW-GS). The LMW-GS weighs about 12–60 kDa and the HMW-GS weighs 60–120 kDa (Song and Zheng, 2007). The HMW-GS in particular are shown to be of high importance for dough elasticity or gluten strength, and specific alleles of HMW-GS are identified that affect bread-making quality (Shewry et al., 1992). This knowledge is utilized in breeding companies all over the world to improve gluten quality in new cultivars.

The presence of sulphur in the cysteine residues on α, β, γ-gliadins as well as in HMW-GS and LMW-GS is extremely important in the structure and functionality of gluten protein; they are responsible in forming disulphide bonding within the protein and between proteins (Grosch and Wieser, 1999, Shewry and Tatham, 1997).

Bread-making quality of wheat flour is mainly the function of the different fractions of gluten protein and their ratios. Especially, the high-molecular-weight glutenin sub-units are major influential gluten proteins. Correlations have been shown in many literatures between these proteins and protein sub-units with bread making qualities (Johansson and Svensson, 1995, Uhlen, 1990).

Gluten quality in a given variety of wheat grown in different or in the same locations in different growing seasons is mainly affected by climatic variation during the grain-filling period. Various studies have documented this for many years stating that how lower or higher temperature influence on gluten strength (Uhlen et al., 2004, Randall and Moss, 1990, Moldestad et al., 2014). Some literature suggested that exposure of wheat plant to short heat shock with a temperature above 35 °C at different time period during the grain-filling period results in weakening of gluten strength (Ciaffi et al., 1996, Corbellini et al., 1997). Gluten strength as well as amount of protein was influenced by the nitrogen application, higher protein content and strong gluten was obtained with increasing supply of nitrogen fertilization (Belderok et al., 2000, Johansson et al., 2001).

The other big challenge related to gluten quality is *Fusarium* infestation. Some literatures suggest that high level of Deoxynivalenol (DON) from *Fusarium* ssp. infection heavily affect the starch and protein content of wheat. Mainly the storage proteins that are gliadins and glutenins are affected by *Fusarium* spp. proteases. According to Papoušková et al. (2011) and Eggert et al. (2011) increased intensity of *Fusarium* spp. infection on wheat highly reduced the rheological qualities and affects storage proteins and starch negatively.

Another study showed that *Fusarium* spp. proteases actively works over the wide range of temperature (10 to 100 ^{o}C) and pH (4.5 to 8.5), therefore, these proteases can act and damage storage proteins throughout the entire process dough preparations as well as baking (Wang et al., 2005). Unlike the above positive correlations between rheological qualities and *Fusarium* spp. infection with high DON content; Prange et al. (2005) suggested that *Fusarium* spp. infection with high DON content doesn’t necessarily affect the rheological qualities of wheat.

3 MATERIALS AND METHODS

3.1 Sample collection and preparation

This study used two different materials defined as material 1 and 2. The data included in material 1 is from the variety testing experiments in winter wheat performed in Norway during the periods 2005-2013. The data was "cleaned" and subjected to statistical calculations. To investigate the possible environmental influences on varieties, weather data from different locations that are close to the experimental field trials was collected from Bioforsk (the Norwegian Institute for Agricultural and Environmental Research) Meteorological Services *(www.bioforsk.no)*.

Material 2 consists of ten different varieties where most of them are newly introduced market varieties to be tested for quality variations and compared with the older varieties. The cultivars were collected from two different locations (Østfold and Vollebekk). Weather data obtained from Bioforsk Meteorological Services is also used to investigation environmental effects on the varieties.

3.2 Material 1:- Quality analysis of winter wheat (Data from winter wheat trials collected from 2005-2013)

The first material is the data from field trials included in the official variety-testing program performed by Bioforsk (The Norwegian Institute for Agricultural and Environment Research), Arable Crop Division. In the official variety testing, field experiments are laid out yearly and on several locations covering the main areas for winter wheat production in Norway. The varieties included are the commercial varieties recommended for Norway as well as new varieties/breeding lines to be tested. Hence, the varieties included may differ from one season to another as new varieties are included and old varieties that obtain low or decreasing market share are excluded from further testing.

Since 2005, a deeper quality testing of spring and winter wheat have been carried out in Norway. This yearly quality testing was organized in cooperation between Bioforsk, Nofima, IPV-NMBU and Norske Felleskjøp. The aim of this yearly quality analysis was to analyze bread-making quality in the varieties and also to study variations in quality between seasons and also between locations within season, and to give the milling and baking industries yearly predictions of the quality, particularly the gluten quality for the new wheat harvest.

This study is based on selected samples from the official variety testing field experiments. The selections of samples were made based on:

1. Only samples from field trials treated with fungicides,
2. Only samples from field trials without pre-harvest sprouting (FN>200), and
3. The main varieties having a high market shares reflecting the wheat delivered for milling and baking industries were selected.

Data from this advanced quality testing were the basis for material 1 in this thesis. Different varieties were included in different years, as shown below (Table 4).

Table 4. A table showing the introduction of new varieties and removal of older ones from the production line.

Varieties	**2005**	**2006**	**2007**	**2009**	**2010**	**2011**	**2012**	**2013**
Bjørke	X	X	X	X	X			
Magnifik	X	X	X	X	X	X	X	X
Mjølner	X	X	X	X	X	X	X	X
Olivin	X	X	X	X	X	X	X	X
Ellvis						X	X	X
Finans						X	X	X

Since different varieties were included in different seasons, the data set was divided into three sub-sets to obtain orthogonal data. Thus, sub-set 1 includes the varieties Magnifik, Mjølner and Olivin from the seasons 2005-2013, sub-set 2 contains Bjørke, Magnifik, Mjølner and Olivin from the seasons 2005-2010, and the third subset includes Ellvis, Finans, Magnifik, Mjølner and Olivin for the seasons 2011-2013. Sub-set 1 is needed to evaluate the older varieties. The importance of sub-set 2 is to compare and evaluate the cultivar Bjørke with the other three cultivars even though Bjørke is not in the production anymore. Moreover, the last one, which is sub-set 3, is needed to investigate quality differences between the older varieties and the newly introduced one.

Two replicates were analyzed for each of the varieties in each field trials. For all the sub-sets, field trials with missing data for both replicates of one or several of the varieties were discarded, and therefore, no field trial is selected and analyzed from the year 2008. Moreover, for SDS sedimentation analysis the data from 2011 for all the field trials was not included since the data was not analyzed. However, all field trials in the season 2011 were included for the rest of the data analysis in this thesis.

3.3 Material 2:- Quality analysis of new winter wheat varieties in 2013

The second material consists ten varieties (*cv. Akratos, Akteur, Ellvis, Finans, Frontal, Kuban, Magnifik, Matrix, Olivin, and Skagen*), which were grown in field trials at two different locations: Idd, Østfold and Ås, Akershus. Graminor has laid out the experiments, and they consisted of 25 varieties/breeding lines and 2 replicates. Among these, ten varieties were selected for this study. These ten cultivars include two old variety (*Olivin and Magnifik*), which were introduced in 2005, and two other recent varieties (*Ellvis and Finans*) which were introduced in 2011. The remaining six cultivars were new, which were introduced in Graminor's field trials in 2013. All the samples are grown and harvested in the year 2012/2013. In addition, quality analysis for gluten strength between five selected cultivars (*cv. Ellvis, Finanas, Kuban, Magnifix and Olivin*) was carried out all the analysis data was obtained from Bioforsk, except determination of SDS sedimentation volume and extensograph analysis, which were performed at Vollebekk and Nofima.

On both sites Graminor, Idd and Vollebekk, Ås the fertilization used was Nitrogen-Phosphorous-Potassium (NPK) fertilizer and it was 60 kg ha^{-1}. Heading dates were recorded in both field trials. Yellow ripeness was recorded only at Vollebekk. Management practices were according to normal application on both locations, and involved treatment with herbicide to control weeds. No fungicides were applied. The harvest was done by using combiners at full maturity.

3.4 Milling

The wheat samples for material 2 were milled using Perten hammer mill instrument (model kt-3100) obtaining approximately 100 gram of flour. The flour obtained from the mill was suitable for the analysis of falling number, Sodium-dodecyl sulphate (SDS) sedimentation test, mixograph and for Kieffer Extensibility analysis (http://www.perten.com/Products/Lab-mills/).

3.5 Test and Kernel weight test

Test and kernel weight for material 2 (*cvs Kuban, Magnifix, Olivin, Finanas, Akratos, Akteur, Matrix, Ellvis, Skagen and Frontal*) was measured at Vollebekk. To determine test weight and thousands of kernel weight a common laboratory balance was used. To determine the wheat samples kernel weight, the weight of 400 kernel was measured and converted to thousands of kernel weight.

3.6 Falling number test

Hageberg falling number measurement was conducted on the flour from the grain samples that were harvested at both locations after yellow ripening. The moisture content of the whole meal flour was analyzed by using an instrument known as Near-infrared spectroscopy.

Falling number analysis was performed according to AACC 56-81B (AACC, 2000) by using Perten 1700 falling number instrument (Perten Instruments). A sample of whole meal wheat flour was measured, which was adjusted depending on the moisture content of the samples based on 7g for 14 % moisture content, of flour is measured in 50 ml test tube and 25 ml of distilled water was added. It was well shaken in order to mix and have a good water-flour suspension and to avoid any solid residue at the bottom the flour with the water before it was mounted on the instrument. Two test tubes per sample were run and the mean values were calculated per sample. A sample that gave the difference of more than 30 sec in a run was repeated.

3.7 SDS sedimentation test

Mechanical mixer was used to determine the SDS sedimentation volume for material 2. The rack on the mixer is pivoted at the center of each end and it oscillates through different angles on each side of horizontal position in circular motion. This movement helps to mix the flour with the chemicals uniformly. In addition, the rack was designed to hold ten graduated cylinders and it is possible put the test tubes quickly and securely on the mixer while it is in motion.

Six gram of whole grain wheat flour is used to determine the SDS sedimentations volume for the varieties. The flour was placed into a 100 ml graduated cylinder and then 50 ml of water containing brome-phenol blue was added. The flour and water was mixed by hand thoroughly for few seconds before it was placed on the mixer rack. After five min of mixing, 50 ml of isopropyl alcohol-lactic acid was added to the flour-water mixture and placed on the mixing rack again for another 5 min. Finally, after a total of 10 min of mixing time, the cylinders were taken off the rack and were placed on the table to settle down. After 15 min elapsed since the first cylinder taken off the rack, the reading was done starting from the first cylinder and for the rest the reading was done according to their sequence when they were taken off the rack keeping the 15 min settling period for each cylinder (AACC, 2000).

Figure 4. Automatic mixing rack used for SDS sedimentation test. (Photo-Yohannes B. Mekonnen).

3.8 Mixograph analysis

A 10-g Mixograph instrument (National Manufacturing Division, TMCO, Lincoln, NE, USA) is used to determine the mixograph properties of the samples. Mixograph test is a test of the mixing properties of dough. The mixograph is an important test for breeders' first generation samples and initial test in determining the quality. It tells us whether the samples will have good mixing properties or not. If the samples will not give the desired properties after the test, they will be screened out at a very early stage without actually baking the samples. The quality of a loaf of bread is highly influenced with the mixing properties, and with the exact combination of flour and water in the mixer.

A sample of 9.5 g of flour mixed at optimum volume of water depending on the protein contents of the corresponding samples. The weights of the samples were adjusted on 14 % moisture basis and the mixing of the dough was followed for 7 min from the start. On the mixograph output, dough development time, maximum height, width at 5 and 7 min were determined.

3.9 Kieffer extensibility test

Ten gram of whole meal flour was used for the glutomatic experiment. The flour was mixed with 4.8 ml of 2 % NaCl solution to make the dough. Then after 1 min of mixing, the dough was washed for 10 min with Glutomatic 2100 instrument (Perten AB, Huddinge, Sweden) to remove all the salt soluble components and the bran. A 2 % NaCl solution and two different filters were used during washing. After the dough was washed, it was centrifuged using a special centrifuge mold in a swing-out rotor (Rotor 5.51) at 4100 rpm for 10 min at a temperature of 20 ^{o}C. After 10 min centrifugation, the dough from the special centrifuge mold was taken out slowly and carefully not to deform the shape from the mold and placed on a standard mold to be pressed for 45 min at a temperature of 30 ^{o}C. The dough together with mold was covered with plastic bag to keep its moisture in order to avoid drying. Little oil was also applied on the mold to prevent the dough from sticking on it and to help to remove the dough easily. SMS/Kieffer Dough and Gluten Extensibility Rig (Kieffer et al., 1998) was used to measure the resistance to stretching (R_{max}) and extensibility (Ext).

3.10 Climate and Weather data

Near-site weather stations, which are operated by Bioforsk (*Bioforsk/LandbruksMeteorologisk Tjeneste*), were used to collect the daily weather data including mean daily air temperature (MDT), and precipitations (P) during the whole grain-filling period including heading and yellow ripening from each growing locations. The climate data were downloaded using the website *http://lmt.bioforsk.no/*.

The grain-filling period was divided in to four groups of sub-phases as period 1, 2, 3, and 4 in order to see the effect of the weather condition on the quality traits. Sub-phase 1 includes dates from June 15 to June 30, sub-phase 2 includes dates from July 1 to July 15, sub-phase 3 includes dates from July 16 to July 31 and sub-phase 4 is from August 1 to August 20.

3.11 Statistical analysis

Statistical analysis was made by using Minitab 16 Statistical Software. Graphs and tables were produced using Microsoft Excel 2013 version. Two-way ANOVA and General Linear Model analysis was performed to investigate variation between varieties and between field trials. Least Significant Value (LSD) was calculated for those which shows significant result ($p<0.05$) from the General Linear Model and two-way ANOVA analysis. Regression analysis was also conducted to investigate possible relationships between weather parameters and quality (mainly gluten quality measure with R_{max}).

4 RESULT

4.1 Material 1:- Quality analysis: data from winter wheat trials collected from 2005-2013

4.1.1 Plant growth and weather conditions for material 1

The plant growth and weather conditions from 15 of June to 20 of August were studied, which cover the time from heading to maturity. Weather data was collected for all the years starting from 2005 to 2013 and for all locations under this study for material 1 and similarly for the material 2 for 2013 season at Vollebekk and Østfold. Some differences have been observed within years in different locations, and some interesting variations have been seen between sub-phases of the same seasons.

In 2005, in both locations, very small amount of precipitation was recorded during sub-phase 1 and relatively higher rainfall was received in these locations during sub-phase 3. In 2006, similar amount of rainfall was recorded except from sub-phase 1, which was relatively higher in these locations. Rainfall was higher in 2007 during the whole grain-filling period, and it was the highest of all harvesting seasons. In 2009, only one location was selected and it received relatively higher amount of rainfall during sub-phase 2, 3, and 4 than sub-phase 1.

In 2010, at the beginning of the grain-filling period the rainfall was low, but later on there was a gradual increase in precipitation. During 2011 harvesting season, the two locations under the study received similar amount of rainfall during the whole grain-filling period except with very slight differences during sub-phase 3. In 2013, the rainfall was higher at the beginning and end of the grain-filling period (summarized in Figs. 5, 6, 7 and 8).

During sub-phase 1, the highest precipitation was recorded in 2007 at Buskerud, which was 118.4 mm, and the lowest was from Follo (Ås) in 2005, measured as 6 mm. In 2007, Vestfold was also receiving higher precipitation during this period, which was 111 mm (Fig. 5). Again, Buskerud and Vestfold had received the highest precipitation (184.2 mm and 174.4 mm, respectively) during sub-phase 2. The least precipitation during this period was recorded from Apelsvoll in 2005 that was 1.9 mm. In 2013, in all three locations lower precipitation was also recorded (Fig. 6).

During sub-phase 3, relatively higher precipitation was observed in all location in all years, except in 2007 and 2013. In 2007, there was a decrease in all locations except from Romerike. In 2013, precipitation was also very low. During sub-phase 4, in nearly all locations the precipitation was relatively higher in all harvesting seasons except in 2007 (Figs. 7 and 8).

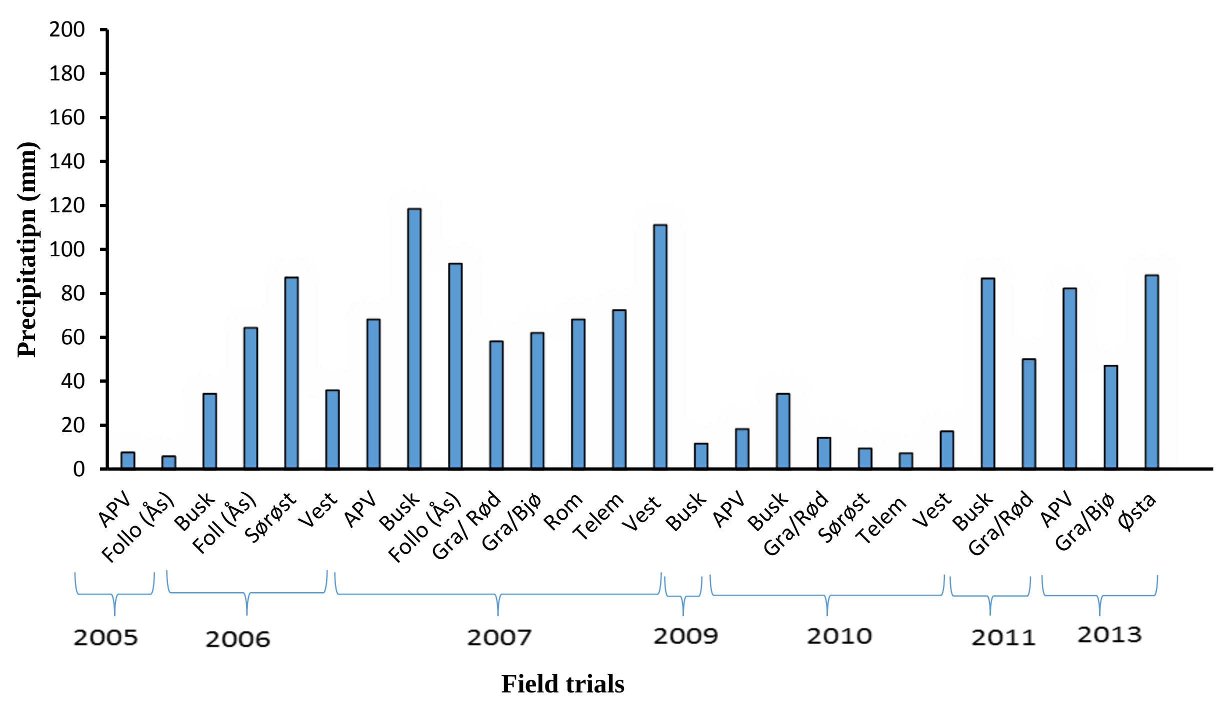

Figure 5. Total precipitation received by the different field trials during sub-phase 1 of the grain-filling period.

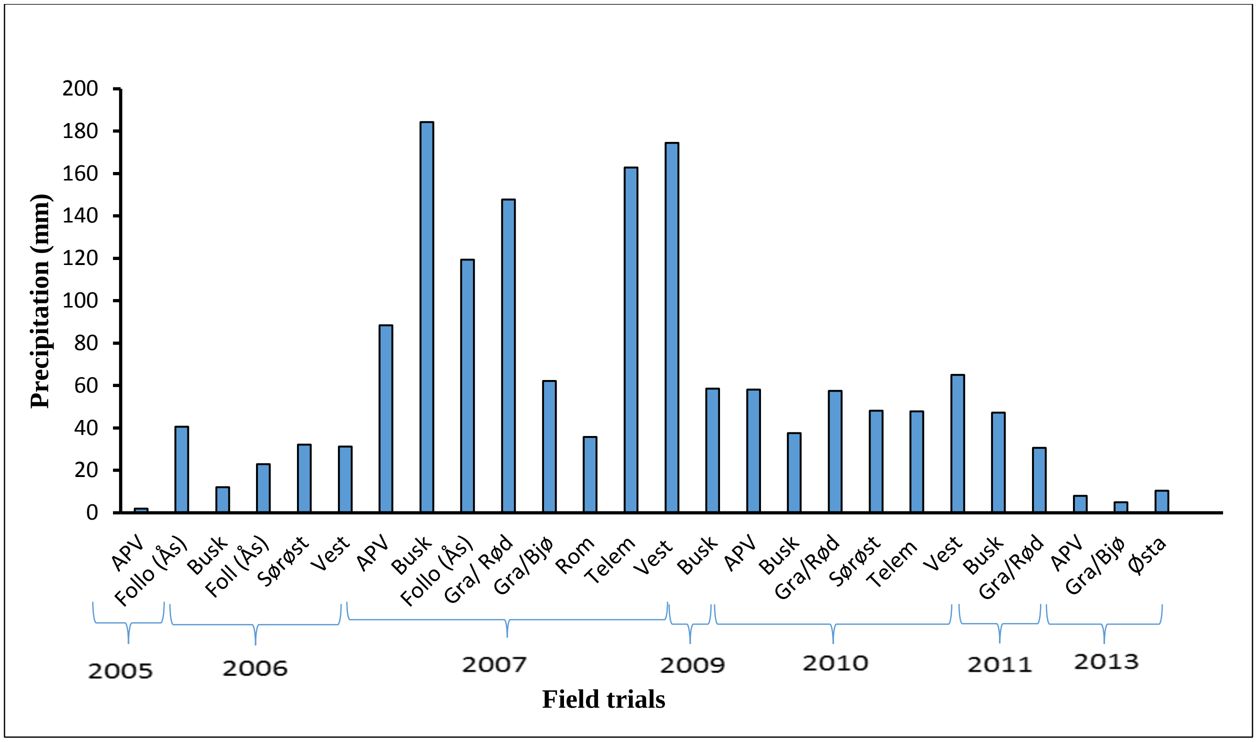

Figure 6. Total precipitation received by the different field trials during sub-phase 2 of the grain-filling period.

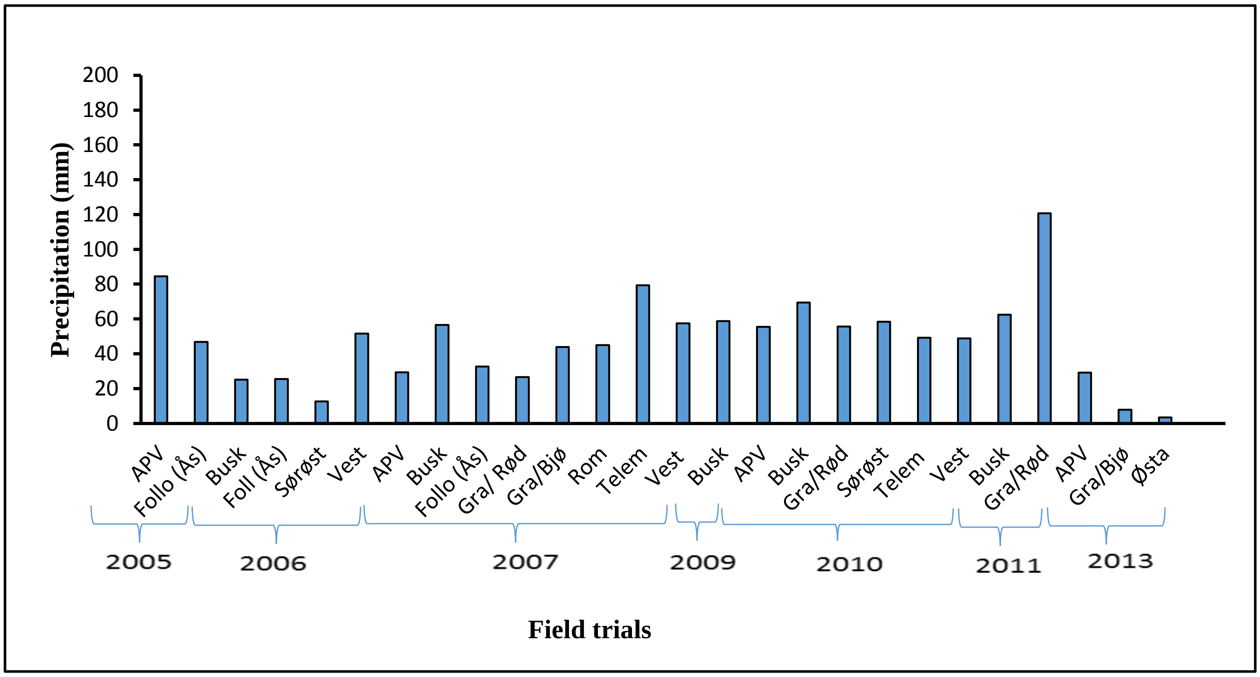

Figure 7. Total precipitation received by the different field trials during sub-phase 3 of the grain-filling period.

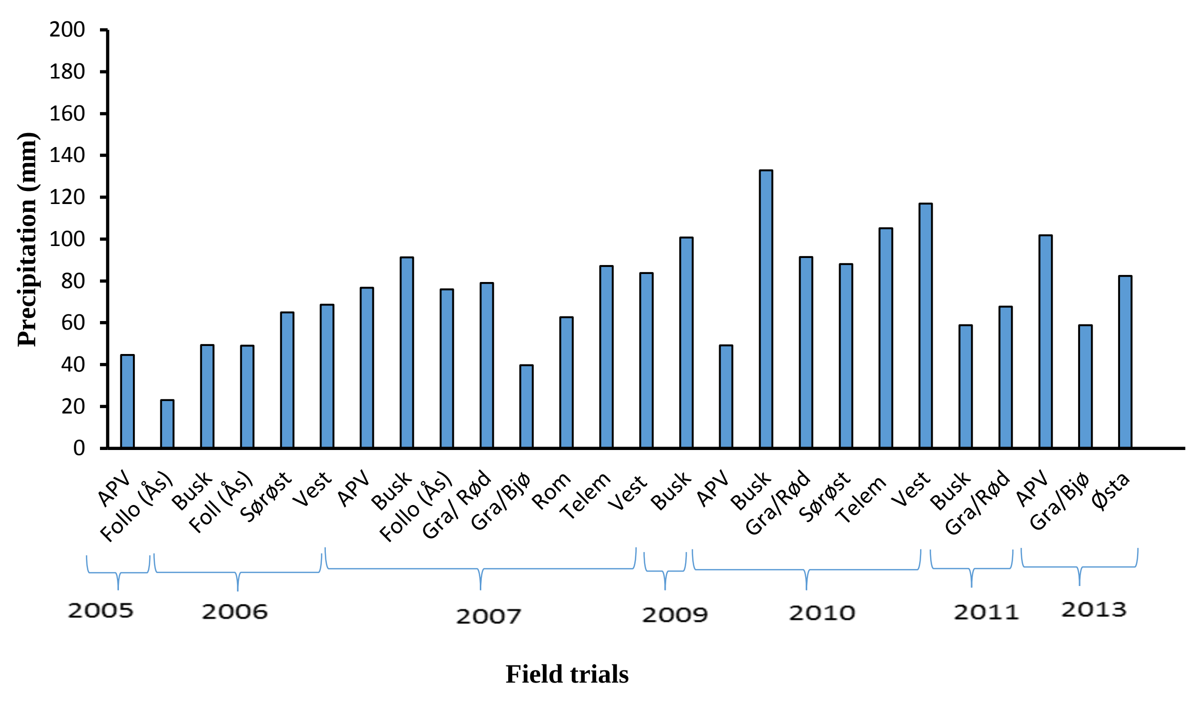

Figure 8. Total precipitation received by the different field trials during sub-phase 4 of the grain-filling period.

Temperature distributions in all locations during sub-phase 1 was almost similar with slight differences between locations as well as in different years ranging from 13.3 ^{o}C to 17.1 ^{o}C at Vestfold in 2010 and Buskerud in 2009, respectively (Fig. 9). Much variation was observed in sub-phase 2 between locations in different years, slight increase in DMT observed from sub-phase 1 in all locations, except Vestfold in 2007. This increase in DMT continued during the third sub-phase of the grain-filling time in most locations. Some locations exhibited a dramatic decrease in DMT; in 2005, DMT deceased in both locations by an average close to 4 ^{o}C. In most of the locations, the DMT remained relatively higher during sub-phase 4, but in both locations in 2005 it remained lower (Figs. 10, 11, and 12).

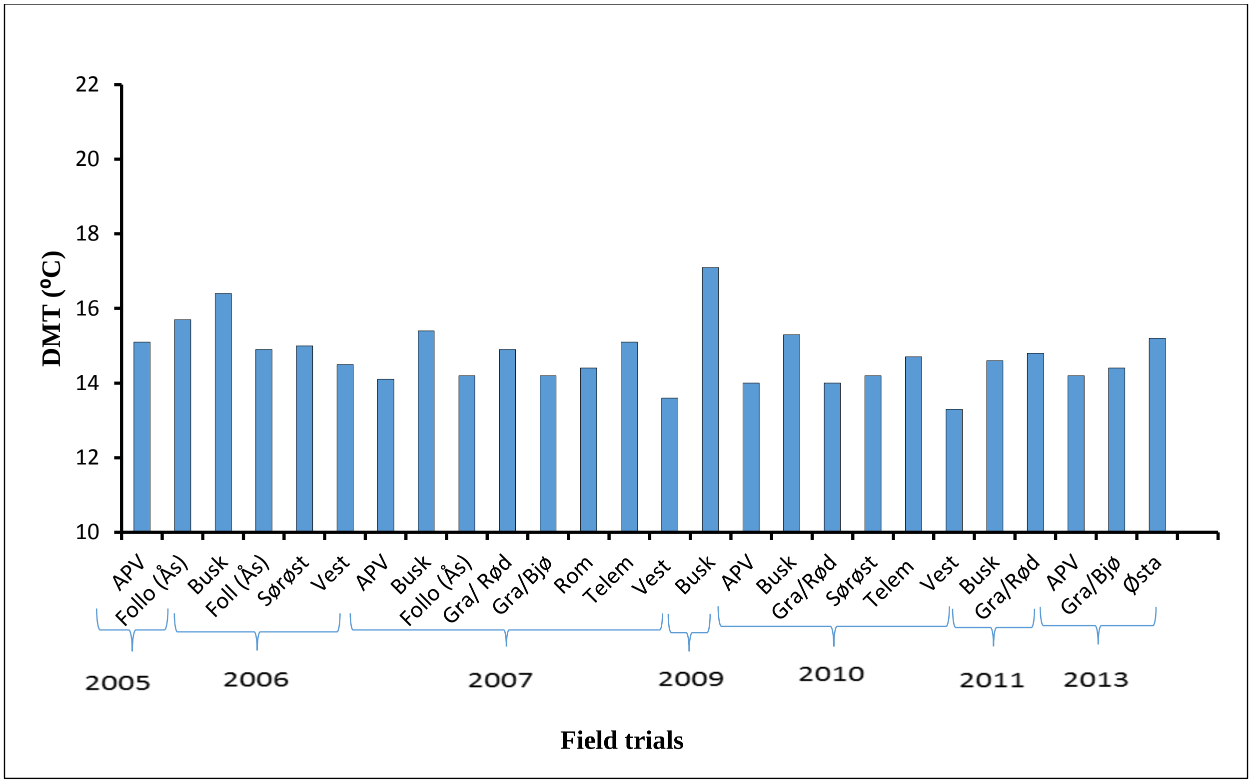

Figure 9. DMT during sub-phase 1 of the grain-filling period for the different field trials in different growing and harvesting seasons.

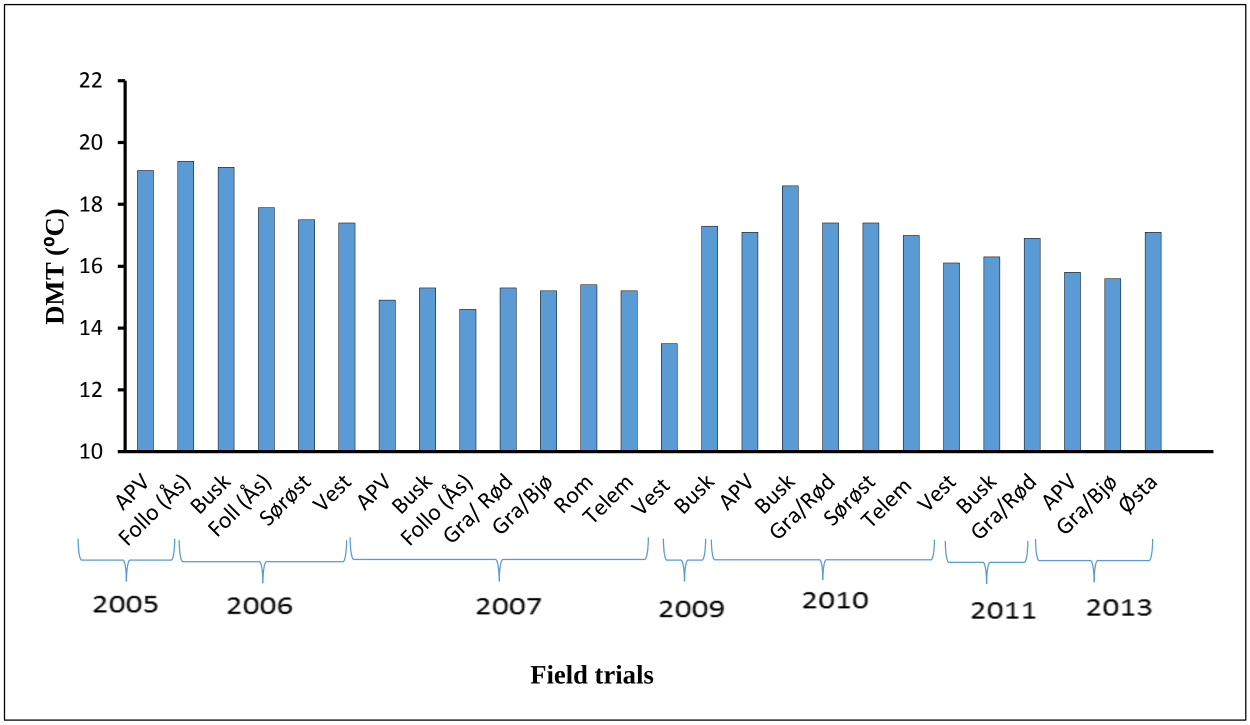

Figure 10. DMT during sub-phase 2 of the grain-filling period for the different field trials in different growing and harvesting seasons.

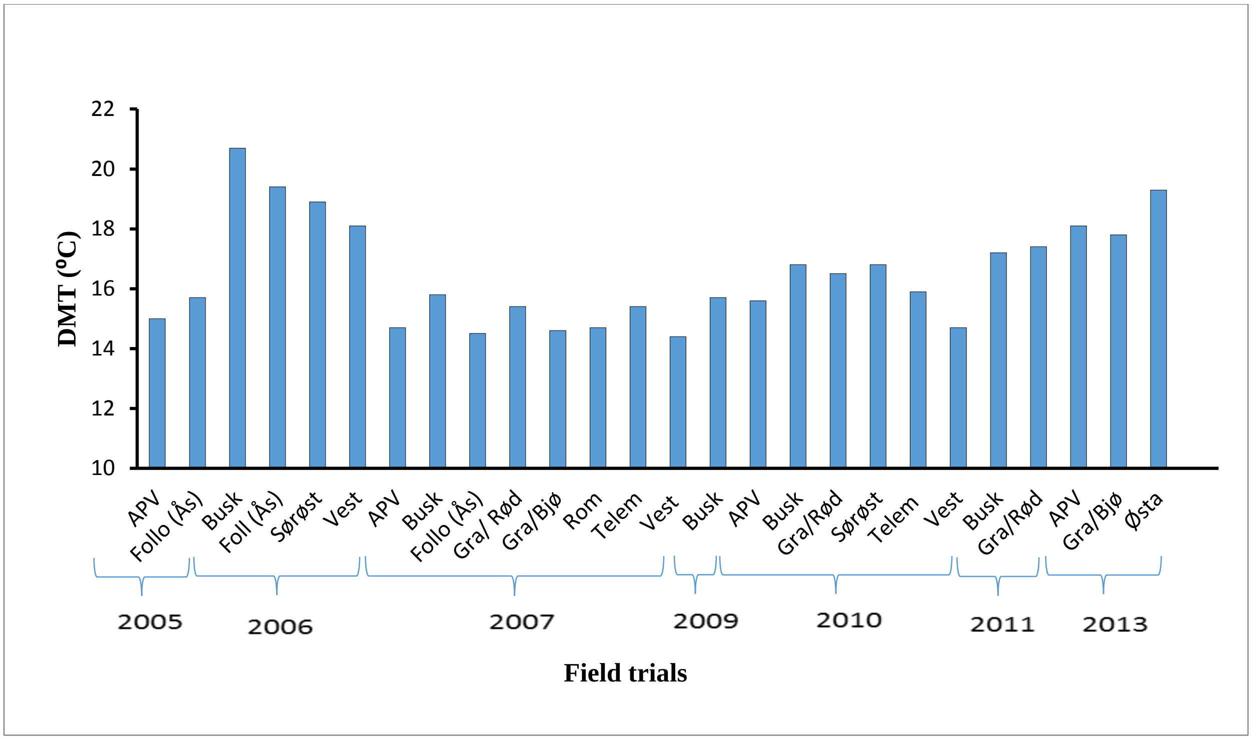

Figure 11. DMT during sub-phase 3 of the grain-filling period for the different field trials in different growing and harvesting seasons.

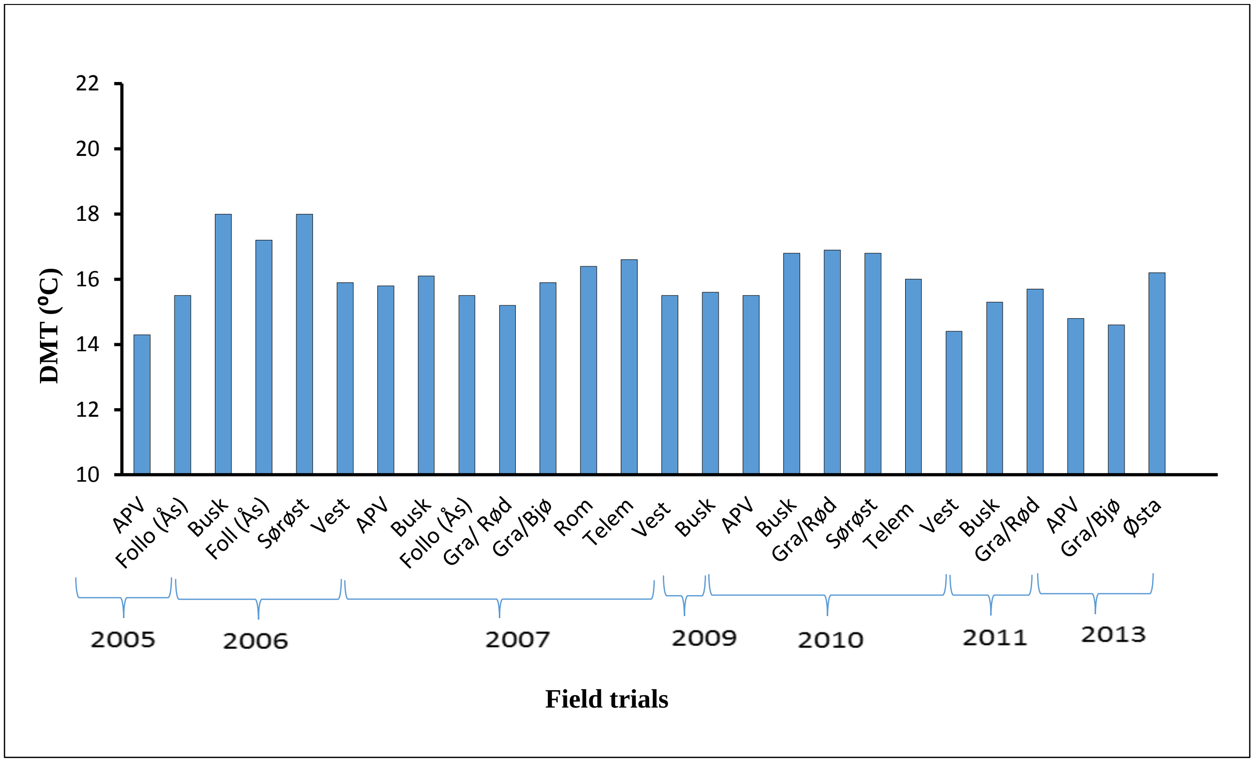

Figure 12. DMT during sub-phase 4 of the grain-filling period for the different field trials in different growing and harvesting seasons.

4.1.2 Quality analysis of marked varieties (cv. Magnifik, Mjølner and Olivin) from 2005-2013

4.1.2.1 Analysis of variance

The study revealed highly significant differences among varieties and environment in all the quality parameters analyzed. For the interaction between varieties and environment, except for protein content, SDS sedimentation volume and Extensibility values, all other quality parameters were highly significant (Table 5).

Table 5. P-values from General Linear Model (ANOVA) for the varieties Magnifik, Mjølner and Olivin.

	Protein content (%)	**R_{max} (N)**	**Ext**	**SDS (ml)**	**SSDS**	**R_{max} /Ext**	**FN (s)**	**Test weight (g)**
Varieties	**<0.001**	**<0.001**	**0.011**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
Environment	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
Environment*Variety	0.999	**<0.001**	0.773	0.062	**<0.001**	**0.001**	**<0.001**	**<0.001**

- Bold figures show results that are significant.

4.1.2.2 Mean values for the varieties

Table 6 shows the mean values for all the tested quality variables with Fisher's LSD values. Significant variation was observed for all the variables where Olivin exhibits higher values in all the tested quality variables, whereas Magnifik and Mjølner showed very similar values in most of the cases. Magnifik had on average slightly lower protein content than Olivin and Mjølner. For gluten quality measured by the Kieffer extensograph, Olivin had both higher resistance to stretching as well as a higher extensibility. Mjølner had the lowest R_{max} value, but there were no significant difference in R_{max} between Mjølner and Magnifik. Mjølner showed lower SDS sedimentation volume and SSDS values, while no significant differences were found between Olivin and Magnifik. Thus, the two analyses used in this study to examine gluten quality (SDS sedimentation volume and Kieffer Extensograph) showed different ranking of the varieties.

Table 6. Mean values for the three varieties (Magnifik, Mjølner and Olivin) with Fisher's LSD value and groupings.

Varieties	Protein content (%)	R_{max} (N)	Ext	SDS (ml)	SSDS	R_{max}/ Ext	FN (s)	Test weight (g)
Mjølner	12.5^{a}	0.43^{b}	148.8^{a}	65.7^{b}	52.9^{b}	3.0^{b}	252^{b}	80.9^{c}
Magnifik	12.2^{b}	0.47^{b}	145.5^{b}	74.5^{a}	61.5^{a}	3.4^{b}	263^{b}	82.2^{b}
Olivin	12.6^{a}	0.57^{a}	150.9^{a}	76.3^{a}	61.1^{a}	3.9^{a}	316^{a}	82.8^{a}
LSD value	0.17	0.04	4.61	1.99	1.58	0.36	18.54	0.51

- SDS sedimentation volume and SSDS values did not represent the 2011 growing season since the data was not analyzed.
- Values followed by the same latter are not significantly different at $P=0.005$.

4.1.2.3 Mean values for the field trials

According to general linear model (ANOVA) result, in Table 7, significant variations were observed among the 30 field trials for all of the quality parameters. Table 7 is arranged in increasing order of R_{max} result in order to see the clear differences between the gluten strength among varieties from different field trials. As it is seen from the table, the lowest R_{max} was obtained from Graminor/Rød (Gra/Rød 36), which was analyzed in 2011 harvesting season although it had higher protein content (13.2 %) and falling number which is well above the acceptable values (FN=250).

Table 7. Mean values for the different quality parameters with Fisher's LSD values for the 30 field trials from the growing seasons of 2005 to 2013.

Field trials	**Year**	**Protein content (%)**	**R_{max}**	**Ext**	**SDS (ml)**	**SSDS**	**R_{max}/ Ext**	**FN (s)**	**Test weight (g)**
Gra/Rød 36	2011	13.2	**0.17**	115.2	-	-	1.4	293	**78.6**
Vest 17	2007	13.2	0.19	**190.2**	77.3	58.7	**1.1**	273	80.5
Telem 18	2007	12.8	0.31	172.2	74.5	58.0	1.8	210	82.6
Rom 15	2007	12.0	0.32	171.6	62.2	51.8	1.9	242	80.9
Sør 13	2007	13.1	0.34	167.1	**80.2**	61.2	2.0	237	82.4
Busk 16	2007	12.3	0.35	147.0	76.8	62.5	2.4	259	83.9
APV 12	2007	11.2	0.35	154.2	69.5	62.7	2.3	281	82.8
Busk 25	2009	**16.2**	0.37	139.4	82.0	50.7	2.7	**212**	78.4
Sør/Fol 14	2007	12.2	0.37	163.9	78.7	64.3	2.3	231	81.4
APV 32	2010	**9.7**	0.38	124.1	**59.3**	61.4	3.1	314	80.1
Gra/Bjø 20	2007	12.8	0.40	166.4	78.2	61.0	2.4	302	84.0
Gra/Bjø 46	2013	13.2	0.49	144.6	68.8	52.3	3.4	269	82.0
Busk 31	2010	10.9	0.49	130.9	68.3	62.7	3.8	230	81.2
Vest 27	2010	13.2	0.51	156.5	77.2	58.4	3.2	323	83.6
APV 7	2005	12.3	0.51	162.7	71.0	57.8	3.2	279	83.8
Sør/Øst 30	2010	12.4	0.52	152.2	76.2	61.4	3.4	279	82.3
Sør 8	2006	12.8	0.53	169.6	81.5	63.7	3.1	345	84.1
Telem 28	2010	11.4	0.54	148.0	71.5	62.8	3.6	287	83.4
Gra/Bjø 26	2009	13.7	0.55	139.9	69.8	51.3	3.9	296	79.6
Gra/Rød 29	2010	13.2	0.55	150.3	75.0	56.8	3.7	256	83.6
Busk 4	2005	11.6	0.58	151.2	61.7	53.1	3.9	255	83.8
Opp 45	2013	13.2	0.60	120.8	65.5	49.8	4.9	213	81.3
Busk 11	2006	11.8	0.61	153.5	72.8	61.5	3.9	304	**84.3**
Busk 34	2011	11.9	0.62	**104.1**	-	-	**6.0**	312	79.8
Gra/Rød 19	2007	11.8	0.63	149.0	69.0	58.5	4.2	314	83.8
Fol 9	2006	12.7	0.64	163.5	82.0	64.7	4.0	**359**	83.5
Fol 2	2005	12.5	0.69	135.5	72.6	58.1	5.3	330	78.8
Østa 43	2013	12.0	0.69	135.7	72.2	60.3	5.3	279	82.3
Vest 10	2006	11.7	0.70	147.4	73.5	62.8	4.8	298	82.0
APV 42	2013	10.9	**0.72**	126.4	**54.5**	49.8	5.6	235	80.6
LSD value		0.543	0.116	14.473	5.503	4.381	0.995	51.347	1.4

- SDS sedimentation volume and SSDS values for locations Buskerud (Busk 34) and Graminor (Gra/Rød 36) was not included in 2011 growing season since the data was not analyzed.
- Bold figures show the highest or lowest values.

The highest R_{max} was recorded from Apelsvoll (APV 42) in 2013 harvest despite the fact that it had a little low protein content and SDS sedimentation volume. Fisher's LSD values were also calculated to show their least significant differences.

Protein content in four field trials was higher than 13 %, in some it was around 12 % and the lowest protein content was obtained from Apelsvoll (APV 32) which was 9.7 % harvested in the year 2010 and the highest is recorded from Buskerud (Busk 25) which is 16.2 %. Since field trials which scored falling number above 200 were selected for comparison, most of the field trials exhibited higher falling number (for example FN=359 in Follo, Ås) and some lower towards to 200, but not less. Regarding test weight, in generally, all the field trials had higher test weight well above the acceptable value. The highest SDS sedimentation volume was obtained from different locations in different years. Increase in SDS sedimentation volume is observed with the increasing in protein content generally *($P<0.001$).* There was also a highly significant relationship was observed between SDS sedimentation volume and SSDS values *($P<0.001$).*

The two locations (Gra/Rød 36 and Vest 17) showed unusual low values in terms of R_{max} despite the fact that they had higher protein content and higher SDS sedimentation volume and test weight value for samples from Vestfold (Vest 17). Sample from Vestfold (Vest 17) had the highest extensibility from all the samples from all locations despite the fact that it had lower R_{max} and SDS sedimentation values. Therefore, these unusual low and inconsistent values cannot be easily explained by looking only the weather data. It should be seen deeply with the interactions together with other theories like *Fusarium* infestation and mycotoxines.

4.1.3 Quality analysis of marked varieties (cv. Bjørke, Magnifik, Mjølner and Olivin) from 2005-2010

4.1.3.1 Analysis of variance

Table 8 shows p-values for all the quality parameters from the general linear model (ANOVA) result. There is a highly significant variation observed between the varieties, environment where they have been grown and with the interaction between variety and environment. No statistically significant variation was observed in the interaction between varieties and environment for protein content and extensibility.

Table 8. P-values from General Linear Model (ANOVA) for the varieties Magnifik, Mjølner and Olivin.

	Protein Content (%)	R_{max} (N)	Ext	SDS (ml)	SSDS	R_{max}/ Ext	FN(s)	Test weight (g)
Variety	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
Environment	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
Environment*Variety	1.000	**<0.001**	0.662	**0.004**	**<0.001**	**<0.001**	**<0.001**	**0.002**

- Bold figures show results that are significant.

4.1.3.2 Mean values for the varieties

Table 9 shows the mean values for the four varieties grown from 2005 to 2010 arranged in increasing order of their R_{max}. For all the quality parameters there were highly significant variations observed between cultivars (p-values are listed in Table 8). The lowest R_{max} value was recorded with Mjølner. Olivin here also showed higher R_{max}, FN, protein content, extensibility and test weight values than Magnifik and Mjølner, but it showed similarity in extensibility with Mjølner. Bjørke showed higher values in all the parameters except for extensibility and test weight.

Table 9. Mean values for the varieties (Bjørke, Magnifik, Mjølner and Olivin) with Fisher's LSD value and groupings.

Varieties	Protein Content (%)	R_{max} (N)	Ext	SDS (ml)	SSDS	R_{max}/ Ext	FN(s)	Test weight (g)
Mjølner	12.5^{b}	0.42^{c}	156.1^{a}	66.4^{c}	53.4^{c}	2.7^{c}	253^{b}	81.1^{c}
Magnifik	12.2^{c}	0.47^{b}	151.0^{b}	76.4^{b}	62.5^{b}	3.3^{b}	268^{b}	82.6^{b}
Olivin	12.5^{b}	0.54^{a}	156.3^{a}	77.3^{b}	61.9^{b}	3.5^{b}	317^{a}	83.2^{a}
Bjørke	12.8^{a}	0.57^{a}	142.4^{c}	83.9^{a}	65.5^{a}	4.2^{a}	327^{a}	81.2^{c}
LSD value	0.2	0.04	5.23	2.5	1.98	0.43	17.04	0.39

- Values followed by the same latter are not significantly different at *P=0.005*.

Table 10. Means of the different quality parameters with Fisher's LSD value for the 25 field trials from the growing seasons of 2005 to 2010.

Field trials	Year	Protein content (%)	R_{max} (N)	Ext	SDS (ml)	SSDS	R_{max}/ Ext	FN (S)	Test weight (g)
Vest 7	2007	13.1	0.20	188.9	79.3	60.3	**1.1**	278	80.3
Telem 18	2007	12.9	0.32	170.8	79.0	61.2	1.9	240	82.6
Rom 15	2007	12.3	0.32	167.3	68.3	55.4	2.0	248	81.1
Busk 16	2007	12.4	0.34	145.3	79.3	64.1	2.3	275	83.4
APV 12	2007	11.3	0.35	156.0	71.9	63.9	2.3	290	82.4
Sør/Fol14	2007	12.3	0.38	159.2	81.0	66.0	2.4	237	81.0
Sør 13	2007	13.0	0.40	158.9	84.3	64.9	2.6	263	82.8
APV 32	2010	**9.7**	0.41	122.4	60.0	61.1	3.4	321	80.1
Gra/Bjø 20	2007	12.9	0.41	162.5	81.9	63.7	2.6	309	83.8
Busk 25	2009	**16.1**	0.43	139.0	**84.0**	**52.3**	3.1	**234**	**77.9**
Busk 31	2010	11.1	0.50	130.8	70.0	62.9	3.9	240	80.8
Sør 30	2010	12.7	0.53	150.6	81.0	63.9	3.5	288	81.8
Vest 27	2010	13.2	0.54	154.8	80.1	60.7	3.5	335	83.2
APV 7	2005	12.4	0.54	160.7	73.6	59.6	3.4	284	83.8
Telem 28	2010	11.6	0.54	148.9	75.1	64.6	3.6	299	82.8
Gra/Rød 29	2010	13.4	0.55	149.8	79.9	59.4	3.7	264	83.3
Sør 8	2006	12.9	0.56	162.2	83.8	64.7	3.5	**358**	**84.0**
Gra/Bjø 26	2009	13.7	0.56	141.6	73.3	53.7	4.0	308	79.6
Busk 4	2005	11.7	0.63	144.6	**63.8**	54.5	4.6	272	83.6
Fol 9	2006	12.8	0.65	160.6	82.6	64.4	4.1	357	83.2
Busk 11	2006	11.9	0.65	147.2	73.1	61.4	4.4	322	83.8
Gra 19	2007	12.0	0.68	148.6	71.4	59.6	4.6	328	83.9
Vest 10	2006	11.9	0.71	144.4	72.6	61.4	4.9	311	81.5
Fol 2	2005	12.8	**0.78**	123.8	73.6	57.7	6.9	329	78.3
LSD value		0.48	0.09	12.54	6.0	4.76	1.02	40.86	0.94

- Bold figures show the highest or lowest values.

4.1.3.3 Mean values with Fisher's LSD value for the field trials in the growing seasons 2005-2010

There are significant differences between the different field trials, and for this, the means of the quality variables with LSD values are summarized in the table above (Table 10). The table is arranged in ascending order of R_{max} value. The least R_{max} value is obtained from Vestfold (Vest 7) field trials from 2007 harvest even though it had relatively high protein content, Ext, SDS sedimentation volume and test weight values. The highest R_{max} value is from Follo, Ås from 2005 harvest. The lowest protein content was observed from Apelsvoll (APV 32) which was 9.7 % from 2010 harvest and the highest was from Graminor/Bjørke (Gra/Bjø 26) which was 13.7 % from 2009 harvest. Falling number in most of the field trials remained higher, but the least is obtained from Buskerud (Busk 25) from 2009 harvest and it was 234 in addition to this test weight from this location was lower; 77.9 g. In most of the field trials higher test weight with little difference was observed (LSD=0.94).

4.1.4 Quality analysis of marked varieties (cv. Ellvis, Finans, Magnifik, Mjølner and Olivin) from 2011-2013

4.1.4.1 Analysis of variance

Except from extensibility and ratio of gluten resistance to extensibility (R_{max}/Ext), significant results were obtained the varieties. For all the quality parameters, highly significant variations obtained between the field trials. For the interaction between environments with variety, significant results were also recorded for R_{max}. R_{max}/Ext, FN, and test weight values. However, protein content, Ext, SDS sedimentation volume and SSDS values were not significant (Table 11).

Table 11. P-values from General Linear Model (ANOVA) for the varieties Ellvis, Finans, Magnifik, Mjølner and Olivin.

	Protein Content (%)	R_{max} (N)	Ext	SDS (ml)	SSDS	R_{max}/ Ext	FN (s)	Test weight(g)
Varieties	**0.026**	**0.010**	0.329	**0.003**	**0.006**	0.150	**<0.001**	**<0.001**
Environment	**<0.001**	**<0.001**	**0.001**	**<0.001**	**<0.001**	**<0.001**	**0.003**	**<0.001**
Environment*Varieties	0.052	**0.002**	0.076	0.267	0.160	**0.001**	**0.003**	**<0.001**

- Bold figures show results that are significant.

4.1.4.2 *Mean values for the varieties*

Descriptive statistics for all the 5 varieties from 2011 and 2013 harvest seasons is shown in Table 12, this Table is arranged in ascending order of R_{max}; there are highly significant variations between these five varieties for the quality variables (P-values are listed in Table 11). The highest R_{max} value is observed with Olivin. Olivin has showed the highest values for protein content, SDS sedimentation volume, SSDS and for test weight too. On the other hand, Finans was also remained statically similar with Olivin showing similarity in R_{max}, SDS sedimentation volume and SSDS values. Magnifik and Mjølner exhibited the lowest values compared with the other cultivars with all the tested variables except that of test weight, which was among the highest. Fisher's LSD values for Ext and R_{max}/Ext were not calculated for the descriptive statistics since there were no significant differences among cultivars (Table 12).

Table 12. A table showing mean values for the varieties Ellvis, Finans, Magnifik, Mjølner and Olivin from the growing season of 2011-2013.

Varieties	Protein content (%)	R_{max} (N)	Ext	SDS (ml)	SSDS	R_{max}/ Ext	FN(s)	Test weight (g)
Magnifik	12.1^{b}	0.45^{b}	122.3	63.5^{ab}	52.8^{abc}	3.8	242^{c}	80.8^{a}
Elvis	11.9^{bc}	0.48^{b}	117.2	61.3^{b}	53.3^{ab}	4.1	379^{a}	79.7^{a}
Mjølner	12.5^{ab}	0.49^{b}	119.8	61.6^{b}	49.7^{c}	4.0	247^{c}	80.3^{a}
Finans	11.9^{bc}	0.50^{b}	114	64.6^{ab}	55.3^{ab}	4.7	332^{b}	76.1^{b}
Olivin	12.7^{a}	0.69^{a}	131	70.6^{a}	56.6^{a}	5.4	311^{b}	81.2^{a}
LSD value	0.52	0.13	-	8.35	3.4	-	37.42	1.71

- SDS sedimentation volume and SSDS values did not represent the 2011 growing season since the data was not analyzed.
- Values followed by the same latter are not significant different at *P=0.005*.

4.1.4.3 *Mean values with Fisher's LSD value for the field trials in the growing seasons 2011-2013*

Table 13 shows significant variations between the field trials (P-values are listed in Table 11). For all the quality variables, very clear variations were observed between all the six field trials. High R_{max}, SDS sedimentation volume, SSDS, R_{max}/Ext and test weight values were recorded at Østafjells (Østa 43), whereas falling number value is statistically remained the same with that of Buskerud (Busk 34). The lowest value for R_{max} was found from Graminor (Gra 36), and in addition to this test weight, Ext, R_{max}/Ext were the lowest in this location. Protein content was higher in Graminor (Gra 36), Graminor/Bjørke (Gra/Bjø 46) and Oppland (Opp 45) and the lowest protein content was from Apelsvoll (APV 42).

Table 13. Means of the different quality parameters with Fisher's LSD value for the six field trials from the growing seasons of 2011 to 2013.

Field trials	**Year**	**Protein content (%)**	**R_{max} (N)**	**Ext**	**SDS (ml)**	**SSDS**	**R_{max}/ Ext**	**FN (s)**	**Test weight (g)**
Gra 36	2011	13.1^{a}	0.14^{d}	102.9^{c}	*NA*	*NA*	1.3^{d}	318^{ab}	76.9^{c}
Gra/Bjø 46	2013	13.3^{a}	0.47^{c}	145.7^{a}	68.3^{ab}	51.5^{b}	3.2^{c}	304^{b}	80.5^{a}
Opp 45	2013	12.9^{a}	0.54^{c}	122.1^{b}	64.0^{b}	49.7^{b}	4.4^{b}	264^{b}	80.6^{a}
Busk 34	2011	11.8^{b}	0.59^{bc}	102.4^{c}	*NA*	*NA*	5.7^{a}	347^{a}	78.1^{b}
APV 42	2013	10.8^{c}	0.72^{ab}	123.6^{b}	55.8^{c}	51.6^{b}	5.8^{a}	269^{b}	80.1^{ab}
Østa 43	2013	11.4^{b}	0.77^{a}	128.5^{b}	69.5^{a}	60.9^{a}	6.2^{a}	312^{ab}	81.5^{a}
LSD value		0.573	0.141	18.739	3.815	2.949	1.394	40.991	1.869

- SDS and SSDS for location Buskerud and Graminor was not included in 2011 growing season since the data was not analyzed.
- Values followed by the same latter are not significant different at $P=0.005$.

4.1.5 Regression analysis

Regression plot was drawn between R_{max} and DMT during the grain-filling periods in order to look for any association between gluten strength and weather conditions. According to the result, significant positive regression has been observed between gluten strength (quality) measure with R_{max} and daily mean air temperature during sub-phase 2 and sub-phase 3 of the grain-filling periods (Fig. 13). For the rest of the grain-filling period (sub-phase 1 and sub-phase 4), the correlations were not significant. The result, which appeared to be an outlier on both regression, plots, the location Vest 17, for having unusually low R_{max} value might not be explained by these correlations. According to the regression plot, this location should have higher R_{max} value with the increase in temperature. Therefore, there must be explained differently; like may be this due to *Fusarium* infestation although no record was made on *Fusarium* infestation on this location during this period.

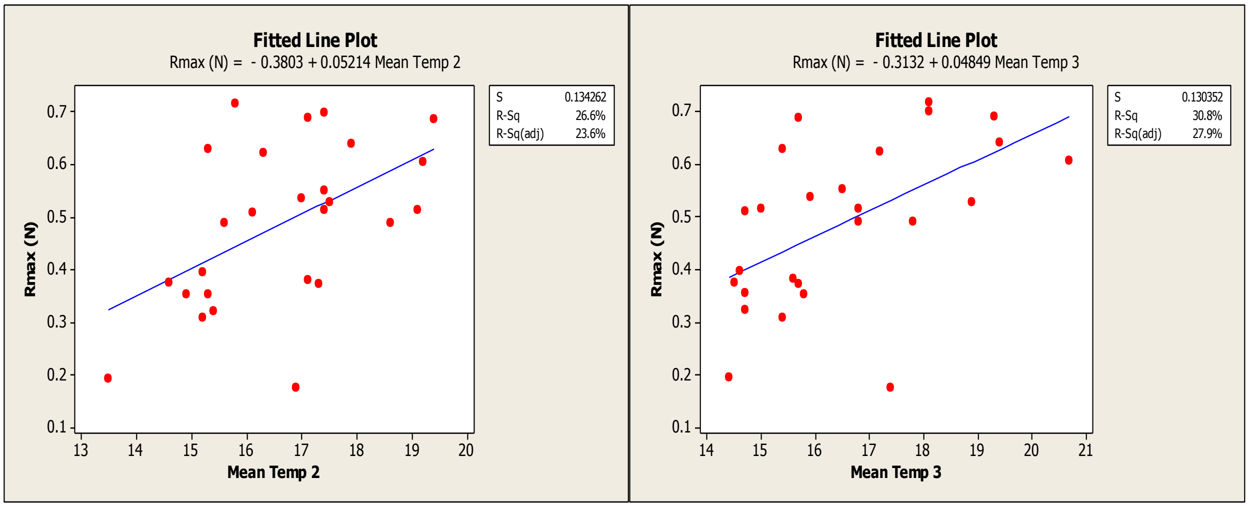

Figure 13. Regressions between R_{max} and DMT during sub-phase 2and sub-phase 3 of the grain-filling period.

Similarly, regression analyses were made between R_{max} and precipitation received during the grain-filling periods and therefore, negative correlations were observed between precipitation during sub-phase 2 and sub-phase 3 with R_{max} (Fig. 14). No responses were obtained from the regressions between R_{max} and precipitation during the other sub-phases.

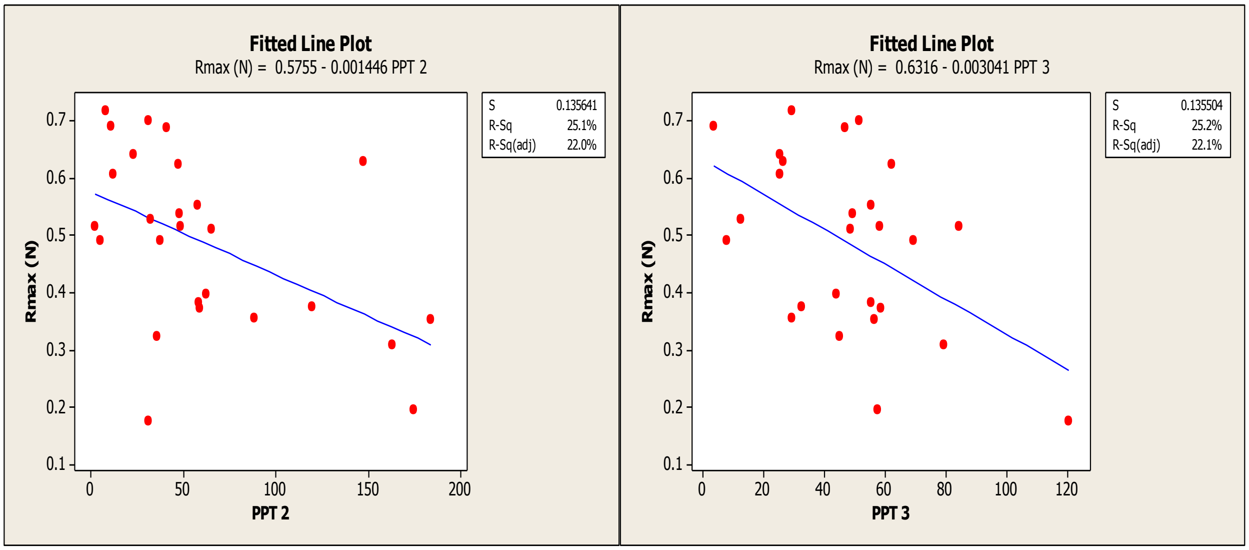

Figure 14. Regressions between total precipitations received during sub-phase 2 and sub-phase 3 of the grain-filling period.

To investigate the influence of precipitation on the falling number, regressions were made between the falling number values and precipitations during each sub-phase of the grain-filling period. Therefore, for the first three sub-phases of the grain-filling periods no correlations were found between the amount of precipitation and falling number values, but negative correlation were found from the regression between amount of precipitation during the last sub-phase and falling number values (Fig. 15).

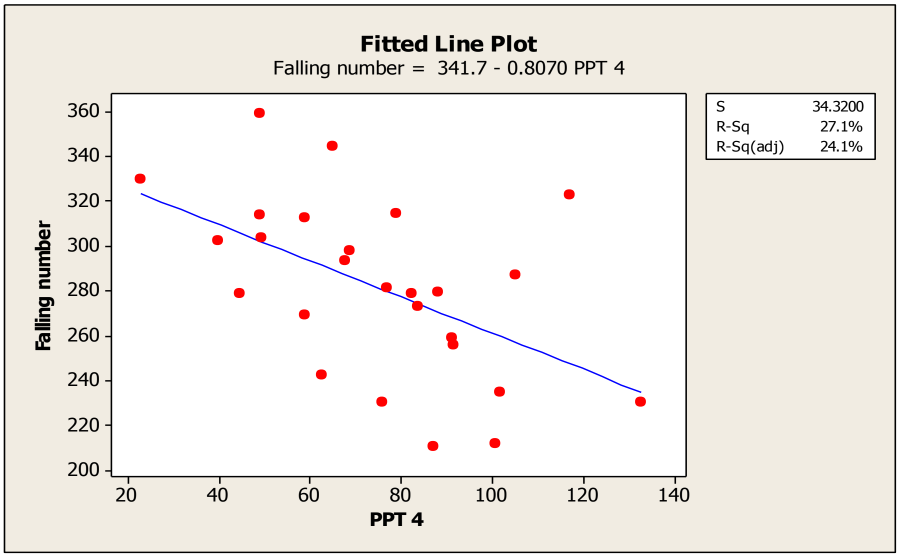

Figure 15. Regression between Falling number and precipitation 4. (Precipitation during sub-phase 4; from August 01- August 20).

4.2 Material 2:- Quality analysis of new winter wheat varieties in 2013

4.2.1 Climatic conditions

Weather distribution for both locations (Idd and Vollebekk) has shown a similar pattern throughout the grain-filling period, it has exhibited a gradual increase in DMT starting from June 15 until it reached maximum in July and then decreased in August. The lowest average DMT was recorded during the period between June 15 to June 30 in both locations and in a similar pattern, the highest average DMT recorded during the period of July 16 to July 31 (Fig. 16A).

The same is true with total precipitation received in both locations. The rainfall was higher during the period of June 15 to June 30, and then it decreased sharply to the lowest during the second sub-phase of the grain-filling period. During the third and fourth sub-phases of the grain-filling period, there was a gradual increase in precipitation on both locations with slight differences (Fig. 16B).

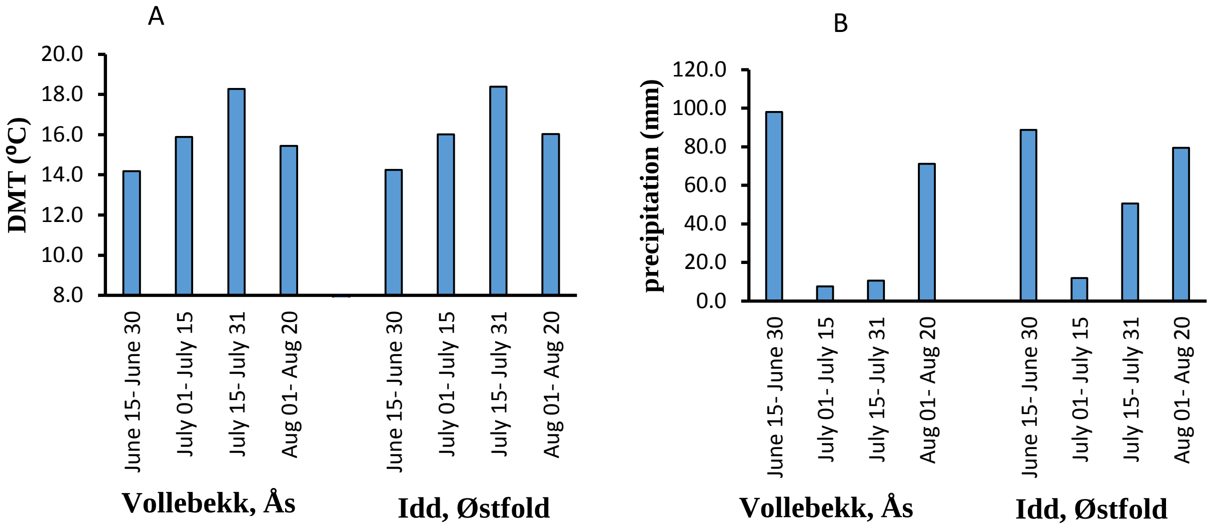

Figure 16. Average DMT (A) and average precipitation (B) during the grain-filling period in Vollebekk, Ås and Idd, Østfold in 2013 harvest season.

The winter survival at Østfold was very poor in some parts of the field trial and as a result of this; the plant growth was very poor in these parts of the field trials (as seen in Fig. 17). Sometimes it was a bit difficult to get enough samples to perform quality analysis because of poor growth of the plants.

Figure 17. Photo taken at the time of heading in 2013 shows poor winter survival of winter wheat in some parts of the field trial plot at Idd, Østfold. (Photo-Yohannes B. Mekonnen).

4.2.2 Quality analysis of new verities in 2013

4.2.2.1 Analysis of variance

Table 14 shows the P-values for the cultivars and the environmental factors for the tested quality parameters. The influence of environmental factors was substantial for most of the quality parameters. Except for SSDS and FN values, all other values for the quality parameters (protein content, SDS sedimentation volume, test weight and kernel weight) were significant between different field trials. Significant variations also obtained between SDS sedimentation volume, FN and test weight values among varieties. Moreover, the result revealed no significant differences on protein content, SSDS and kernel weight values among varieties.

Table 14. P-values for the quality parameters comparing between varieties and environment.

	Protein content (%)	**SDS (ml)**	**SSDS**	**Falling number (s)**	**Test weight (Kg/hl)**	**Kernel weight (mg)**
Varieties	0.268	**0.042**	0.363	**0.028**	**0.013**	0.082
Environment	**<0.001**	<**0.001**	0.225	0.228	<**0.001**	<**0.001**

- Bold figures show result that are significant.

4.2.2.2 Mean values for varieties

Table 15 shows mean values for all the cultivars from Idd and Vollebekk. Although, neither one way ANOVA nor General Linear Model (analysis of variance) showed no statistical differences between varieties for protein content varieties showed variation ranging from 11.5 % – 14.1 %, the lowest one for Matrix and the higher one for Akteur. No variation was obtained for SSDS and kernel weight between varieties too. Magnifik showed the lowest kernel weight (35.2 mg) and other two varieties which are Skagen and Akratos showed the highest values (41 mg). Fisher's LSD values were calculated for those quality parameters which were significant ($P<0.05$).

Table 15. Mean values of quality parameters for the cultivars from Idd and Vollebekk.

Varieties	Protein content (%)	SDS (ml)	SSDS	Falling number (s)	Test weight (Kg/hl)	Kernel weight (mg)
Matrix	11.5	67.5^{b}	58.6	272^{bc}	73.3^{b}	38.4
Finans	12.2	64.0^{b}	52.6	319^{ab}	69.8^{b}	37.8
Magnifix	12.5	70.0^{b}	55.7	283^{abc}	75.5^{ab}	35.2
Frontal	12.7	72.5^{ab}	57.8	227^{c}	70.0^{b}	35.6
Olivin	12.7	69.0^{b}	54.3	291^{abc}	77.0^{a}	35.7
Elvis	12.7	66.0^{b}	51.8	340^{a}	71.0^{b}	37.0
Kuban	12.7	70.5^{ab}	55.9	316^{ab}	77.3^{a}	38.0
Skagen	12.9	77.5^{a}	60.8	330^{ab}	73.5^{ab}	41.0
Akratos	13.4	78.5^{a}	59.2	228^{c}	73.3^{b}	41,0
Akteur	14.1	76.0^{ab}	55.1	305^{ab}	75.5^{ab}	40.9
LSD value	-	8.53	-	64.3	3.94	-

- Values followed by the same latter are not significant different at $P=0.05$.

Five cultivars were selected from both locations to compare gluten resistance among cultivars and to see the effects of weather conditions on quality parameters. However, no significant differences were detected between these varieties regarding gluten strength measure with R_{max}, Ext and R_{max}/Ext, but they have shown huge differences on their protein content. Elvis from Østfold showed the lowest R_{max} value, however, it has the highest extensibility from all the cultivars. Although nitrogen fertilizations on both field trials was the same, but cultivars from these two locations showed huge differences on protein content. Protein content was higher in cultivars from Østfold field trials than cultivars from Vollebekk. However, the variations in protein content did not show significant result (Table 14).

Table 16. A table showing variations in Protein content (%), R_{max}, Ext and R_{max}/Ext between varieties based on two locations.

	Ås, Vollebekk					Østfold, Idd			
Varieties	Protein content (%)	R_{max} (N)	Ext, (mm)	R_{max}/ Ext		Protein content (%)	R_{max} (N)	Ext, (mm)	R_{max}/ Ext
Elvis	10.6	0.63	138.0	4.6		14.8	0.22	147.3	1.5
Finans	10.6	0.81	124.8	6.5		13.7	0.57	145.5	3.9
Kuban	10.8	0.65	93.2	6.9		14.6	0.67	137.4	4.9
Magnifik	10.4	0.77	137.0	5.6		14.6	0.59	108.9	5.4
Olivin	10.7	0.76	102.3	7.5		14.6	0.69	139.9	4.9

4.2.2.3 Mean values for the field trials

Mean values of quality variables for the two locations were summarized below (Table 17). For SSDS and FN values no significant difference found between field trials whereas protein content, SDS sedimentation volume and kernel weight values were significantly varied between the two locations. Protein content, FN and SDS sedimentation values were higher in Idd, Østfold than Vollebekk, though test weight and kernel weight were higher in Vollebekk.

Table 17. Mean values together with P-values for the significant differences between the two locations compared with quality variables.

Field trials	**Protein content (%)**	**SDS (ml)**	**SSDS**	**FN (s)**	**Test weight (Kg/hl)**	**Kernel weight (mg)**
Østfold	14.8	81.5	55.1	299	70.7	34.6
Vollebekk	10.6	60.8	57.2	283	76.5	41.6
p-values	***<0.001***	***<0.001***	*0.225*	*0.228*	***<0.001***	***<0.001***

- Bold figures show results that are significant.

4.2.3 Mixograph analysis

According to the result from the mixograph analysis curve, there are significant differences among samples from the two locations. Mixogram curves for samples from Østfold showed distinct features of the Mixogram parameters as shown in the figure below (Fig. 18). Only three random representative samples were shown in the figure just to show the comparison of the Mixogram curve look like between the two locations. Since samples from Østfold had higher protein content, the curve was very clear and well defined unlike samples from Vollebekk where lower protein content recorded.

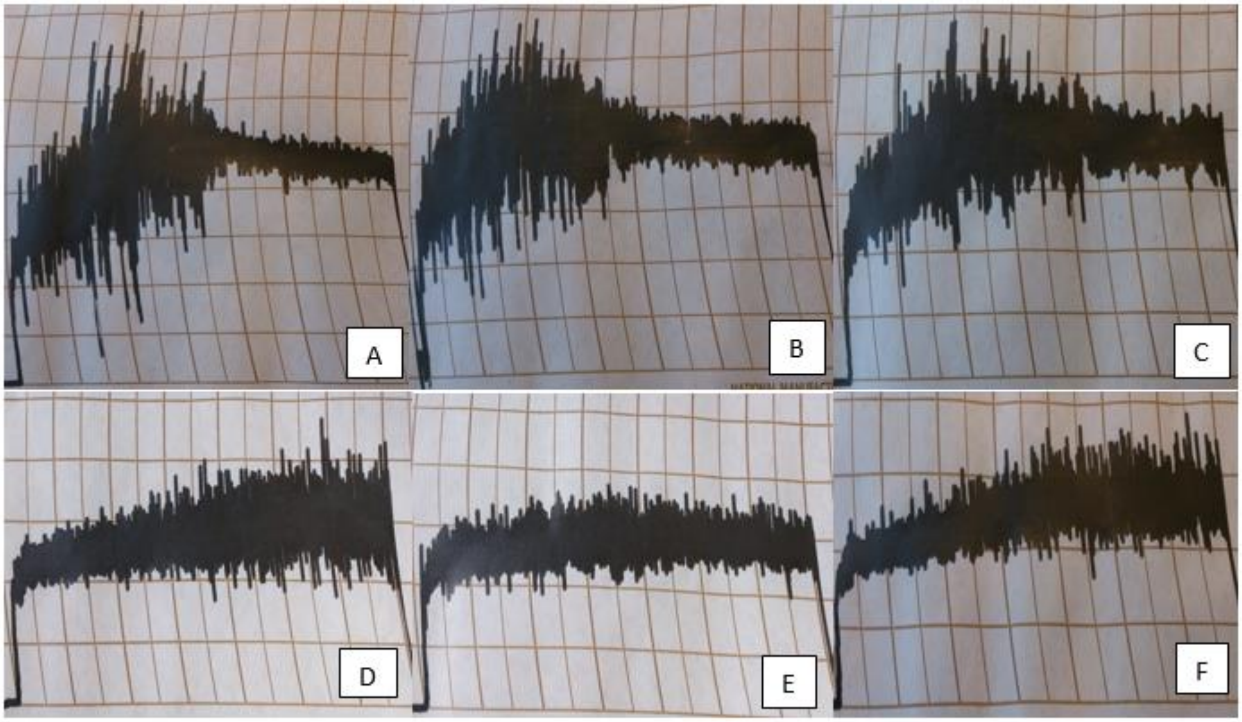

Figure 18. Mixograph curves for selected samples from Østfold and Vollebekk. (A) Skagen (B) Matrix and (C) Olivin from Østfold and Skagen (D), Matrix and (E), Olivin (F) from Vollebekk (Photo- Yohannes B. Mekonnen).

5 DISCUSSION

5.1 Material 1:- quality analysis- data from winter wheat trials 2005-2013

Gluten quality is the major and an important variable in determining the quality of wheat grains, although some other parameters such as test weight, SDS sedimentation volume, protein content, falling number and other parameters are also used. In this study, R_{max}, protein content, SDS sedimentation volume, and test weight were used to assess and compare the quality variations between the different cultivars in different harvesting seasons and different field trials.

5.1.1 Genetic variation among cultivars

The gluten quality (strength) is usually assessed using mixograph analysis, SDS sedimentation volume, or Kieffer (Extensograph) analysis. However, it is believed that R_{max} gives more reliable results than the other assessment methods. This is because R_{max} values were obtained from the extensograph analysis where gluten dough is used where as in the other tests, the whole dough (starch, the gluten network, and other dough constituents) were used. Indeed, this might not be always true because of some other factors.

Kieffer analysis is performed using gluten dough, which is prepared by washing the whole dough and separating the gluten network from the soluble part of the starch and resting for 45 min at a temperature of 30 °C. During this mixing, washing and the long resting period, it is believed that there will be un-polymerization and re-polymerization of the gluten proteins, which might cause differences between the results from SDS sedimentation volume and R_{max}.

Normally genetic variations were expected between the cultivars under investigation. Highly significant values ($P \leq 0.001$) were obtained among the values of protein content, R_{max}, SDS sedimentation volume, R_{max}/Ext, FN, test weight and extensibility (Table 5). These significant variations revealed the genetic variations among the three varieties (*cv*. Magnifik, Mjølner and Olivin).

According to the Norwegian wheat classification, Olivin and Magnifik are grouped in class 4 for having strong gluten and Mjølner is in class 5 because of its weak gluten (Felleskjøpet, 2013/14). Cultivars in the same class are believed to have more or less similar characteristics. However, our study showed that Olivin has higher gluten strength, which was measured with R_{max} ($R_{max}=0.57$), than Magnifik *(R_{max}=0.47)*. The variation between these two cultivars is not only with gluten strength, but also with other quality parameters. Magnifik had lower protein content, falling number, extensibility and ratio of R_{max} with extensibility values than Olivin. These variations were found statistically significant. Mjølner is classified as a weak winter wheat and it retains this weak gluten quality (*R_{max}=0.43*). The study showed that Mjølner and Magnifik were significantly different (Table 6).

The data set for varieties from 2005-2010 in material 2 is used to compare Bjørke with the other varieties *i.e.* Magnifik, Mjølner and Olivin. According to the result from this data set, even though cultivation of Bjørke has stopped since from 2011, it showed the highest values in most of the quality parameters. It was grouped together with Magnifik and Olivin in class 4 for having strong gluten; however, as it shown in Table 9, it is clearly different from both cultivars. Highly significant P-values obtained from the result are strong evidence for the genotypic variations between these cultivars (Table 8). Bjørke was the highest and the best in most of the qualities tested, it had higher gluten strength, higher protein content, higher SDS sedimentation volume (Table 9). Even though it had lower test weight than Olivin and Magnifik, the value is still well above the recommended value in Norway, which is 79 kg/hl (Felleskjøpet, 2013/14).

Finans and Ellvis are new varieties that were introduced in 2011, and since then they are in the production line. We compared these new cultivars with the other older ones, (*cv*, Magnifik, Mjølner and Olivin) during the harvest seasons of 2011-2013. There were highly significant variations found in this study among the above cultivars regarding FN and test weight values *($P \leq 0.001$)*. The values for protein content, R_{max}, SDS sedimentation volume and SSDS were also significant among cultivars (Table 11). Therefore this the findings of this study result revealed that Olivin exhibited a very strong gluten compared with Ellvis as measured with R_{max} and also with SDS sedimentation volume, in which both belong to the same class for having strong gluten. Nevertheless, Finans and Ellvis showed similarity in most of the quality parameters including gluten strength measured with R_{max} (except with FN and test weight values) despite the fact that they belong to different classes. Finans is categorized in class 5 for having weaker gluten whereas Ellvis is in class 4 for its possession of stronger gluten.

5.1.2 Variations due to environmental factors

The weather data is collected from the near site weather stations operated by Bioforsk (*Bioforsk/LandbruksMeteorologisk Tjeneste*). Although anthesis data is missing, the period selected from June 15 until August 20 for collecting weather information is believed to cover the whole grain-filling period. Since this study used winter wheat that is sown in autumn, the time of anthesis will mostly be affected by temperature from the start of the growing season in spring. Several studies have documented the effect of temperature on the growth and development of wheat plant (Slafer and Savin, 1991, Macdowall, 1973, Macdowall, 1974). Normal anthesis time for winter wheat in Norway occurs during the period of June 15-20 and yellow ripeness to occur late July to mid-August. However, this estimation of the grain-filling period is imprecise; we believe that the dates for weather data collection did cover the grain-filling period.

The grain-filling period was grouped into four sub-phases to see the effect of weather conditions during each sub-phase in relation to the different phases or physiological processes of the plant. In addition to this, the groups are needed to investigate at what period the weather is influential on the development and quality of the plant.

There was substantial environmental influence on the cultivars causing quality variations in all the three sets of data, and the variations between the different field trials confirm this. Large variations in temperature and precipitation were noted among the field trials within the same season as well as between different seasons, and because of this, huge variations on gluten quality (strength) and all other quality parameters were observed among the field trials. This variation was consistence in all the three sets of the data (Tables 5, 8 and 11).

The variation in gluten strength is usually related to weather conditions especially temperature during grain-filling period. Daily mean air temperature during the sub-phase 2 and 3 of the grain-filling period was correlated positively (*$P=0.007$ and $P=0.009$*, respectively) to gluten strength and this agrees with the findings from Moldestad et al. (2011) and Wrigley et al. (1994). According to the results from the regression analysis shown in Fig.13, 23.6 % and 27.9 % of the variations among the field trials is related to temperature during sub-phase 2 and sub-phase 3 of the grain filling, respectively. Even though, the temperature during this time of the grain-filling period was able to explain some of the variations in gluten strength among the field trials in material 1, still much of the variations could not be explained only by this weather data alone.

The mid periods (sub-phase 2 and 3) from heading until yellow ripeness are characterized by accumulation of prolamins and starch following differentiation of endosperm during sub-phase 1. Therefore, high temperature during this period of grain-development has a substantial influence on proteins and starch content of the endosperm. According to Randall and Moss (1990), exposure of higher temperature during grain-filling period had positive correlation with gluten strength. However, exposure to very high temperature (>30 °C) correlated negatively with gluten strength (Blumenthal et al., 1993, Randall and Moss, 1990, Wardlaw et al., 2002). This might not be a problem here in Norway, because the daily mean air temperature rarely reaches above 30 °C, and when it exceeds 20 °C weaker gluten have been recorded (Johansson et al., 2002, Moldestad et al., 2011).

At the very beginning and end of the grain-filling period, the temperature was lower; hence, very weak response was obtained in gluten strength. And this may be because that the processes during this time of grain-filling period might not be affected by temperature. Here it is good to remember that weaker gluten strength have been observed in relation with low temperature as documented in several literatures (Uhlen et al., 2004, Johansson and Svensson, 1998, Moldestad et al., 2011).

Precipitation during the grain-filling period was also highly varied among the field trials and regression analysis was done in order to see its effect on gluten strength. Of all the sub-phases, significant negative correlations was recorded between gluten strength and precipitation during sub-phase 2 and sub-phase 3. As this result revealed, precipitation during these times of the grain-filling period is the cause for 22.6 % and 27.9 % variation on gluten strength between field trials *(P=0.009)* (Fig 14). According to Rehman et al. (1997) the total storage proteins content along with the two components of gluten; gliadins and glutenin can be influenced by many factors including precipitation during grain development. Higher precipitation during this period might have decreased the availability of nitrogen in the soil because of leaching. Although all the cultivars selected were non-sprouted, this study showed that there was significant negative correlation between FN values from all the field trials and precipitation during sub-phase 4 *(P=0.006)* (Fig.15).

Different ranking was obtained from Tukey's grouping in all the three sets of data using the quality parameters SDS sedimentation volume, SSDS and R_{max} values. The ranking from SDS sedimentation volume and SSDS were similar in data set 1 and 2, but a bit different in the third data set. Both SDS sedimentation volume and SSDS values ranking were clearly different from the ranking from R_{max}. In Norway, classification of varieties into different quality classes is based on the rankings from SDS sedimentation volume and/or SSDS values. In order to have reliable methods for identifying the finest variety for baking industries, this classification should be done using the best method that can determine qualities accurately. In this study, the ranking among varieties based on SDS sedimentation volume and SSDS values are considerably different from the ranking from the Kieffer extensograph (R_{max}.) values as shown in Tables 6, 9 and 12.

5.2 Material 2:- Quality analysis of new varieties in 2013

Near-site weather stations were used to collect weather data for the whole grain-filling periods at Vollebekk and Østfold field trails. According to the data shown in Fig. 10A, there was no huge difference in DMT between the two locations. Total precipitation received in both locations was also similar except with very little difference, such as; at the beginning of the grain-filling period, precipitation was slightly higher at Vollebekk than Østfold, and during the third and fourth sub-phase a little higher precipitation was recorded at Østfold than Vollebekk (Fig. 10B).

This study documented some genetic variations among cultivars (Table.14). The variations were observed on SDS sedimentation volume, FN and test weight values were observed among cultivars (Table 15). Akratos showed higher values of SDS sedimentation volume and kernel weight 78.5 ml and 41 mg, respectively. Elvis showed higher FN and lower SDS sedimentation values, and the lowest FN value was recorded for Frontal despite having relatively higher SDS sedimentation value. For all the cultivars, FN values showed that there was no sprouting among cultivars. The variations in FN values among cultivars shows the genetic potential for susceptibility and resistance to pre-harvest sprouting.

Even though there were significant differences between test weight values among cultivars, the values for all the cultivars were below the Norwegian recommended value, which is 79 kg hl^{-1}. The variations which this study found in SDS sedimentation values among cultivars is an important finding, which can still be used to screen and classify cultivars into different quality classes (when

R_{max}. values fails to discriminate cultivars), as is the case here in Norway. In most breeding programs SDS sedimentation test is used to assess and screen cultivars based on gluten strength at the early stages (Dexter et al., 1980). In the researches aimed at developing a better seed that is resistant to PHS, the variation among cultivars with FN showed in this study cannot be underestimated since it shows the genetic potentials of cultivars to withstand sprouting.

Although the values for protein content range between 11.5 % and 14.1 % in Matrix and Akteur, respectively, most of the cultivars had more or less similar protein content. No significant difference was observed among varieties with regard to protein content. The cultivars in each locations showed more or less equivalent amount of protein content (Table 16). This could be one reason why the variation among cultivars is insignificant. The same might hold true with kernel weight where the values ranges between 35.2 mg and 41 mg but again this difference was not significant among the cultivars.

Winter survival of wheat is dependent on mainly genotype of cultivars, climatic conditions and management practices such as temperature, seeding depth, seeding rates, and nitrogen availability in the soil (Campbell et al., 1991, Rasmussen, 2004, Easson et al., 1993, Loeppky et al., 1989). If plants have poor winter survival, their development will be greatly affected, and consequently the plants give low yield, high protein content, lower starch and lower test weight values. In our finding highly significant variations were seen regarding protein content among the cultivars between the two locations ($P \leq 0.001$). The winter survival of wheat cultivars from Østfold was very poor and the plants were poorly developed in some parts of the field trials (Fig. 17). Therefore, this could be the reason why these samples have higher protein content and lower test weight values. Hence, this might be the reason why the variation between cultivars was not significant, even if there was a great variation (ranges between 11.5 % and 14.1 %) among cultivars.

At the beginning of the grain-filling period, the rainfall was very high at Vollebekk (98.0 mm) and this might have an effect on the availability of nitrogen fertilization to the plant due to leaching. Therefore, this could be one reason why the samples from Ås had a lower protein content. The temperature following the rest of the grain-filling period was drier and relatively warmer, so this could presumably the reason why the samples from Ås had good gluten strength although not significantly different among the cultivars (Table 16).

Environment had clear effects on quality variables (Table 14). Significant variations were found for protein content, SDS sedimentation volume, test and kernel weight values between the two locations. Protein content and SDS sedimentation volume values were higher among samples from Østfold whereas test and kernel weight were higher in samples from Vollebekk. Even though there was no significant variation regarding R_{max} among cultivars, substantial difference has been found between the two locations.

Mixograph analysis (Fig. 9 A, B, and C) showed that there is a very clear variation between cultivars as well as between the two locations in protein content and gluten strength. Most of the cultivars from Østfold showed a typical mixograph curves, and this might be related to protein content and gluten strength. These samples showed a high protein content, but weaker gluten strength when compared with samples from Ås. An average of 2.8 min was needed for dough development for samples from Østfold (Appendix 02).

Mixograph curves for the samples from Vollebekk (Fig. 9 D, E, and F) were not clearly defined to show the properties for a typical mixograph curve, and it was difficult to interpret it. This could be due to low protein content of the samples. It is not uncommon to get curves of abnormal peaks in wheat samples containing lower protein content, and the interpretation is difficult (Khatkar et al., 1996).

Mixograph mixing time is influenced by the amount and quality of protein. Since the quantity and quality of protein is influenced by the environmental factors, we can say that the mixograph mixing time is the function of quality and quantity of protein content and environment. Hence, mixograph curves from the two locations indicated that there is a huge difference in protein content and quality.

6 CONCLUSIONS

Average values among varieties showed less, but significant differences. The ranking regarding gluten strength using SDS sedimentation volume and R_{max} values is different for the experiment on the field trials from 2005-2013. The ranking between Olivin and Magnifik was similar regarding SDS sedimentation volume whereas Mjølner was lower. Olivin had higher R_{max} value than Magnifik and Mjølner. Therefore, Olivin had stronger gluten strength than Magnifik and Mjølner. Bjørke had the strongest gluten quality than Olivin, Magnifik and Mjølner. Among the newer varieties, Ellvis and Finans had similar gluten strength with Mjølner and Magnifik. Olivin had stronger gluten from all the newer cultivars. The result showed that Magnifik, now classified in class 4, had gluten quality similar to the class 5 wheat, comparable to Mjølner, and Finans.

Variations in protein content, gluten resistance, SDS sedimentation volume, and FN values between the different field trials could partly be explained by variability in the weather conditions. This study have documented climatic variations between different field trials within and in between different harvesting seasons. Gluten resistance variation between these field trails was significantly correlated with daily mean air temperature and total precipitation during the grain-filling period. The existence of relatively higher temperature during sub-phases 2 and 3 played the major role for 23.6 % and 27.9 % variations occurred between field trials. The contribution from precipitation during sub-period 2 and 3 has also considerable impact and explained 22.0 % of the variations regarding gluten resistance among field trials.

The result from material 2, comparing gluten quality for the newly recommended varieties, or varieties still under testing, could not document significant differences as measured with R_{max}. Significant variations on SDS sedimentation, FN and test weight values were detected among cultivars. Gluten resistance appeared to be stronger in samples from Vollebekk than Østfold, but not significantly different. However, protein content, SDS sedimentation volume, test weight and thousands of kernel weight values were significantly varied between the two locations. Poor winter survival at Østfold and relatively higher precipitation at the beginning of the grain-filling period at Vollebekk could have played major role for these variations.

Even though the data showed non-significant variations regarding gluten strength, it showed some promising results for stronger gluten. Skagen, Akratos and Matrix demonstrated relatively higher

SDS sedimentation volume and SSDS values suggesting that they have the potential for stronger gluten. Olivin have also displayed relatively higher protein content as well as stronger gluten resistance that agrees with the results from material 1 showing it had good rank on gluten strength. Yet, more investigation is still needed to identify and compare quality variations between these newly released cultivars and between different locations focusing on weather conditions as main factor for the variations.

7 RECOMMENDATIONS

The findings of this study suggested that the better way to describe variations between cultivars is gluten strength measured by rheological tests (extensograph analysis). Gluten network is used in extensograph analysis, which is more close to baking process, and it is quite free from other dough constituents whereas in SDS sedimentation test, whole dough (starch, gluten network, and other soluble components) is used. In some ways, these dough components might affect the results from SDS sedimentation test and might not be accurate in telling the gluten strength, but it could be best indicators of cultivars having potentially strong gluten resistance. However, using rheological tests are more time consuming and expensive.

These clear variations on the ranking among cultivars using R_{max} and SDS sedimentation values should be stressed and carefully examined by those companies responsible for classifying wheat into different quality classes. Therefore, according to the result from this study it can be recommend that using R_{max} values in classifying wheat in Norway is more accurate than using SDS sedimentation though it is expensive and more time consuming. Moreover, the current wheat classification in Norway needs to be revised, and moving Magnifik from class 4 to class 5 should also be considered. However, to decide whether using R_{max} values or SDS sedimentation volumes to show gluten strength and which one is more accurate may need more work and attention.

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APPENDIX 01

Weather data for the whole grain-filling period for the different field trial locations in different harvesting seasons.

Location	15 June- 30 June		1 Jul-15 Jul		16 Jul- 31 Jul		1 Aug- 20 Aug	
	DMT	**P**	**DMT**	**P**	**DMT**	**P**	**DMT**	**P**
2005								
APV	15.1	7.8	19.1	1.9	15.0	84.5	14.3	44.6
Follo (Ås)	15.7	6.0	19.4	40.6	15.7	46.8	15.5	23.0
2006								
Busk	16.4	34.4	19.2	12.0.	20.7	25.2	18.0	49.4
Vest	14.5	36.0	17.4	31.2	18.1	51.6	15.9	68.6
Sørøst	15.0	87.2	17.5	32.2	18.9	12.6	18.0	65.0
Foll (Ås)	14.9	64.4	17.9	23.0	19.4	25.4	17.2	49.0
2007								
APV	14.1	68.1	14.9	88.5	14.7	29.3	15.8	76.8
Busk	15.4	118.4	15.3	184.2	15.8	56.6	16.1	91.2
Gra/ Rød	14.9	58.3	15.3	147.7	15.4	26.6	15.2	79.0
Gra/Bjø	13.0	62.0	15.2	62.1	14.6	43.9	15.9	39.7
Rom	14.4	68.2	15.4	35.8	14.7	45.0	16.4	62.6
Telem	15.1	72.4	15.2	162.8	15.4	79.4	16.6	87.2
Follo (Ås)	14.2	93.4	14.6	119.4	14.5	32.6	15.5	76
2009								
Busk	17.1	11.8	17.3	58.6	15.7	58.8	15.6	100.8
2010								
APV	14.0	18.5	17.1	58.1	15.6	55.5	15.5	49.2
Busk	15.3	34.4	18.6	37.6	16.8	69.4	16.8	132.8
Gra/Rød	14.0	14.5	17.4	57.5	16.5	55.6	16.9	91.4
Telem	14.7	7.4	17.0	47.8	15.9	49.2	16.0	105.2
Sørøst	14.2	9.6	17.4	48.2	16.8	58.4	16.8	88.0
Vest	13.3	17.4	16.1	65.0	14.7	48.8	14.4	117.0
2011								
Busk	14.6	86.8	16.3	47.2	17.2	62.4	15.3	58.8
Gra/Rød	14.8	50.1	16.9	30.7	17.4	120.7	15.7	67.7
2013								
APV	14.2	82.2	15.8	8.0	18.1	29.2	14.8	101.8
Gra/Bjø	14.4	47.2	15.6	5.0	17.8	7.8	14.6	58.8
Østa	15.2	88.2	17.1	10.4	19.3	3.4	16.2	82.4
Vollebekk, Ås	14.2	98.0	15.9	7.6	18.3	10.6	15.4	71.2
Idd, Østfold	14.2	88.7	16.0	11.9	18.4	50.5	16.0	79.5

APPENDIX 02

Mixogram parameters for the samples from Østfold, Idd together with protein content.

Varieties	T-max	Max. height (mm)	Height at 5min (mm)	Height at 7min (mm)	Width at 7min (mm)	Protein content (%)
Akratos	3	57	53	53	9	16.2
Akteur	3	56	46	44	12	17.3
Ellvis	2.5	51	47	47	7	14.8
Finans	2.5	49	45	44	8	13.7
Frontal	2.5	50	46	44	12	14.6
Kuban	3	60	54	52	10	14.6
Magnifix	3	47	44	44	5	14.6
Matrix	2.5	55	49	48	8	12.9
Olivin	3	45	43	42	8	14.6
Skagen	3	56	54	51	6	14.9

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