Assessment of pre-harvest sprouting resistance in spring wheat in Norway

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Abstract

Pre-harvest sprouting is the precocious germination of kernels while still in the mother plant due to early breakage of seed dormancy, which usually occurs when humid weather conditions persist before harvest. It causes a serious problem throughout the world in some season, resulting in huge economic losses caused by downgrading of wheat quality from food to feed as well as reduction in yield. In the last few years, wheat quality and yield in Norway has been seriously affected by pre-harvest sprouting. Thus, pre-harvest sprouting resistant cultivars are needed in order to avoid losses in wheat quality and yield. Therefore, the objective of this study was (i) to compare different methods of PHS assessment in wheat and (ii) to find the markers that are associated with PHS resistance. Field experiment was conducted in Vollebekk, Ås, Norway in 2010 with a total of 159 spring wheat lines. Germination index (GI), falling number (FN) and dormancy index (DI) was used to assess the dormancy of wheat grains. The result showed a significant negative correlation for GI and FN (-0.456) and GI and DI (-0.575), and significant positive correlation for FN and DI (0.413). A total of 25 microsatellite markers previously identified in chromosome 3A, 3B, 3D and 4A were used to characterize the wheat lines. Highest number of significant markers was identified in the adapted lines and with GI. The important Norwegian wheat cultivars showed a very low level of dormancy and contained none or very few markers associated with dormancy. The best performing lines had low GI, high FN and high DI and carried 3 or more significant markers associated with dormancy, which could be useful as breeding parents for improving the resistance to PHS.

Key words: Dormancy, pre-harvest sprouting, germination index, falling number, dormancy index

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List of abbreviations

°C	Degree centigrade
°N	Degree north
µl	Micro liter
ABA	Absisic acid
ANOVA	Analysis of variance
CAPs	Cleaved amplified polymorphic sequence
CIMMYT	International maize and wheat improvement center
cm	Centimeter
DBM	Days before maturity
DF	Degrees of freedom
DI	Dormancy index
DNA	Deoxyribonucleic acid
dNTP	Deoxyribonucleotide triphosphate
EEA	European economic area
FN	Falling number
GA3	Gibberelic acid
GDD	Growing degree day
GI	Germination index
gm	Gram
H_2O	Water
Ha	Hectare
kg	Kilogram
m	Meter
Max	Maximum
Min	Minimum
ml	Milliliter
ml/l	Milliliter/liter
mm	Millimeter
mRNA	Messenger ribonucleic acid

NPK………………	Nitrogen, phosphorus, potassium
PCR……………….	Polymerase chain reaction
PHS……………….	Pre-harvest sprouting
PP………………….	Precipitation
QTL………………..	Quantitative trait loci
RH………………….	Relative humidity
SAS.................	Statistical analysis system
SNP................	Single nucleotide polymorphism
SSR………………..	Simple sequence repeat
T....................	Temperature
WGP..............	Whole grain filling period
WTO………………	World trade organization

Literature Review

To fully understand pre-harvest sprouting (PHS) it is important to know the characteristic features of wheat grain and the process of seed germination. It is also essential to know what PHS really is and what impact it has on cereal grains. It is also necessary to understand how PHS arises, what factors could influence it and how it is assessed. Therefore, this review of literature presents a simple mechanism of seed germination, background information on PHS and seed dormancy, damages of PHS and mechanisms of PHS. It also focuses on the role of abscisic acid (ABA) as well as the influence of environment on PHS. Germination index (GI), dormancy index (DI) and falling number (FN), the major measurement methods for grain dormancy and grain damage or alpha amylase activity is also described. Finally, the genetics of dormancy and PHS is discussed.

Seed structure and mechanism of germination

The seed consists of a structure in which a fully developed embryo is dispersed, and ensures the appearance of next generation by allowing the embryo to survive the duration between seed maturation and seedling establishment. In general, the wheat seed contains three major parts: the seed coat, the endosperm and the embryo. The seed coat is made up of dead cells and is of considerable importance to the seed as it presents the barrier between the embryo and the outer environment (Bewley and Black, 1994). The fully developed endosperm contains the major reserves of both carbohydrate and protein and is surrounded by a layer of living aleurone cells. The aleuronic cells store protein in abundance (Koning, 1994). The cells of the starchy endosperm undergo desiccation and die at the end of the seed maturation, whereas the cells of the aleurone layer are tolerant to dessication and remain alive in a mature dry grain (Rigor, 2008). A wheat seed contains approximately 84% endosperm, 6.5 % aleurone, 4.5 % pericarp, 2.5 % seed coat and 2.5 % embryo (King, 1989).

Germination of a wheat grain begins with the uptake of water by the quiescent dry seed known as imbibition (figure 1)(Koning, 1994). Water enters the seed coat and starts softening the dry and hard tissue inside, and the grain swells up. The water entering the seed coat and the embryo dissolves the hormone called Gibberellic Acid (GA_3) produced in the embryo. The dissolved GA_3 is transported with water to the aleurone cells. The GA_3 turns on certain genes in the nuclear DNA of the aleuronic cells, which leads to the transcription of those genes. The mRNA thus produced is transported to the cytoplasm, where the ribosomes begin the process of making a protein known as amylase. The amylase protein is transported from the aleurone to the endosperm that leads to the hydrolysis of starch into sugar molecules. The released sugar is transported to the embryo where it is used as a fuel for the growth of the embryo leading to the emergence of the radical from the seed coat.

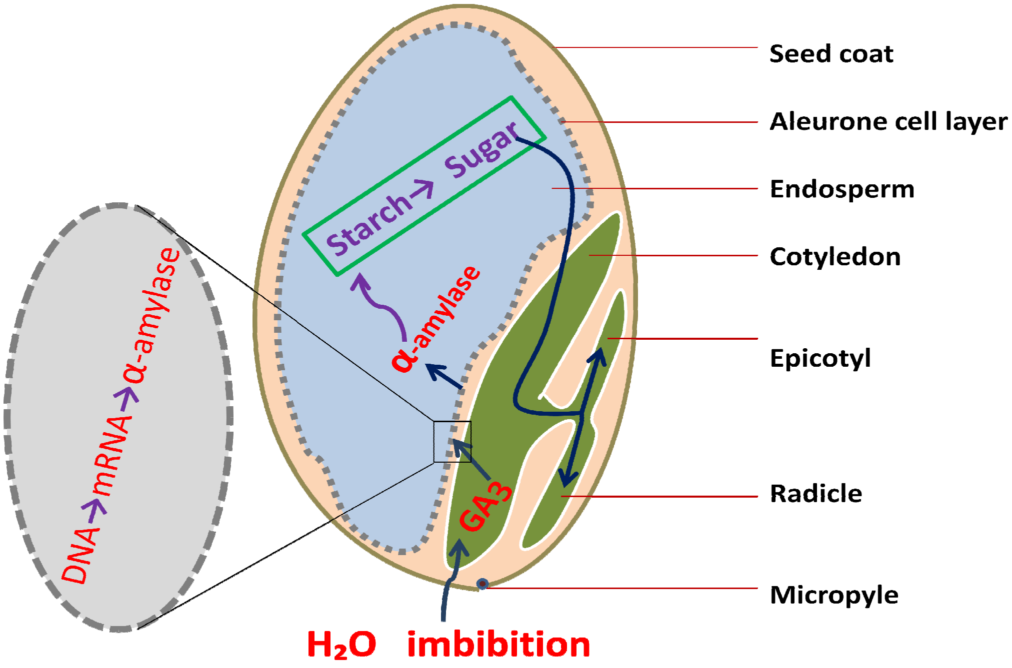


Figure 1. Germination mechanism in wheat. Adapted from Koning (1994).

Pre-harvest sprouting and dormancy

Pre-harvest sprouting is the pre-mature germination of kernels in the spike (photo 1) before harvesting (Thomason et al., 2009). It usually occurs when humid weather conditions persist excessively just before or during harvest (Imtiaz et al., 2008), and is mainly due to early breakage of seed dormancy (Groos et al., 2002).

Seed dormancy is defined as an inability of the viable seeds to germinate under conditions that are favorable for germination (Fofana et al., 2008). The lack of dormancy or early breakage of dormancy can induce PHS under wet conditions due to early hydrolysis of starch in the endosperm and germination of grains in the spike before harvest (Groos et al., 2002).

This reduced level of seed dormancy is a result of heavy selection against dormancy in order to attain uniform and immediate grain germination during domestication and breeding activities (for instance, malting process)(Harlan et al., 1973). Such selection pressure has led to the development of genotypes that are able to germinate even before harvesting (Gualano and Benech-Arnold, 2009). In such genotypes whose dormancy level of the grains from the physiological maturity to harvest is low, even a short exposure to rain may initiate embryo growth leading to pre-harvest germination (Gualano and Benech-Arnold, 2009).

Seed dormancy is an adaptative trait that is generally affected by environmental conditions such as moisture and temperature during seed development and after-ripening process of the seeds (Biddulph et al., 2008). As dormancy is an intrinsic characteristic of the seed, different cultivars may vary differently in their sprouting behavior according to the rate of loss of dormancy after physiological maturity (Gualano and Benech-Arnold, 2009).

Photo 1. Sprouting in spike (Keshab P. Dahal)

In general, dormancy can be classified into two types on the basis of cause of dormancy: coat-imposed dormancy and embryo dormancy (Bewley and Black, 1994). In coat-imposed dormancy, the dormancy is imposed by the seed coat and other enclosing tissues like endosperm, pericarp or extra-floral organs (Taiz and Zeiger, 2010), which imposes the blockage to germination (Bewley and Black, 1994). When the embryo of such coat-imposed dormant seeds is isolated, it germinates readily in the presence of water, but the intact seed remains dormant. Species that exhibit such coat-imposed dormancy include most cereals, conifers, and many dicots (Kermode, 2005). In embryo dormancy, the dormancy is intrinsic to the embryo and there is no influence of seed coat and other surrounding tissues (Taiz and Zeiger, 2010). In such dormancy, embryonic axis does not elongate even when the embryo is isolated and placed in water. Such type of dormancy is found in Rosaceae and some woody species and also in some grass species like wild oat (Kermode, 2005).

Dormancy can also be divided into primary dormancy and secondary dormancy on the basis of timing of onset of dormancy (figure 2)(Kermode, 2005). Primary dormancy is initiated during seed and embryo development and is normally related with the transient increase in ABA concentration during seed development (Hilhorst, 2007). Seeds undergo primary dormancy when they are dispersed from the mother plant in a dormant state (Bewley, 1997). Dormancy can also be induced in matured and already dispersed non-dormant seeds. This type of dormancy is known as secondary dormancy or induced dormancy (Kermode, 2005). Secondary dormancy is the type of dormancy that is imposed after seeds have lost primary dormancy. Secondary dormancy may be the result of prolonged inhibition of germination either due to endogenous ABA, secondary metabolites or unfavorable conditions for germination (Hilhorst, 2007)

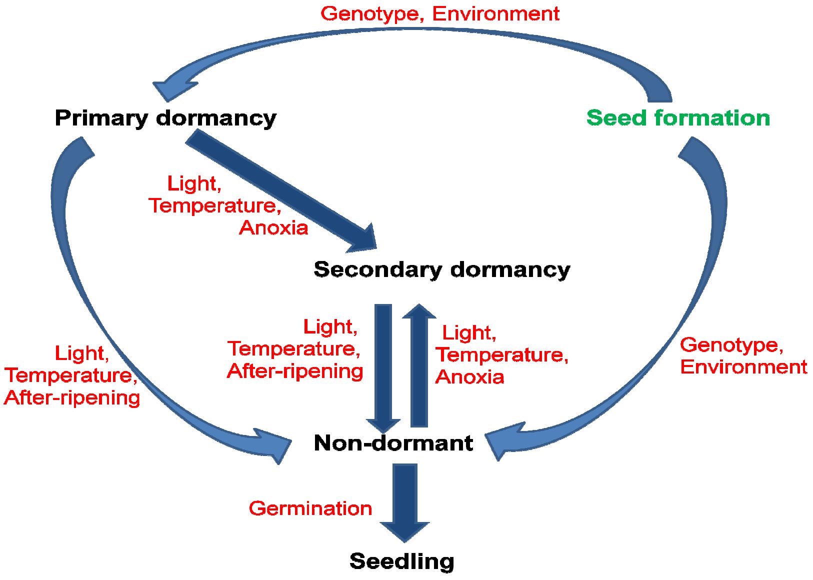


Figure 2. The induction of primary and secondary dormancy in seeds. Adapted from Kermode (2005).

Damage of PHS

Pre-harvest sprouting is known to incur a huge amount of financial losses to the cereal producers. It is recognized as one of the major factors affecting cereal production across the world by downgrading the bread-making quality of the grains particularly in the environment specified by high humidity and rainfall just before harvest (Imtiaz et al., 2008). It is manifested in various cereal crops like wheat, barley, rye, triticale (Gordon, 1970) and rice (Juliano and Chang, 1987), and is a serious problem for cereal growers throughout the world.

In wheat, PHS causes tremendous amount of damage by reducing yield and by decreasing milling and baking quality of the grains (Groos et al., 2002). In addition, it diminishes the processing quality of the grains as well as the grain nutritional quality (Imtiaz et al., 2008). Numerous studies have also shown the PHS related negative effect in the quality parameters of different end-products of wheat like: noodles, Arabic flat-breads (Edwards et al., 1989), breads, cookies, pies (Lorenz et al., 1983). In many wheat growing areas, it can cause a significant damage in some years resulting in 30-50 percent or even higher amount of severely damaged grains harvested during such year (Stoy, 1983).

The exposure of grains to humid conditions at ripening stage results in the initiation of a sequence of physiological processes. One such process is the release of hydrolytic enzymes known as alpha-amylase. The increase in amylase activity results in the breakdown of grain carbohydrate reserves. As a consequence, bread quality of wheat is affected causing sticky crumb and collapsed loaves (Imtiaz et al., 2008). Loaves with a sticky crumb creates problem during slicing and are usually unacceptable to the consumer (Moot and Every, 1990). Alpha-amylase activity has a direct effect on the quality of bread and pasta and adversely impacts the malting process (Perten, 2005).

Role of ABA

In the normal process of seed development, there is no germination usually until the embryo has fully completed the developmental process within a seed. If embryos that are not matured are excised from the seed and placed in water or culture medium, their normal developmental process is stopped and they germinate readily. However, when ABA is incorporated in the culture medium the premature germination is suppressed (Eisenberg and Mascarenhas, 1985).

ABA is of crucial importance due to its involvement in the possible inhibition of germination as well as prevention of precocious hydrolysis of starch reserves of the grains (King, 1976). A substantial amount of loss both in quality and quantity can occur as a result of the before-harvest germination of wheat. This pre-harvest sprouting damage is induced by starch breakdown, which is caused by alpha-amylase accompanied by damage of grain proteins by proteolysis (Simmons, 1987). ABA has been found to inhibit the activity of alpha-amylase as well as its synthesis by the suppression of GA3-enhanced alpha-amylase synthesis in the aleuronic cells (Ho and Varner, 1976; King, 1976).

It has been observed that ABA plays a significant role in the regulation of germination and embryonic maturation of seed (King, 1976). ABA is shown to have an inhibitory effect in the germination of an embryo of an immature wheat grain (Simmons, 1987). Similar results have been observed in other species like soybean (Eisenberg and Mascarenhas, 1985) and rape (Finkelstein et al., 1985). External application of ABA has shown to suppress the embryonic germination. It also stops the expression of germination-specific enzymes, and boosts the development of an embryo. In contrary, precocious germination has been seen in immature embryos of wheat in culture when ABA was absent (Simmons, 1987). ABA non-responsive or ABA deficient mutants in corn have been found to germinate precociously (Robichaud et al., 1980). Similarly, Arabidopsis mutants that are ABA deficient or non-responsive are prone to precocious germination and also have decreased seed dormancy (Karssen et al., 1983).

The amount of free ABA content is higher in developing seeds and, in general, is comparatively lower or non-detectable in matured seeds (Romagosa et al., 2001). As development proceeds, the amount of ABA content increases during the first half of seed development and decreases during the late maturity period with a concomitant decrease in seed water content (Hilhorst, 2007). ABA can be found in different parts of the seed, but its concentration is much higher in the embryo than in other parts of the seed. It may accumulate from both the production in the embryo and translocation from the mother plant via vascular supply in the seed coat. During the period of development, seeds tend to change their sensitivity to ABA. Generally ABA sensitivity is higher during the early stages of seed development (Rigor, 2008).

Influence of environment

The impact of environment on PHS is based on the effect it causes in dormancy behavior of seeds. Dormancy in wheat grains contributes resistance to sprouting, and is influenced by the environmental conditions experienced during seed development (Lunn et al., 2002). The level of dormancy in seed builds up during the later stages of grain filling and seed maturation and during this time the environmental factors interact with the dormancy. Strand (1989) showed that about 9.9-64.5% of non-genetic variation in seed dormancy is attributed to weather conditions 14 days prior to physiological maturity.

According to Mares (1993), two factors mainly temperature and rainfall during flowering to maturity have a major influence in the expression of seed dormancy. Whereas, Auld and Paulsen (2003), reported that the environmental effect during maturation is low compared to the effect following maturation and ripening. Generally, low temperature (10°C) at the time of seed development induces higher and sustained dormancy whereas low temperature during germination breaks dormancy of seeds harvested freshly (Reddy et al., 1985).

Thomason et al. (2009)(figure 3) reported that lower temperature during grain filling and maturity results in seeds with higher dormancy and less sprouting. Also, higher temperature in combination with drought stress produce seeds with higher level of sprouting tolerance.

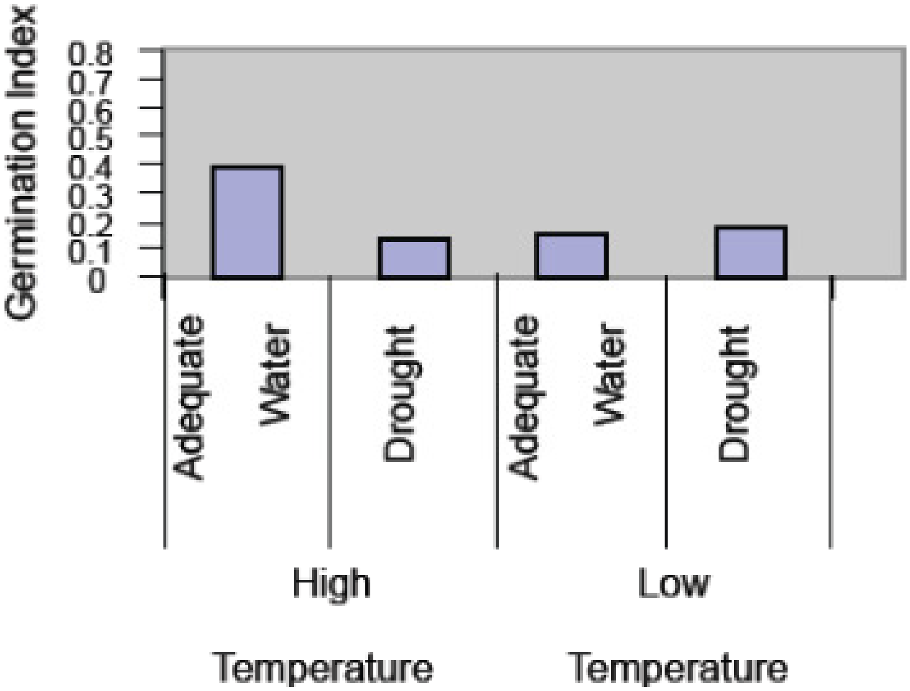


Figure 3. Wheat seed germination as influenced by moisture and temperature experienced during grain filling (Thomason et al., 2009).

Rainfall prior to harvest lowers the level of dormancy in the seeds. Mares (1993) showed that rainfall accounted for about 84% of the variation in falling number after a standard wetting treatment of 15 days in a trial where rain was allowed to wet the heads during seed maturity. He found that seeds that received more rain were less tolerant to sprouting. This could be explained in a way that rainfall during seed maturity reduces the drying rate of the seeds and results in higher amount of moisture content in the seeds (Lunn et al., 2002). Also, the more wet and dry cycles the seed receives, the more likely it is to end dormancy and sprout in the head (figure 4). As water must pass through the seed coat and move into the seed before it can germinate, multiple wetting and drying cycles makes it easier for more water to soak into the seed rapidly (Thomason et al., 2009).

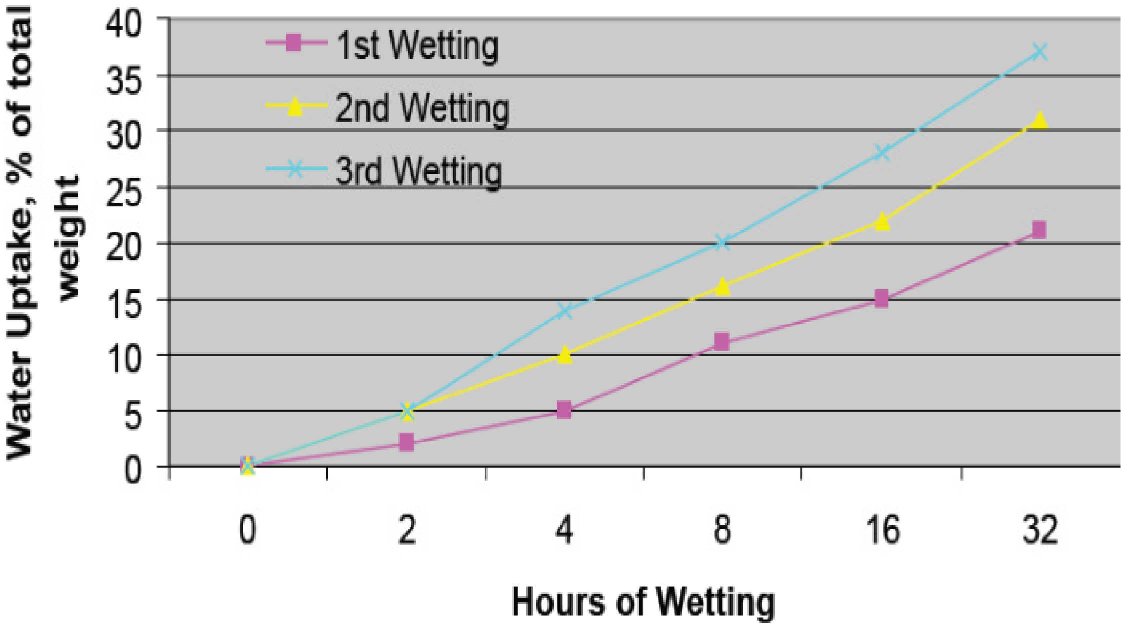


Figure 4. Effect of wetting and drying cycles on wheat seed water uptake (Thomason et al., 2009).

Germination index

Germination index is used to measure the dormancy of seeds. It is a weighted index that gives higher value to seeds that germinate early and less value to seeds that germinate later (equation 1)(Reddy et al., 1985). The maximum index is 1.0 if all the seeds germinated on day 1. Whereas, lower indices indicate the increasing level of seed dormancy or decreased germination ability (Simmons, 1987). As seed germination is inversely related to the degree of seed dormancy, germination index can predict the susceptibility of the genotypes to pre-harvest sprouting (Nyachiro et al., 2002). Moreover, GI is appropriate because it can measure sprouting susceptibility after 100% germination is reached (Hagemann and Ciha, 1984). Therefore, measuring dormancy by GI is one of the main processes used by plant breeders and plant physiologists in an effort to improve pre-harvest sprouting tolerance in cereals (Biddulph et al., 2008).

$$GI = \frac{d\,X\,n_1 + (d-1)X\,n_2 + (d-2)X\,n_3 + 1\,X\,n_L}{dN}$$ Equation 1

Where,

GI= Germination Index

d=total number of days the seeds are counted for

$n_1, n_2, n_3 and\ n_L$ = number of seeds germinated on day 1, day 2, day 3 and day last

N=total number of seeds germinated/line

Dormancy index

Dormancy index (DI) is the method that is based on percent dormancy at two temperatures (equation 2). Seeds of all the genotypes to be tested are harvested at same day degrees after yellow ripeness and germinated at 10°C and 20°C. It is the common method for screening PHS in spring wheat breeding in Norway (Lillemo and Dieseth, 2011).

$$DI = \frac{(\%\ dormant\ seed\ at\ 10°C\ X\ 2) + (\%\ dormant\ seed\ at\ 20°C)}{3} \qquad \text{Equation 2}$$

Falling number

The Falling Number is the standard and accepted method in cereal industry worldwide, and is recognized as an established trading parameter for detecting damages caused by sprouting in flour and meal of wheat, barley and other grains as well as malted cereals (Perten, 2005). The falling number method uses flour as a substrate to determine the damage of pre-harvest sprouting by measuring the activity of alpha amylase. This method is based on a quick gelatinization of flour suspension in a boiling water-bath and subsequent measurement of starch degradation by alpha amylase under condition that is similar to those found during baking (Perten, 1964). The falling number method has been tested by the International Association of cereal chemists (AACC) and approved of being applicable to both meal and flour of small grains and malted cereals (AACC 56-81.03).

The falling number values ranges from 60 to 400 seconds or higher. Wheat flour with high alpha amylase activity (flour from the sprout-damaged grains) results in low falling number values, whereas the flour with low alpha amylase activity will have higher falling number values (Hagberg, 1961).

A certain quantity of alpha-amylase is essential for achieving a good quality of baking. The alpha-amylase in flour breaks down starch to provide sugars that fuels the fermentation process (Smith et al., 2006). The amount of alpha-amylase present in the flour can have a direct effect on the bread quality that will be produced. If the activity of alpha-amylase is optimal, the bread produced will be firm and with high volume and soft texture (FN = 250 in photo). But, if the activity of alpha-amylase is excessive, a bread with low volume and sticky crumb may result (FN = 62 in photo). And, if the activity is very low, a bread with small volume and dry crumb may result (FN = 400 in photo) (Perten, 2005). The FN value is inversely proportional to the alpha-amylase activity (Best and Muller, 1991), meaning that the higher the activity of alpha-amylase the lower the value of FN, and vice-versa.

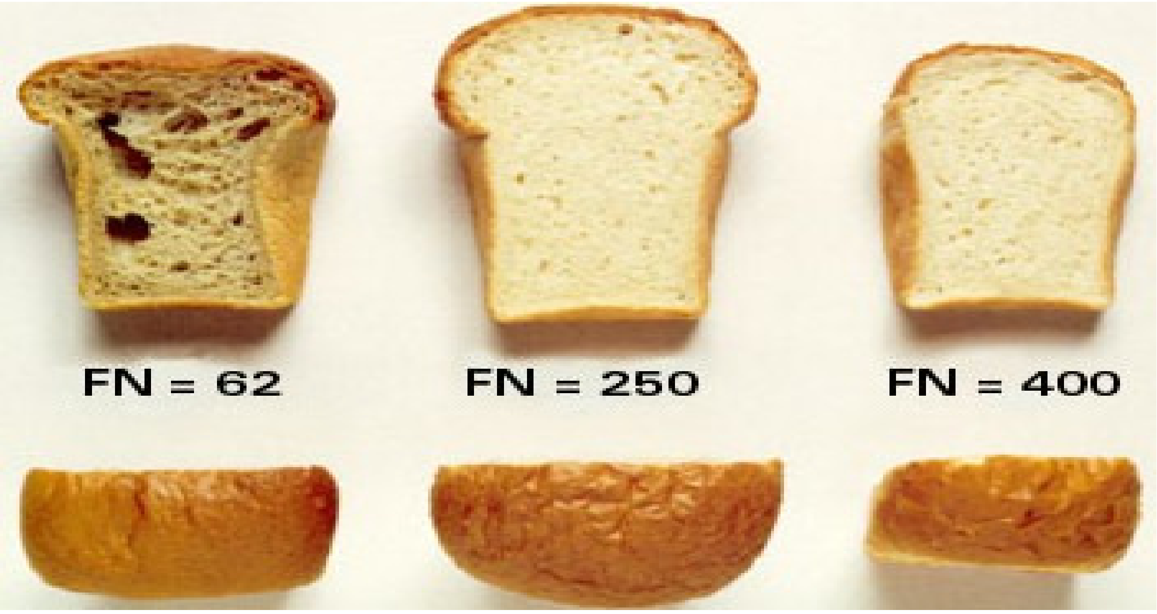


Photo 2. Breads with different falling numbers (Perten, 2005).

Genetics of PHS

Historically, resistance of wheat to PHS has been affirmed on the ability of the seeds to resist sprouting under environmental conditions that are favorable for the induction of germination (Bassoi and Flintham, 2005; Gubler et al., 2005; Morris et al., 1989; Strand, 1990). This dormancy based character of PHS has a wide genetic variation (Simmons, 1987), which is influenced by a combination of factors mainly climatic conditions during after-ripening stage of the seeds (Strand, 1990).

Pre-harvest sprouting susceptibility is mainly determined by the genotype. A wide variability exists in the susceptibility of wheat to PHS and seed dormancy (Reddy et al., 1985). Grains from a mature plant of a sprouting susceptible wheat cultivar will germinate readily when placed in water, whereas grains from the mature sprouting resistant wheat cultivar will not germinate easily. Similar cultivar variations with respect to sensitivity to PHS can also be found in the field in an intact wheat spike even under conducive environmental conditions (Simmons, 1987).

Generally, red-grained wheat has been reported to be more resistant to sprouting than white-grained wheat, and it is also well documented that red kernel color in wheat has a complete association with longer seed dormancy and/or PHS resistance in wheat (Gfeller and Svejda, 1960). Although huge variation can be found in both red-grained and white-grained wheat, red grain colour has often been viewed as a traditional marker for selecting PHS resistant wheat in many breeding programs (Imtiaz et al., 2008). Nevertheless, various studies have also reported the PHS resistance in white-color common wheat as well as amber durum wheat cultivars having resistance comparable to red color wheat (Anderson et al., 1993; Clarke et al., 1994; Mares and Ellison, 1990), indicating that there are several other genes for seed dormancy besides those linked to kernel color.

Nilsson-Ehle (1909) was the first person who postulated the presence of three independent allelomorphs for the red colour in the pericarp and their association with grain dormancy, which is confirmed by numerous succeeding studies (Bassoi and Flintham, 2005; Gfeller and Svejda, 1960; Miyamoto and Everson, 1958).

Dormancy of wheat grains is a polygenic trait influenced by a pleiotropic effect of *R* (red grain colour) genes that confer red colour to the pericarp as well as by other genes such as Phs, which has a major effect in the embryo (Bassoi and Flintham, 2005). Dominant alleles of *R* genes (1 each on chromosomes 3A, 3B, and 3D) promote the biogenesis of phlobaphenes, a pigment that is reddish brown in colour (Miyamoto and Everson, 1958). According to Stoy and Sundin (1976), the water soluble precursors of the red pigment phlobaphene in wheat grains, catechins and catechins-tannins, might inhibit germination of embryo. Red colour of a pericarp as well as increased seed dormancy is inherited as a pleiotropic effect of the dominant R alleles, which is known to be located at the homeologus loci on the end region of the long arms of chromosome 3A, 3B and 3D of the hexaploid wheat (Himi and Noda, 2005).

Assessment of dormancy is based primarily on classical methods of breeding. Crossing with dormant cultivars and phenotyping by calculating germination index (GI), sprouting index (SI), and dormancy index (DI) and falling number (FN) is the routine practice. Lately, use of molecular markers has made it easier to investigate the genetic basis of dormancy and PHS in cereals, including wheat. As a result, QTL mapping of wheat for the PHS resistance has been carried out extensively in the major wheat producing areas of the world. Presently, PHS resistance or dormancy genes or QTLs have been identified in all the 21 chromosomes of the 3 genomes of the common wheat (Anderson et al., 1993; Imtiaz et al., 2008; Kumar et al., 2009). However, chromosomes 3A, 3B, 3D and 4A (table 1) are considered more important for the genetic control of PHS tolerance and dormancy (Kulwal et al., 2005). Recently, a study by Ren et al. (2012) using transgenic approaches found that down-regulation of thioredoxin gene (Trx h9) in wheat resulted in a reduction in the occurrence of pre-harvest sprouting. Similarly, gene expression study (Nakamura et al., 2011) using micro-array analysis has shown that wheat homolog of MOTHER OF FT AND TFL1 (MFT) was up-regulated after physiological maturity in dormant seeds grown at lower temperature. The study also identified a single nucleotide polymorphism (SNP) in the promoter region of the gene that differentiated dormant and non-dormant lines. Based on this polymorphism, a CAPs marker has been developed that can be used for breeding.

Table 1. Markers used in this study.

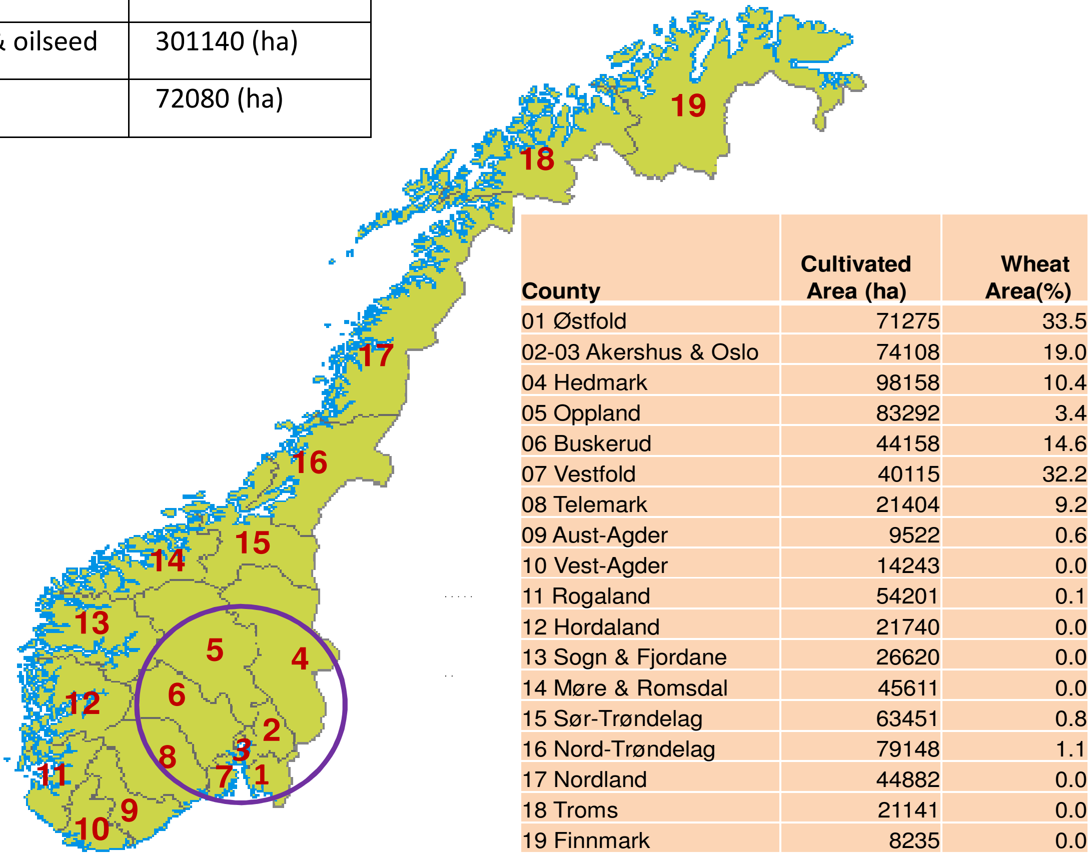
Chromosome	**Marker**	**Reference**
3A	vp-1a3	(Osa et al., 2003)
3A	wmc153	(Mohan et al., 2009)
3A	gwm155	(Mohan et al., 2009)
3A	cfa2193	(Fofana et al., 2009)
3A	wmc559	(Fofana et al., 2009)
3B	wmc307	(Fofana et al., 2008)
3B	gwm938	(Kumar et al., 2009)
3B	gwm285	(Mares et al., 2009)
3B	gwm802	(Kumar et al., 2009)
3B	vp1-b2	(Chang et al., 2010)
3B	gwm66	(Somers et al., 2004)
3D	gwm3	(Ogbonnaya et al., 2007)
3D	barc125	(Munkvold et al., 2009)
3D	wmc552	(Fofana et al., 2008)
3D	gpw4152	(Munkvold et al., 2009)
4A	barc170	(Mares et al., 2005; Torada et al., 2005)
4A	duPw4	(Singh, 2008)
4A	wmc650	(Singh, 2008)
4A	gwm937	(Ogbonnaya et al., 2008)
4A	BE426203	(Singh, 2008)
4A	gwm894	(Ogbonnaya et al., 2007)
4A	hbe3	(Torada et al., 2008)
4A	cd920298	(Singh, 2008)
4A	gwm637	(Ogbonnaya et al., 2007)
4A	wmc513	(Somers et al., 2004)

Thesis Goals

Norway is a relatively long and narrow country situated in the western Scandinavia, stretching along the Atlantic from 58° N to 71° N (Arnoldussen, 1999). The total arable land in Norway accounts for only 3 % of the total land area (table 2), while remaining 97 % of land is covered by mountains, forests, lakes and wetlands (Statistics Norway, 2010). In 2010, out of 1 million ha of arable land only 72080 ha was used for wheat production (Statistics Norway, 2010). The total wheat production in 2010 was 331,000 tons with an average of 4.6 ton/ha, while yields of up to 6 tons has been recorded during the good years (Statistics Norway, 2010). The major wheat producing area is situated in the south-eastern part of the country (figure 5).

Table 2. Land area and use in Norway in 2010 (Statistics Norway, 2010).

Total Land cover	323787 km²
Arable	1003010 (ha)
Grain & oilseed	301140 (ha)
Wheat	72080 (ha)



County	Cultivated Area (ha)	Wheat Area(%)
01 Østfold	71275	33.5
02-03 Akershus & Oslo	74108	19.0
04 Hedmark	98158	10.4
05 Oppland	83292	3.4
06 Buskerud	44158	14.6
07 Vestfold	40115	32.2
08 Telemark	21404	9.2
09 Aust-Agder	9522	0.6
10 Vest-Agder	14243	0.0
11 Rogaland	54201	0.1
12 Hordaland	21740	0.0
13 Sogn & Fjordane	26620	0.0
14 Møre & Romsdal	45611	0.0
15 Sør-Trøndelag	63451	0.8
16 Nord-Trøndelag	79148	1.1
17 Nordland	44882	0.0
18 Troms	21141	0.0
19 Finnmark	8235	0.0

Figure 5. Distribution of wheat cultivation area in Norway in 2010. Main wheat producing areas are indicated by a circle (Statistics Norway, 2010). Wheat area (%) is the percent of total cultivable area in the county.

During 1950s, the introduction of combined harvester created new challenges for the cultivation of wheat in Norway. In order to be harvested by combined harvester, it was necessary that wheat is dried to an acceptable moisture level in the field. But, due to prolonged rains this often created problems to the farmers. As wheat cultivars were susceptible to sprouting, most of the farmers opted for barley instead of wheat. This nearly led to the extinction of wheat cultivation in Norway. Special attention to improve the resistance to pre-harvest sprouting began and a detailed investigation was done to improve seed dormancy, which led to the development of seed dormancy index (Lillemo and Dieseth, 2011).

During 1970s, the release of two landmark varieties Runar and Reno identified spring wheat cultivation as a competitive option for the farmers. These varieties combined a powdery mildew resistance gene from German breeding line ELS with higher yields and sprouting and lodging resistance. These varieties dominated spring wheat cultivation in Norway for more than two decades and triggered the unprecedented increase in wheat acreage that has continued till today.

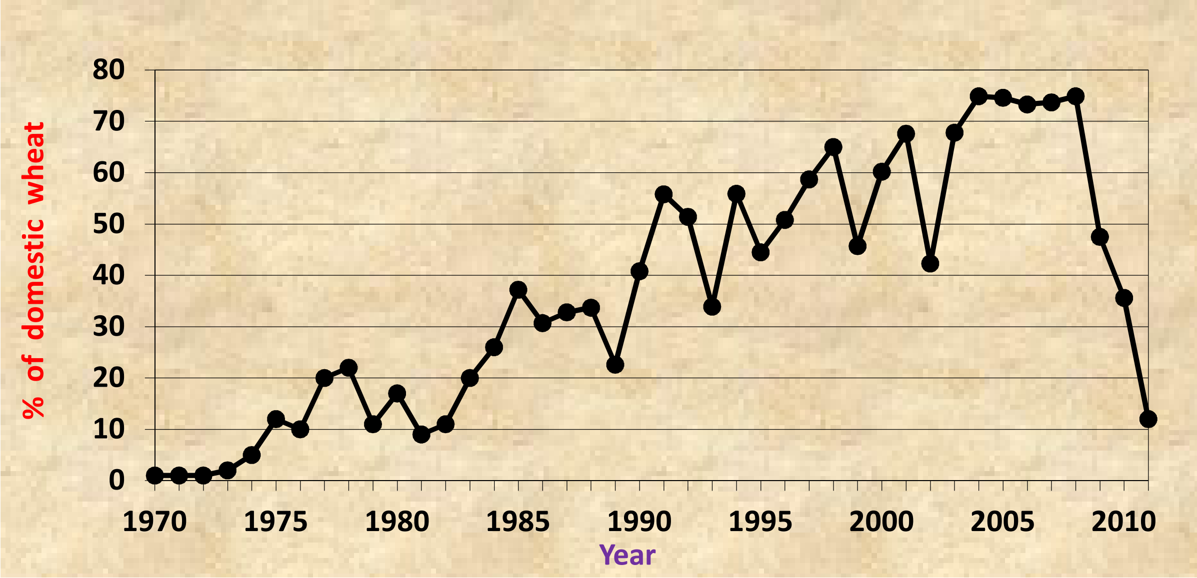


Figure 6. Percentage of domestic wheat in the Norwegian wheat flour (Statistics Norway, 2011).

There has been a tremendous increase in domestic wheat production in the last few decades, which has led to the increased proportion of home grown wheat in the flour blend (figure 6) (Statistics Norway, 2011). This drastic increment in production is due to the strong political will of protecting the domestic cereal production. This is also manifested by the unchanged Norwegian agricultural policy even after its integration with European Economic Area (EEA) as well as having an agreement with the World Trade Organization (WTO). Additionally, the higher price of wheat in the international market as well as prolonged instability of global wheat market also necessitates the increase in domestic production for the self-sufficiency of wheat as a food and feed in the future.

However, the growing conditions in Norway are variable, and so are yields. During the last 3 years (2009, 2010, 2011), there has been a considerable reduction in domestic wheat share in the flour due to downgrading in quality of wheat from food to feed (figure 6). Due to the unstable autumn weather with frequent rainfall, quality damage due to pre-harvest sprouting is common. To prevent this, wheat is often harvested with relatively high water content, sometimes as high as 30 % in order to avoid price reduction due to loss in quality. Harvesting is generally done around mid-august to mid-September and this is the time when the amount of precipitation is highest in Norwegian conditions (table 5). In some years (figure 6), this causes a serious problem resulting in the reduction in grading quality of wheat from food to feed because of pre-harvest sprouting. Due to the effect of climate changes in Norway, the pre-harvest sprouting induced yield reduction and quality deterioration of wheat is likely to be more severe in the future. Thus, use of PHS resistant cultivars is sought for avoiding the losses in wheat quality and yield due to heavy rainfall.

Enormous effort has been made in breeding programs to integrate a moderate amount of seed dormancy in commercial varieties in order to prevent losses due to PHS. However, success in this respect has been restricted due to the lack of appropriate genetic resources with adequate PHS resistance as well as efficient selection techniques. Identification of appropriate method that gives quick, reliable and repeatable phenotyping results under natural conditions would be of great importance in PHS assessment.

Therefore, the main objective of this study was (i) to compare different methods used for assessing PHS in wheat and (ii) to identify markers associated with PHS in Norwegian wheat cultivars.

Materials and Methods

Plant material

A total of 159 spring wheat cultivars were used for PHS assessment. Fourteen wheat lines were the candidate cultivars from official variety testing program, 46 breeding lines and 99 wheat lines were from a special collection of lines called “Masbasis”. Masbasis consists of wheat varieties that are of high importance either as an important source for disease resistance, important cultivars in terms of quality or used as crossing parents in breeding programs.

For marker analysis a total of 192 wheat cultivars were used. 162 cultivars were from the masbasis and 30 reference cultivars for PHS resistance. Further details of the genotypes are given in appendix 1.

Field experiments and harvesting

The wheat lines were sown on 12.05.2010 in Vollebekk, Aas, Norway. Each line was planted in a 4-row field plot. Each plot size was of 0.75 m x 6 m with 50 cm of distance between the plots and 15 cm of space between the rows. The rate of Seeding was 80 gm per plot. Fertilization was done with 12 kg N/daa in NPK fertilizer 22-3-10 (Yara). Herbicide treatment was done as normally practiced (Areane at Zadoks 13-15). The trial was not randomized and only 10 lines were replicated.

Harvesting was done after physiological maturity in August, 2010. The date of Physiological maturity was determined on the basis of yellow ripeness of the plant. A plot was deemed as physiologically matured when 50 % of the plants in that plot lost green colour of the spike and the peduncle. At this stage, small samples of spikes were harvested, threshed and dried in oven at 130 ° C overnight. Moisture content was calculated, and the date approaching 38 % moisture content (as defined for yellow ripening) was recorded. For some plots, the grain moisture content was predicted to contain 38% moisture content based on experience and weather (temperature). The plots having below 38% moisture content was considered physiologically mature.

Dates for yellow ripeness based on moisture content was used to determine the harvesting times. Correct harvesting dates was determined based on the daily mean temperatures after yellow ripeness. Harvesting of wheat samples was done twice. First harvest was done at 150 growing day degree (GDD) after yellow ripeness and second harvest was done at 450 GDD after yellow ripeness. 150 GDD and 450 GDD after yellow ripeness was calculated by

$$GDD = \sum_{i=1}^{24} \frac{T_i}{24} + \sum_{j=1}^{n} D_j$$ Equation 3

Where,

GDD=Growing degree days

T=air temperature

i=hour

D_j=number of days

Assessment of pre-harvest sprouting

Germination index (GI), falling number (FN), dormancy index (DI) and weather information were used to assess the pre-harvest sprouting of wheat lines.

Germination index

For GI, approximately 15 spikes were harvested at yellow ripeness by cutting with a scissors approximately 10 cm below the base of the spike. Spikes were dried for approximately 24 hours in a drying chamber to get the moisture content of 12 %. The dried spikes were kept in a plastic bag (photo 3) and then placed in a freezer below -20°C in order to preserve dormancy until all the samples were ready for germination tests.

Photo 3. Harvested spikes kept inside a plastic bag (Keshab P. Dahal).

A trial experiment was conducted at 3 different temperatures of 12°C, 16°C and 20°C in order to find the germination temperature when germination was optimally expressed. Four wheat cultivars (Saar, Bjarne, Zebra and Avle) with varying level of dormancy index were chosen for the trial germination test that was done on 25.11.2010. A liter of mixture solution was prepared with 4ml/L of fungicide named Proline (active ingredient prothioconazole). Proline was used with an intention to get rid of seed borne diseases, if any. Three spikes from each of the four cultivars were removed from the freezer and threshed carefully with a hand thresher in order to prevent damage to the seeds. 20 seeds from each cultivar were placed in the Petri-dish having 9 cm diameters with a single layer of 70 mm filter paper and 5 ml of mixture solution. Three Petri-dishes with 20 seeds each was prepared for each cultivar with a total of 12 Petri-dishes. One Petri-dish from each cultivar was taken and kept in an incubator (Termaks, type KBP2324) at 12°C, 16°C and 20°C with a total of 4 Petri-dishes for each temperature. Samples were checked every day at the same time. Almost 20 days passed from the start of the germination experiment (25.11.2010) and no seeds were germinated. The same experiment was repeated again without adding proline, and only using distilled water. The samples were checked every day and the seeds were germinated. Based on this trial experiment, 20°C was chosen as an appropriate temperature for the final germination experiment as it showed more variation in seed germination compared to 12°C and 16°C. Also, it was deemed that addition of Proline might have negative effect in the germination of the seeds and so it was excluded from further experiments.

Photo 4. Germinated seeds in petri dish (Keshab P. Dahal)

Photo 5. Discarded germinated seeds (Keshab P. Dahal)

At the time of final germination experiment, 7 spikes were taken and carefully threshed with a hand thresher (photo 6) in order to prevent damage to the seeds. Each cultivar was replicated in two Petri-dishes with 25 healthy kernels per Petri-dish of each cultivar with a single layer of filter paper and 5 ml of distilled water. The Petri-dishes were placed in a plastic box with a cover (photo 7) and the plastic box was placed in an incubator at 20°C (photo 8). A total of 4 plastic boxes were used. Germinated seeds (photo 4) were counted daily at the same time and discarded (photo 5). GI was calculated according to equation (1) described by Reddy et al (1985).

Photo 6. Hand threshing of wheat spikes (Keshab P. Dahal)

Photo 7. Petri dish with seeds in a box (Keshab P. Dahal)

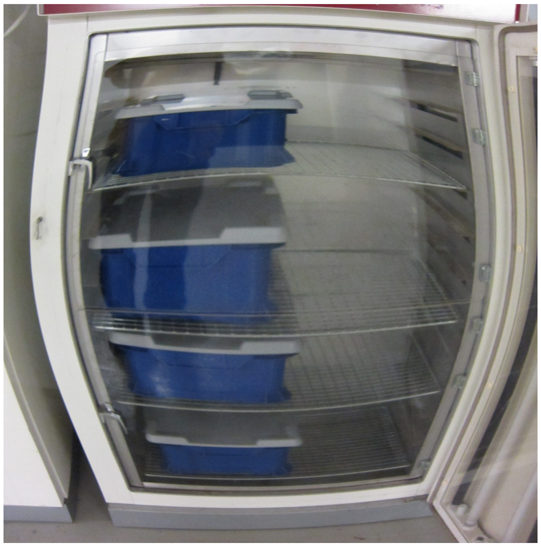


Photo 8. Box in an incubator (Keshab P. Dahal)

Falling number

Hageberg falling number measurement was conducted on the grain samples that were harvested at 450 GDD after yellow ripeness. A sample of approximately 0.5 m^2 was cut by a scissor about 10 cm below the base of the spike. Threshing was done by a mechanical thresher. Seeds were kept in a paper bag and stored at room temperature for about 60 days. All the grains were used for the milling. Milling was done by Perten 3100 falling number mill (Perten Instruments AB, Huddinge, Sweden). The moisture content of the whole meal flour was analysed by oven dry method. About 2 to 3 gm of whole meal flour was placed in a moisture dish and heated in an oven (Termaks, type: T1056) at 105°C overnight. The samples were left to cool in a desiccator for 1 hour and the residue was weighed (Mettler Toledo, type: new classic MF). Moisture content was determined by the difference between the weight of the sample before and after heating in percent of raw weight. The amount of weight loss due to heating is the moisture content of the sample, which is expressed as percent moisture content. To analyse the falling number, 25 ml distilled water and 7 gm of flour adjusted for 15 % moisture content was used by using equation 3.

$$F = \frac{595}{100-X} \qquad \text{Equation 4}$$

Where,

F=flour, in gm

X=moisture content of the flour.

Falling number analysis was performed according to AACC 56-81.03 (AACC International, 1999) by Perten 1700 falling number instrument (Perten Instruments). Two test tubes per sample were run and the mean values were calculated per sample. A sample that gave the difference of more than 20 second in a run was repeated again.

Dormancy index

A sample of approximately 0.5 m^2 was harvested by sickle at 150 GDD and 450 GDD and threshed. Fresh grain samples were immediately sent to the seed testing laboratory (Kimen Såvarelaboratoriet AS - Pb 164, 1431 ÅS) for germination test. Germination test was carried out by Kimen at 10°C and 20°C for each harvest at 150 GDD and 450 GDD. Dormancy Index was calculated using equation (2) according to Strand (1989).

Climatic data

Meteorological information about mean temperature, minimum temperature, maximum temperature, precipitation and relative humidity was collected for the whole grain filling period (i.e. heading to maturity), 7 to 0 days before maturity, 14 to 8 days before maturity, and 21 to 15 days before maturity from the website http://www.vips-landbruk.no/. Also, the climatic data about growing season in Aas was generated using the same website.

Microsatellite markers and genotyping

A total of 192 wheat lines were genotyped. The amount of DNA and reaction mixture used is shown in table (3). A total of 25 microsatellite markers were used in the study that were selected from chromosomes 3A, 3B, 3D and 4A (figure 7). The products from PCR were run in an automated ABI 3700 DNA analyzer (Applied Biosystems). The results were analyzed with Genemapper 4.0 software (Applied Biosystems) for the detection of the different amplification peaks and allelic size in base pairs for each microsatellite markers.

Table 3. The amount of DNA and reaction mixture.

Reaction mix	**Volume (µl)**
H_2O	5.27
10 x PCR buffer	1.00
dNTP	0.20
Forward and reverse primer	0.50
Fluorescence M13 primer	0.45
Taq polymerase	0.08
DNA template	2.50
Total	10

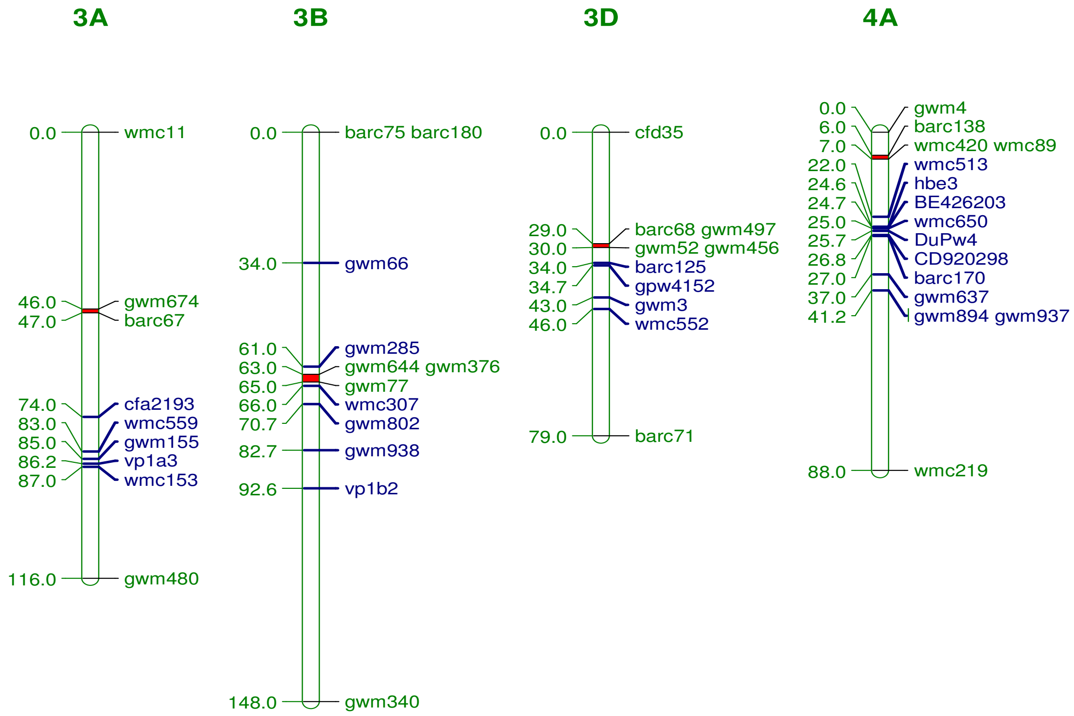


Figure 7. Genetic map showing the relative position of SSR markers.

Statistical analysis

Phenotypic data were analyzed by using SAS 9.1 (SAS Institute Inc., Raleigh, North Carolina). For GI a two way analysis of variance was performed using a PROC GLM model. The effects of wheat lines were fixed and experiment as well as box nested in experiment was random. Descriptive statistics were calculated for the replicated field plot data by using SAS procedure proc MEANS. Pearson correlation coefficient between germination index (GI), dormancy index (DI), falling number (FN), and climatic parameters were calculated using SAS procedure PROC CORR. Pearson correlation coefficients were considered significant when the probability was significant at P-value (≤0.05). Graphs were produced by Minitab and Excel. Also, a one way analysis of variance was performed for each marker. The test was considered significant at P- Value (≤0.05). Linkage map was drawn by using mapchart 2.1 (Voorrips, 2002). A linkage map was constructed to show the relative position of the markers in the wheat consensus map derived from Somers et al. (2004). The markers in blue indicate the markers those were used in this study.

Results

Plant development and climatic condition

Grain filling and maturity (yellow ripeness) was followed from July to late August in 2010. A high variation in rainfall was found in Ås, Norway during this period (figure 8) with highest rainfall of 126.8 mm in the month of August (table 5), which is the time for harvesting. Also, a wide fluctuation in daily temperature was seen ranging from as low as 5 °C to above 20 °C (figure 8), whereas mean daily temperature was around 16°C throughout the grain filling to maturity period (table 4). A wide variation in percent RH was observed ranging from as low as 55 % to over 90 % (figure 8).

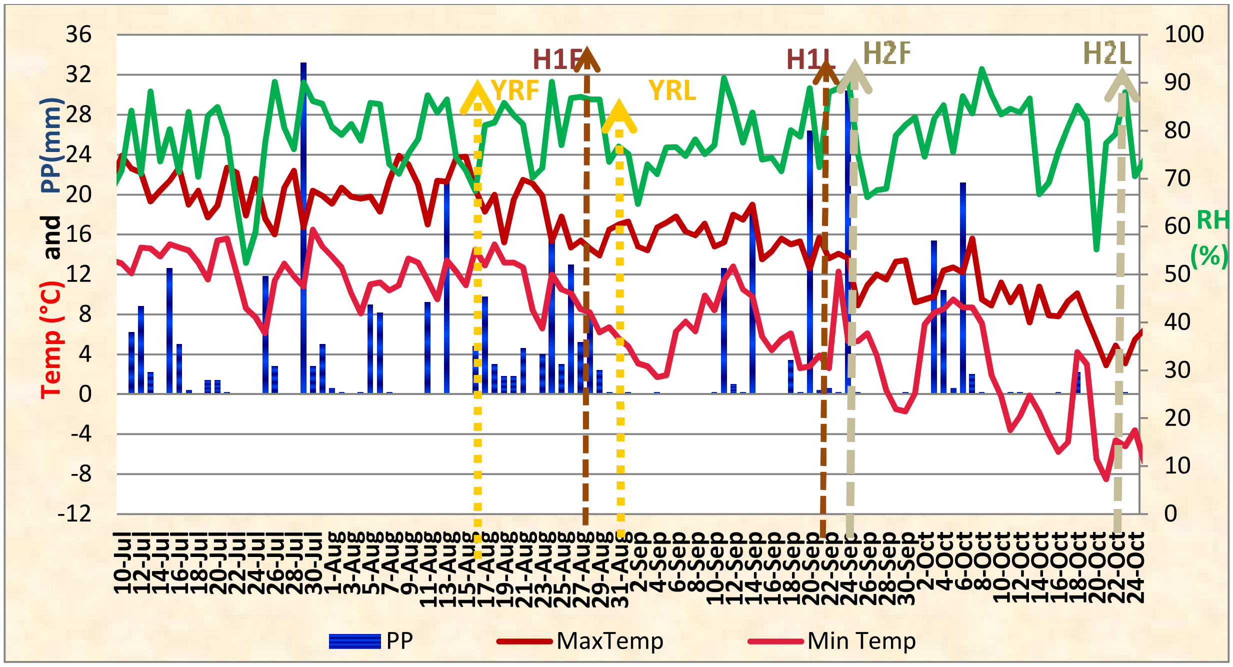


Figure 8. Weather condition from grain filling to 2^{nd} harvest in Aas in 2010 (vips-landbruk.no). YRF (Yellow ripening first day), YRL (yellow ripening last day), H1F (First harvest first day), H1L (First harvest last day), H2F (Second harvest first day), H2L (Second harvest last day).

Average maximum temperature, average minimum temperature, mean temperature, average total precipitation and percent relative humidity was determined for whole grain filling period and 0-7 days, 8-14 days and 15-21 days before maturity to get an overview of plant growing conditions (table 4). There was not much variation in temperature and percent relative humidity, but a high difference in precipitation occurred ranging from 37 mm during 0-7 days before maturity and 25 mm during 15-21 days before maturity.

Table **4. Climatic data recorded in Ås, Norway in growing period 2010 (vips-landbruk.no). Data in bold indicate the mean values for all lines in the experiment and data in parenthesis indicate minimum and maximum values.**

Climate	Whole Grain filling period	0-7 Days before maturity	8-14 Days before maturity	15-21 Days before maturity
Tmax (°C)	**20.1** (19.4, 20.5)	**18.9** (15.4, 21.2)	**20.8** (18.9, 21.6)	**20.4** (19.4, 21.6)
Tmin (°C)	**12.2** (11.5, 12.4)	**11.7** (7.9, 13.2)	**12.0** (10.7, 13.2)	**11.5** (10.6, 13.3)
Tmean (°C)	**16.1**(14.7, 16.5)	**15.3** (11.5, 16.9)	**16.4** (15.2, 17.0)	**16.0** (15.5, 17.0)
PP (mm)	**182** (145.6, 226.6)	**37.3** (25.8, 53.8)	**28.5** (17.6, 45.4)	**25.0** (17.6, 45.4)
RH (%)	**78.4** (77.9, 79.2)	**79.6** (77.9, 83.9)	**79.2** (77.9, 80.7)	**80.2** (78.1, 83.0)

Growing season

Mean temperature and total rainfall from 2004 to 2010 (table 5) were compared to get an idea of the growing season in 2010. There was not much variation in mean temperature in the experiment year of 2010 and previous years, but rainfall in 2010 was higher than 2004, 2005, and 2006, which are good years with regards to wheat production in Norway (figure 6).

Table **5. Mean temperature (MT) (°C) and total Precipitation (PP) (mm) in different years in Aas (vips-landbruk.no).**

	2004		2005		2006		2007		2008		2009		2010	
Month	**MT**	**PP**	**MT**	**PP**	**MT**	**PP**	**MT**	**PP**	**MT**	**PP**	**MT**	**PP**	**MT**	**PP**
May	11.7	37.2	8.9	72.4	10.8	92.0	9.5	82.2	11.0	30.0	10.9	56.0	9.6	96.2
June	13.4	110.0	13.6	62.4	14.7	64.4	15.5	136.0	14.8	78.2	14.5	29.6	13.9	66.4
July	14.8	56.0	17.5	87.4	18.6	48.4	14.5	152	16.9	122.6	16.2	159.4	16.6	104.8
Aug	16.6	101.2	15.0	70.8	16.4	95.6	14.7	77.0	14.4	186.2	15.3	160.2	15.0	126.8
Sep	11.7	98.2	12.0	48.6	13.7	121.6	10.0	76.8	10.1	59.6	12.0	28.2	10.2	94.6
Oct	6.0	0.0	6.7	0.0	7.3	0.0	5.4	33.2	6.7	160.6	3.3	55.8	4.9	83.0

Table (6) shows the historical data of average dormancy index of selected cultivars and the 2010 dormancy index data for those cultivars. The result depicts a relatively lower dormancy index for the 2010 compared to the historical averages. It seems that the year 2010 was not a normal growing season.

Table 6. Comparision of dormancy index of historical averages and 2010.

Cultivar	DI_1 (Historical)	DI_ 2 (Historical)	Number of years	DI_1 (2010)	DI_2 (2010)
Berserk	12.4	9.6	10	10.6	7.6
Demonstrant	14.3	12.0	8	8.5	8.8
Tjalve	7.5	5.1	5	7.0	-
Avle	12.6	9.8	13	13.6	-
Bjarne	15.8	7.5	14	4.1	5.0
Zebra	13.3	11.7	16	19.6	18.8
Bastian	14.2	7.4	18	12.0	2.1
Runar	10.8	2.6	4	0.6	0.0
Brakar	11.0	5.8	8	4.6	0.0
Vinjett	11.5	13.9	9	1.6	6.3

Analysis of variance for GI

Analysis of variance (ANOVA) was conducted for experiment 1 and experiment 2 separately. Experiment 1 is the germination experiment conducted on day 1 and experiment 2 is the germination experiment conducted on day 2. The cultivars for both the experiment were randomized by Edgar. Both the experiments included seven cultivars as checks that were common. Analysis of variance was done separately for both the experiments, which produced no significant effect of box and replication. A new ANOVA was performed by combining both the experiments and nesting the box effect within the experiment. Table (7) shows the ANOVA on germination data for 43 days of germination tests. The result showed significant line effects (P<0.0001) that explained 86 % of variance.

Table 7. Analysis of variance for GI.

Source	DF	Mean Square	F-Value	Pr > F	Variance (%)
Line	158	0.02420549	11.89	<0.0001	86.29
Experiment	1	0.00008714	0.04	0.8363	0.31
Box(Experiment)	6	0.00172255	0.85	0.5359	6.14
Error	172	0.00203536			
Total	337				

Descriptive statistics

Table (8) shows the descriptive statistics of different PHS indices and the lines that had the best and the worst result. GI index had a lowest coefficient of variation. Frontana (Mhazy) was a best line in terms of GI, Frontana (95) for FN and DI_1 and Krabat for DI_2. Similarly Bastian was the worst line for GI and DI_2 and Nanjing 7840 was worst line for FN and DI_1.

Table 8. Descriptive statistics of the PHS indices.

PHS indices	CV	Mean	Minimum	Maximum	Best line	Worst line
GI	7.5	0.8	0.5	1.0	Frontana (Mhazy)	Bastian
FN	18.5	188.0	74.0	309.0	Frontana (95)	Nanjing 7840
DI_1	38.3	13.8	0.0	61.6	Frontana (95)	Nanjing 7840
DI_2	47.7	11.6	0.0	27.3	Krabat	Bastian

Table (9) shows the data for PHS parameters of selected important cultivars of Norway, best performing lines in the study and the maturity day. The important cultivars of Norway had a higher GI, lower FN and lower DI, while other best performing lines that are not important with regards to Norwegian Wheat production had a lower GI, higher FN and higher DI. It also appeared that best performing lines matured at later dates while important cultivars of Norway matured at earlier dates.

Table 9. PHS data of best cultivars as well as important cultivars of Norway. Data in green are best with regards to PHS tolerance.

Cultivar	GI	FN	DI_1	DI_2	Maturity day
Berserk	0.91	167	10.66	7.66	20 August
Demonstrant	0.75	162	8.50	8.83	22 August
Tjalve	0.93	192	7.00	-	20 August
Avle	0.77	110	13.67	-	21 August
Bjarne	0.87	168	4.11	5.00	19 August
Zebra	0.86	206	19.67	18.89	21 August
Bastian	0.93	166	12.00	2.16	19 August
Runar	0.93	109	0.67	0.00	18 August
Brakar	0.92	191	4.67	0.00	16 August
Krabat	0.76	177	28.00	29.00	21 August
Frontana(Mhazy)	0.50	246	49.33	0.67	29 August
NG8675/CBRD	0.50	194	46.33	32.00	29 August
Catbird-2	0.50	192	38.33	10.67	31 August
Ning-8343	0.54	187	33.33	15.00	31 August

Relationship between PHS indices

Pearson's correlation coefficients between various PHS indices are shown in Table (10). Also a falling number data from 2009 was compared with the 2010 PHS indices. Statistically significant, but negative correlation was observed between GI and FN-2010 as well as GI and DI. Correlation of GI and FN-2009 was not significant. FN-2010 as well as FN-2009 showed a positive correlation with DI. Maturity day had a significant negative correlation with GI and FN-2009.

Table 10. Pearson's correlation coefficient between various PHS indices. Data in green are significant (P<0.05).

	GI_43	FN_2009	FN_2010	DI_1	DI_2
GI_43	-	-	-	-0.575	-0.480
FN_2009	0.012	-	-	0.129	0.296
FN_2010	-0.456	0.610	-	0.413	0.448
Maturity day	-0.421	-0.485	0.019	0.230	0.133

Evaluation of adapted and unadapted wheat lines

To assess the relationship between different PHS indices, wheat lines were further grouped into adapted and unadapted ones. The adapted lines are those either grown in Norway or selected for cultivation in a Scandinavian climate, whereas the unadapted lines are from CIMMYT or other parts of the world.

A cumulative germination percent was calculated to see the overall germination pattern in both adapted as well as unadapted lines. Figure (9) shows that the mean cumulative germination percent kept increasing during the experiment period of 43 days for both adapted and unadapted lines. The adapted lines had a higher initial germination rate during first 10 days of germination test than the unadapted lines. After about 2 weeks, the germination rate in unadapted lines was higher compared to adapted lines.

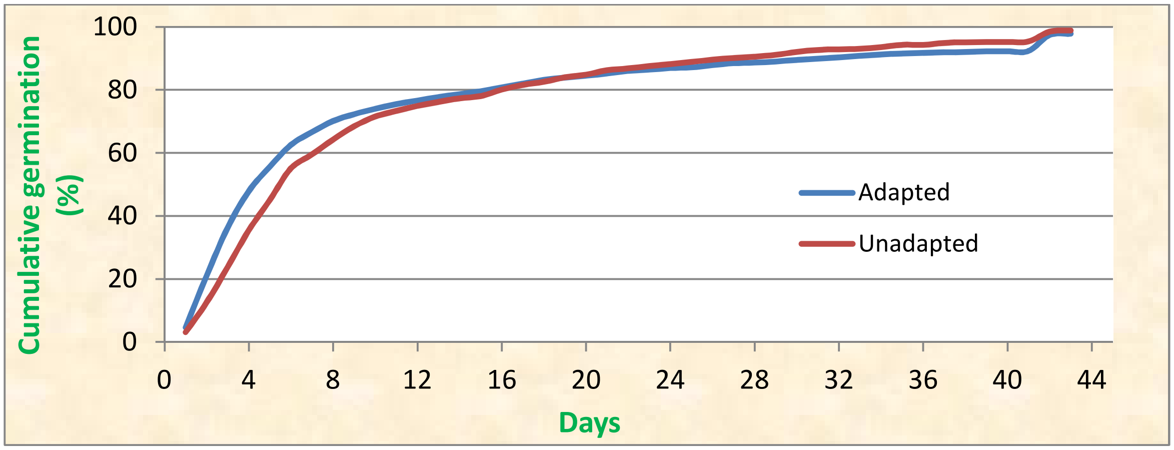


Figure 9. Cumulative germination percent.

A density curve (figure 10) showed a higher mean GI and FN of adapted lines compared to the unadapted lines. The unadapted lines had a higher average DI at 1st harvest, whereas, the adapted lines had a higher average DI at 2nd harvest.

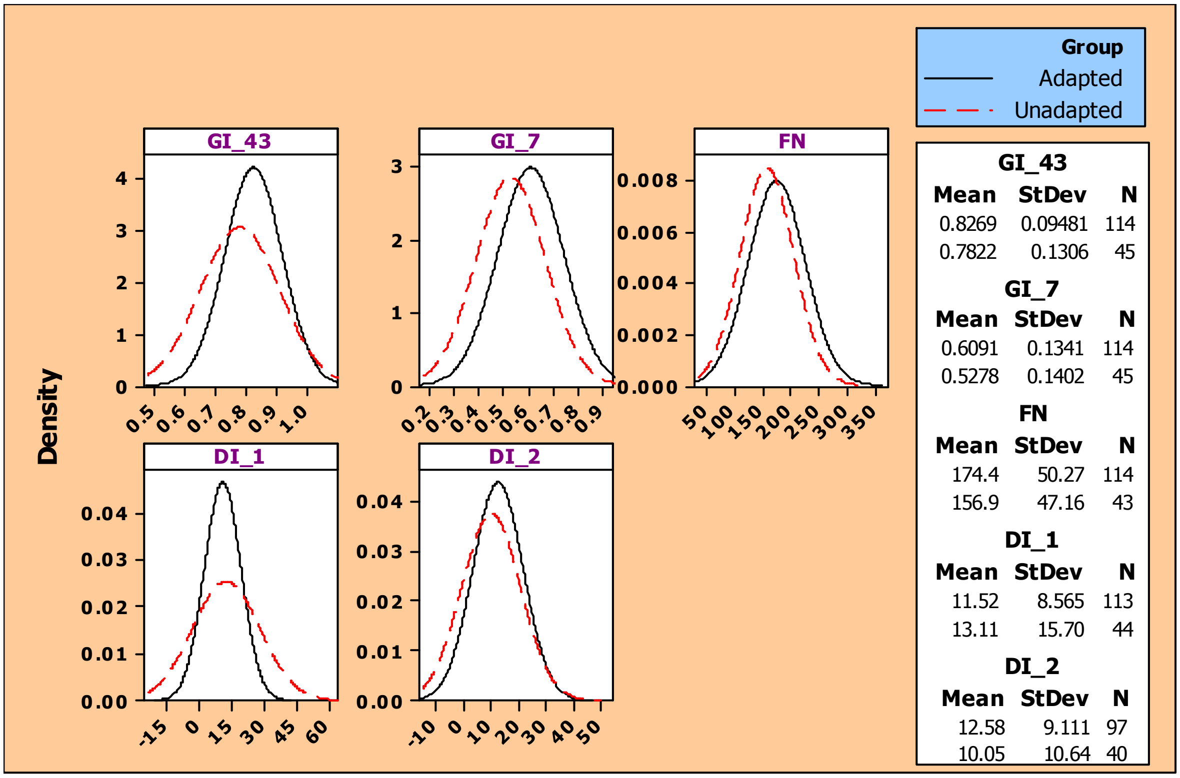


Figure 10. A density curve of different PHS indices.

Similarly, a regression plot was drawn against GI and FN (Fig.11), GI and DI (Fig. 12) and FN and DI (Fig. 13), to look for the association between different PHS indices according to group. In regression of GI and FN a negative correlation was observed for both the adapted as well as unadapted lines. This was true also with the regression of GI and DI. It also appeared that adapted lines have a higher GI as well as FN values than unadapted lines. In case of regression of DI and FN, a positive correlation was observed for both the lines with higher FN values for adapted lines compared to unadapted lines.

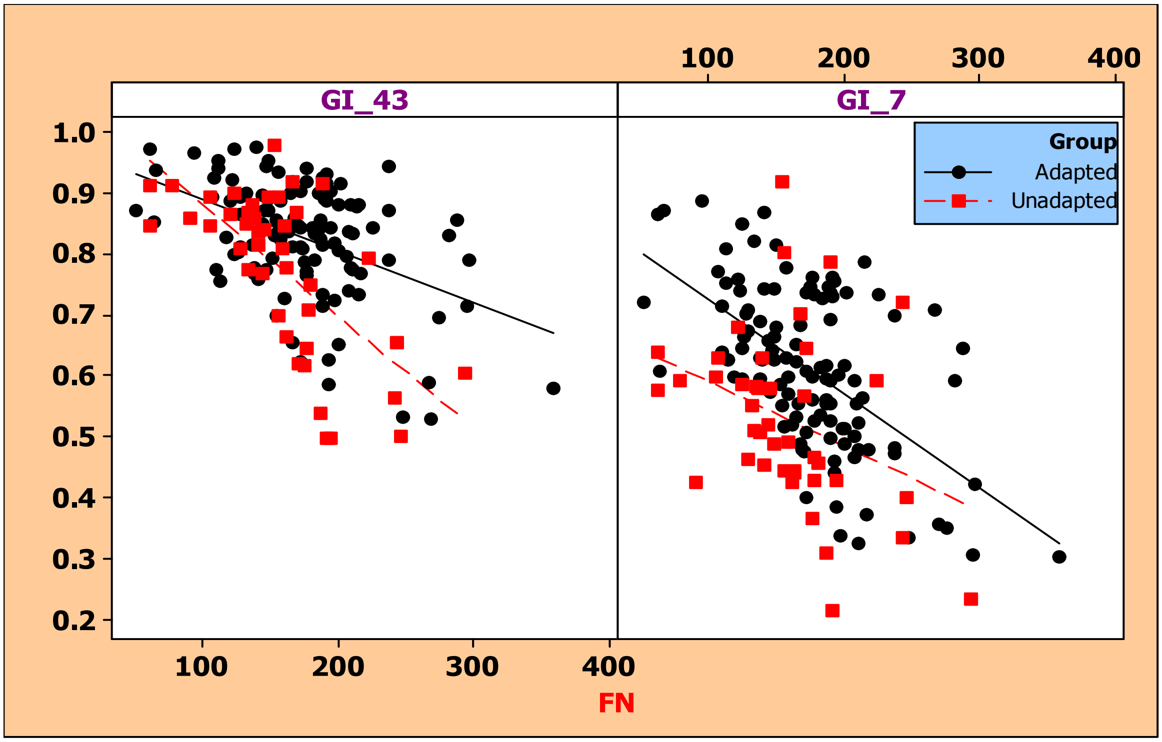


Figure 11. Regression plot of GI and FN.

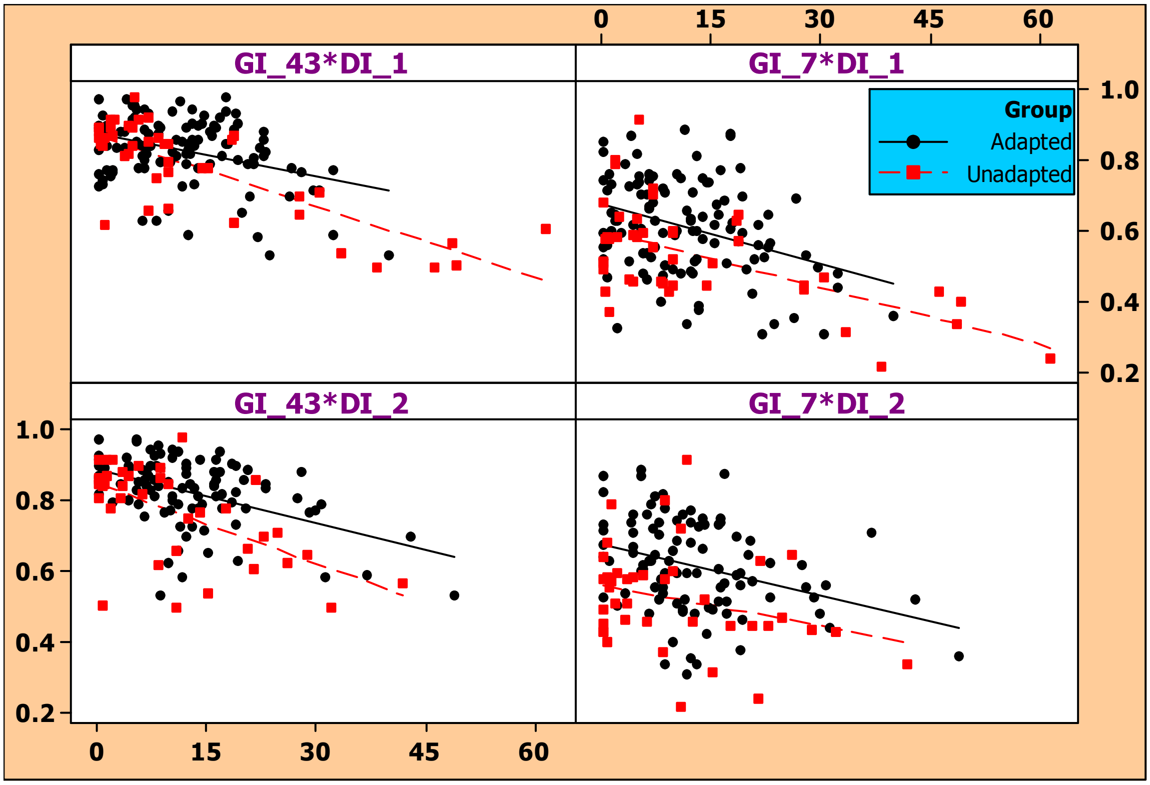


Figure 12. Regression plot of GI and DI.

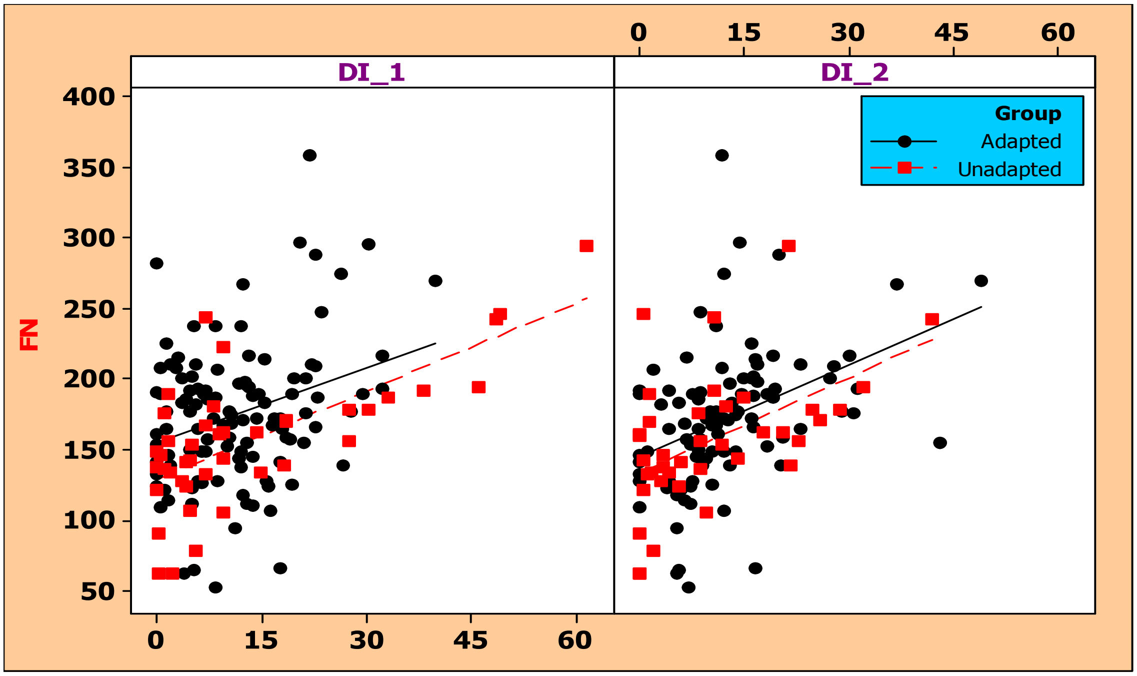


Figure 13. Regression plot of DI and FN.

Relationship between PHS and climatic parameters

To determine the effect of climate in PHS resistance of different cultivars, the climatic data recorded from the date of heading to maturity was used to find the possible relationship of GI, FN and DI first harvest as well as DI second harvest with different climatic parameters described in table (4).

A statistically significant, but weak correlation was observed between PHS indices and various climatic parameters (table 11). Correlation of GI after 7 days and GI after 43 days was used to see if there is any significant variation due to the number of days used for seed germination tests. A similar result was seen in correlation from GI after 7 days to GI after 43 days of seed germination tests, which implies that seven days of seed germination tests is sufficient for the assessment of GI.

GI was positively correlated with mean temperature and maximum temperature during whole grain filling, 0-7 days before maturity and 8-14 days before maturity, whereas, it showed negative correlation with 15-21 days before maturity. Minimum temperature during grain filling and 0-7 days was positively correlated with GI, but 8-14 days before maturity gave a negative correlation. Precipitation and RH during whole grain filling and 0-7 days before maturity showed a negative correlation with GI. No significant correlation was found with FN and climatic parameters except a negative correlation with RH at 15-21 days before maturity.

DI 1st harvest showed a negative correlation with maximum temperature and DI 1st and DI 2nd harvest gave negative correlation with minimum temperature at 15-21 days before maturity and maturity to 1st harvest. Precipitation during whole grain filling period had a positive correlation and, RH at 15-21 days before maturity and maturity to 1st harvest had negative correlation with DI 1st and DI 2nd harvest.

Table 11. Pearson's correlation coefficient between various PHS indices and climatic parameters. Values in green are significant at probability level (P<0.05).

Climatic Parameter	Period	GI_43	GI_7	FN	DI_1	DI_2
Mean Temperature	Whole Grain filling	0.302	0.312	0.078	-0.149	-0.044
	0-7 days before maturity	0.402	0.399	0.015	-0.217	-0.103
	8-14 days before maturity	0.234	0.240	0.137	-0.034	0.061
	15-21 days before maturity	-0.381	-0.325	0.027	0.108	0.084
	Maturity to 1st harvest			-0.173	-0.205	-0.217
	1st harvest to 2nd harvest			-0.039	-0.152	-0.057
Maximum Temperature	Whole Grain filling	0.323	0.329	0.075	-0.183	-0.052
	0-7 days before maturity	0.414	0.421	0.010	-0.274	-0.141
	8-14 days before maturity	0.314	0.287	0.083	-0.063	0.003
	15-21 days before maturity	-0.451	-0.391	0.086	0.209	0.177
	Maturity to 1st harvest			-0.184	-0.161	-0.207
	1st harvest to 2nd harvest			-0.050	-0.176	-0.080
Minimum Temperature	Whole Grain filling	0.364	0.383	0.048	-0.158	-0.035
	0-7 days before maturity	0.379	0.361	0.009	-0.135	-0.064
	8-14 days before maturity	-0.232	-0.144	0.146	0.129	0.196
	15-21 days before maturity	0.026	0.068	-0.121	-0.205	-0.176
	Maturity to 1st harvest			-0.164	-0.226	-0.221
	1st harvest to 2nd harvest			-0.010	-0.089	0.001
Precipitation	Whole Grain filling	-0.378	-0.321	0.048	0.204	0.162
	0-7 days before maturity	-0.140	-0.057	-0.113	-0.079	-0.081
	8-14 days before maturity	0.020	-0.109	0.144	0.172	0.015
	15-21 days before maturity	-0.150	-0.124	-0.103	-0.049	-0.094
	Maturity to 1st harvest			-0.159	-0.080	-0.171
	1st harvest to 2nd harvest			0.166	0.111	0.129
Relative humidity	Whole Grain filling	-0.364	-0.381	-0.046	0.253	0.091
	0-7 days before maturity	-0.397	-0.831	0.015	0.284	0.171
	8-14 days before maturity	0.010	-0.118	-0.149	0.137	-0.069
	15-21 days before maturity	0.391	0.426	-0.157	-0.272	-0.221
	Maturity to 1st harvest			-0.142	-0.261	-0.219
	1st harvest to 2nd harvest			0.185	-0.074	0.146

Allelic diversity of SSR markers

A total of 25 SSR markers were tested, which were chosen from chromosome 3A, 3B, 3D and 4A (figure 7). Of 25 markers tested, 15 were statistically significant (table 12) either with GI, FN or DI. To identify the association of each marker, wheat lines were grouped into adapted and unadapted lines. Majority of markers showed significant relationship with GI in adapted lines. Also, the DI of adapted lines identified more significant marker than the unadapted lines. Only one marker (gpw4152) was statistically significant with all 3 indices of PHS and that too was with the adapted lines.

Table 12. P-Value for the markers. Values in red are significant ($P<0.05$). A (Adapted line), U (Unadapted line).

		GI		FN		DI_1		DI_2	
Chromosome	**Marker**	**A**	**U**	**A**	**U**	**A**	**U**	**A**	**U**
3A	cfa2193	0.464	0.352	0.666	0.517	0.452	0.549	0.232	0.121
3A	wmc559	0.002	0.110	0.227	0.030	0.879	0.330	0.531	0.549
3A	gwm155	0.068	0.066	0.340	0.022	0.569	0.044	0.302	0.643
3A	Vp-1A3	0.978	0.818	0.339	0.513	0.910	0.938	0.402	0.80
3A	wmc153	0.259	0.013	0.968	0.466	0.934	0.248	0.389	0.265
3B	gwm066A	0.558	0.445	0.602	0.315	0.336	0.304	0.673	0.625
3B	gwm066B	0.551	0.347	0.894	0.718	0.233	0.659	0.603	0.601
3B	gwm285	0.436	0.805	0.294	0.373	0.894	0.691	0.754	0.695
3B	wmc307	0.009	0.561	0.497	0.060	0.050	0.655	0.029	0.386
3B	gwm802	0.533	0.056	0.815	0.353	0.106	0.591	0.368	0.479
3B	gwm938	0.002	0.003	0.131	0.023	0.331	0.194	0.064	0.204
3B	Vp1-b2	0.238	…	0.703	…	0.732	…	0.69	…
3D	barc125	0.006	0.596	0.251	0.715	0.758	0.588	0.236	0.170
3D	gpw4152	0.040	0.200	0.048	0.167	0.104	0.216	0.011	0.251
3D	gwm3	0.027	0.313	0.566	0.168	0.500	0.773	0.925	0.614
3D	wmc552	0.004	0.420	0.086	0.176	0.102	0.344	0.033	0.724
4A	wmc513	0.525	…	0.862	…	0.392	…	0.275	…
4A	hbe3	0.001	0.445	0.000	0.221	0.174	0.392	0.278	0.476
4A	BE426203	…	…	…	…	…	…	…	…
4A	wmc650	0.026	0.322	0.833	0.143	0.561	0.072	0.057	0.422
4A	DuPw4	0.001	0.486	0.003	0.215	0.257	0.321	0.776	0.752
4A	CD920298	0.043	0.350	0.025	0.378	0.194	0.336	0.425	0.817
4A	barc170A	0.48	0.277	0.060	0.536	0.401	0.096	0.019	0.946
4A	barc170B	0.236	0.036	0.011	0.119	0.113	0.276	0.291	0.406
4A	gwm637	0.308	0.825	0.179	0.904	0.277	0.850	….	0.104
4A	gwm894	0.610	0.248	0.280	0.777	0.758	0.490	0.519	0.977
4A	gwm937	0.190	0.500	0.194	0.258	0.438	0.566	0.550	0.823

The number of alleles detected from the significant markers and mean PHS indices for adapted lines are shown in table (13) and for unadapted lines in table (14). A number of allelic variants were detected for each significant marker ranging from 2 to 7 alleles. The highest number of alleles was revealed for GI (47) followed by FN (26), DI 2nd harvest (10) and DI 1st harvest (9).

Table 13. Allelic diversity of the significant markers in adapted lines.

Marker	Chromosome	Allele (bp)	N	GI	FN	DI_1	DI_2
wmc559	3A	254	4	0.73	210	16.25	11.08
		256	16	0.86	161	12.17	16.80
		274	14	0.78	207	11.38	12.90
		275	10	0.81	178	11.92	11.00
		277	4	0.92	198	9.77	2.12
gwm155	3A	145	4	0.76	129	15.00	4.66
		161	4	0.65	195	30.16	12.91
		162	5	0.77	122	11.80	10.00
		165	11	0.82	126	10.14	21.33
		169	4	0.87	206	4.46	8.08
wmc153	3A	164	4	0.83	95	3.55	6.00
		179	7	0.76	151	15.47	16.13
		199	21	0.84	160	10.87	8.76
		205	3	0.58	181	33.99	16.78
wmc307	3B	168	41	0.82	192	10.20	12.80
		170	5	0.70	217	26.50	28.80
gwm938	3B	153	24	0.85	180	10.57	15.41
		155	3	0.82	196	12.16	6.33
		169	6	0.70	252	15.72	22.55
		200	10	0.75	151	6.17	10.16
		206	11	0.90	199	5.80	10.66
		218	19	0.82	178	10.51	12.28
		220	3	0.81	175	17.00	31.00
barc125	3D	160	29	0.81	186	10.57	12.56
		162	5	0.72	233	15.00	19.33
		166	16	0.87	180	10.73	11.90
		170	3	0.74	132	11.50	26.00
gpw4152	3D	294	36	0.83	177	10.66	11.40
		296	19	0.78	212	14.86	19.30
gwm3	3D	94	6	0.75	220	16.72	12.00
		96	28	0.79	186	11.41	14.96
		98	7	0.87	169	11.52	12.26
		100	10	0.85	195	12.91	14.77

		102	7	0.87	174	8.09	10.16
wmc552	3D	173	7	0.86	175	8.55	9.80
		176	5	0.71	198	16.19	24.60
		178	6	0.72	258	18.27	12.90
		180	26	0.82	189	10.16	11.90
hbe3	4A	163	32	0.82	179	11.39	12.77
		168	19	0.86	178	11.70	16.76
		170	5	0.69	281	19.49	18.75
wmc650	4A	108	39	0.82	179	11.17	12.78
		119	10	0.89	175	9.96	16.33
DuPw4	4A	213	21	0.86	171	11.47	15.11
		215	7	0.72	259	18.06	16.06
		309	29	0.82	185	11.28	13.24
CD920298	4A	419	22	0.85	176	11.51	16.79
		421	6	0.74	253	19.49	10.83
		524	29	0.82	185	11.28	13.24
barc170A	4A	114	53	0.82	192	11.49	13.10
		115	5	0.79	140	14.93	25.80
barc170B	4A	185	11	0.87	180	12.19	19.33
		192	3	0.79	198	8.11	9.67
		195	36	0.83	177	11.18	12.65

Table 14. Allelic diversity of the significant markers in unadapted lines.

Marker	Chromosome	Allele (bp)	N	GI	FN	DI_1	DI_2
wmc559	3A	252	5	0.79	159	13.30	13.00
		256	6	0.77	201	13.70	13.16
		272	3	0.62	191	29.70	15.30
		274	17	0.83	115	9.20	6.90
		275	4	0.79	165	19.20	12.50
gwm155	3A	145	4	0.76	129	15.00	4.66
		161	4	0.65	196	30.16	12.91
		162	5	0.77	123	11.80	10.00
		165	11	0.82	127	10.14	21.33
		169	4	0.87	206	4.46	8.08
wmc153	3A	164	4	0.83	96	3.55	6.00
		179	7	0.76	152	15.47	16.13
		199	21	0.84	160	10.87	8.76
		205	3	0.58	181	33.99	16.78
wmc307	3B	166	20	0.80	122	11.00	8.10
		168	13	0.79	172	13.30	10.50

		170	4	0.73	167	18.00	15.50
gwm938	3B	153	16	0.83	122	8.40	7.70
		200	8	0.71	149	18.30	15.40
		206	5	0.91	200	6.80	5.70
barc125	3D	164	3	0.79	112	13.30	18.30
		166	26	0.80	154	12.50	10.00
		168	6	0.74	163	20.40	4.20
gpw4152	3D	294	6	0.85	185	5.78	6.10
		296	29	0.78	144	14.20	11.00
gwm3	3D	96	17	0.76	143	16.40	9.60
		98	5	0.78	154	16.40	13.00
		100	5	0.86	216	7.80	8.00
		102	11	0.83	129	9.80	6.90
wmc552	3D	171	10	0.75	131	18.00	11.10
		173	8	0.86	110	4.00	5.80
		178	3	0.85	142	5.80	3.80
		180	7	0.80	199	10.90	13.60
		182	3	0.83	128	7.70	8.00
		184	6	0.75	151	20.10	11.00
hbe3	4A	163	14	0.78	129	14.10	8.90
		168	21	0.82	155	10.60	12.10
		170	3	0.74	195	23.80	12.60
wmc650	4A	106	7	0.84	108	10.60	6.80
		108	3	0.80	128	8.00	7.30
		119	14	0.80	171	12.40	10.20
		125	3	0.64	218	36.20	18.80
		129	4	0.78	166	12.20	16.50
DuPw4	4A	213	20	0.81	157	10.20	11.30
		215	3	0.74	195	23.80	12.60
		309	14	0.78	129	14.10	8.90
CD920298	4A	419	22	0.82	152	10.60	11.50
		421	3	0.74	195	23.80	12.60
		524	13	0.77	132	14.10	9.40
barc170A	4A	114	30	0.80	147	11.20	10.20
		115	10	0.75	163	21.10	10.40
barc170B	4A	182	8	0.75	136	16.50	13.10
		185	6	0.87	211	6.80	6.70
		189	5	0.83	115	8.70	11.80
		195	10	0.83	114	9.60	7.00

Table (15) shows the PHS indices of the most important cultivars of Norway. These cultivars appear to be less dormant and carry fewer alleles associated with dormancy. Demonstrant, Avle and Vinjett carry two alleles and are relatively more dormant than other cultivars that carry only one allele.

Table 15. Marker alleles and PHS indices of important Norwegian cultivars.

Cultivars	Markers	Chromosome	Alleles	GI	FN	DI-1	DI-2
Berserk	wmc650	4A	108	0.91	167	10.66	7.66
Demonstrant	wmc559	3A	254	0.75	162	8.50	8.83
	wmc650	4A	108				
Avle	wmc650	4A	108	0.77	110	13.67	-
	barc170A	4A	115				
Bjarne	wmc650	4A	108	0.87	168	4.11	5.00
Zebra	wmc650	4A	108	0.86	206	19.67	18.89
Bastian	wmc650	4A	108	0.93	166	12.00	2.16
Runar	-	-	-	0.93	109	0.67	0.00
Vinjett	wmc650	4A	108	0.75	114	1.67	6.33
	barc170A	4A	115				

Table (16) shows the PHS indices of cultivars carrying alleles that are associated with highest and lowest dormancy. Paros/T9040, DH20097, Quarna, Frontana (95), Catbird-2, and Ning-8343 appeared to be the promising cultivars with highest dormancy. Likewise, Bastian, T2038, GNO8595, 512-87, 219-(Seri 1) and Filin had the lowest dormancy.

Table 16. Marker alleles and PHS indices of cultivars associated with higher and lower dormancy. Data in green (best performing Adapted cultivars), black (best perfoming unadapted cultivars), yellow (worst performing adapted cultivars) and red (worst performing unadapted cultivars).

Cultivars	Markers	Chromosome	Alleles	GI	FN	DI-1	DI-2
Paros/T9040	**gwm938**	**3B**	**169**	**0.58**	**371**	**22.00**	**11.67**
	barc125	**3D**	**162**				
	gpw4152	**3D**	**296**				
	gwm3	**3D**	**94**				
	hbe3	**4A**	**170**				
	dupw4	**4A**	**215**				
	CD920	**4A**	**421**				
DH20097	**wmc307**	**3B**	**170**	**0.58**	**229**	**32.33**	**31.33**
	gpw4152	**3D**	**296**				
	wmc552	**3D**	**176**				

Quarna	gwm938	3B	169	0.59	287	12.33	37.00
	barc125	3D	162				
	gpw4152	3D	296				
	wmc552	3D	176				
	hbe3	4A	170				
	dupw4	4A	215				
Frontana(95)	gpw4152	3D	296	0.60	309	61.67	21.33
	hbe3	4A	170				
	dupw4	4A	215				
	CD920	4A	421				
	barc170A	4A	115				
Catbird-2	gwm155	3A	161	0.50	164	38.33	10.67
	wmc153	3A	205				
	gpw4152	3D	296				
Ning-8343	gwm155	3A	161	0.54	187	33.33	15.00
	wmc153	3A	205				
	gpw4152	3D	296				
Bastian	wmc650	4A	108	0.98	121	17.67	-
T2038	-	-	-	0.97	109	-	-
GNO8595	wmc650	4A	108	0.97	62	4.00	5.33
512-87	-	-	-	0.98	140	5.00	11.67
219-seri(1)	gpw4152	3D	296	0.91	62	2.33	-
Filin	gpw4152	3D	296	0.91	62	5.67	2.00

Discussions

PHS assessment methods

GI at maturity is the strategy used by many researchers in selection for PHS resistance in many wheat breeding programs. This trait is compared with the response to weathering in the field mainly: FN, SI (Sprouting index) and DI by various climatic parameters. In this study, GI, FN and DI were used for the assessment of PHS.

Germination experiments for GI calculations were conducted on grains harvested at maturity, so the GI measures dormancy of grains at maturity. Germination experiments for DI calculations were done on grains harvested at 150 GDD after maturity and 450 GDD after maturity, so the DI involves the after-maturity period. FN measures grain quality and also involves the after-maturity period as the grains for FN experiments were harvested at 450 GDD after maturity.

Hence, GI reflects primary dormancy, whereas, FN and DI reflect both primary as well as secondary dormancy. Since grains for GI experiments were harvested few weeks earlier than for DI and FN calculations, the lower GI may not reflect well to higher FN or higher DI because the grains for latter experiments are subjected to the prolonged influence of weather conditions. Therefore, the major limitation of FN method to assess PHS is the variation caused by the time differences from maturity to a specific weather conditions and decay of dormancy over time (Biddulph et al., 2008). This might be the reason that best performing cultivars in this study like: Catbird-2 and DH20097 have a relatively lower FN in spite of having a lower GI.

Lower coefficient of variation for GI (table 8) and higher correlation coefficient of GI and FN (-0.456) compared to DI and FN (0.413) suggests that GI might be the better method of screening for PHS tolerance of grains. Similarly, other studies (Gut and Bichoński, 2007) showed a poor correlation in evaluation of PHS tolerance with FN. According to Biddulph (2008), falling number has its limitations and needs to be used in concurrence to dormancy based procedures of PHS tolerance. FN manifests the quality of the endosperm at the time of harvest (Hagemann and Ciha, 1984) and can vary hugely based on the degree of ripening and amount of precipitation before harvest (Mares, 1993).

In contrary, (Fofana et al., 2008) mentioned that FN based method alone could be a reliable and accurate assessment of PHS. Likewise, (Humphreys and Noll, 2002) mentioned that falling number after artificial weathering or field weathering was a reliable method for characterization of PHS tolerance than dormancy based method. However, one of the main advantages of FN method is that it gives information about alpha-amylase activity in the grain samples. This on one hand helps in differentiating the flour quality of the cultivars, while on the other hand provides an indirect measurement of PHS.

Seed dormancy and PHS

This study was conducted to see the overall PHS response of the cultivars that are considered important in the Norwegian wheat production as well as breeding programs. The result revealed a highly significant differences in cultivars ($P<0.001$) in terms of dormancy behavior.

In this study, three PHS indices (GI, FN and DI) were used to characterize the response to PHS. The correlation of GI with FN (-0.456) and DI at first harvest (-0.575) and DI at second harvest (-0.480) showed a significant relationship. The negative correlation between GI and DI at first harvest and DI at second harvest shows that the cultivars with high GI exhibit lower level of dormancy and cultivar with lower GI have higher level of dormancy. Similarly a negative correlation of GI and FN indicates that a dormant line (low GI) have a higher FN value compared to a non-dormant line. Likewise, a positive correlation was seen with FN and DI at first harvest (0.413) and DI at second harvest (0.448). This implies that lines with higher FN values have higher DI (low GI). This is in agreement to that found by Rasul et al. (2011).

Figure (8) showed that some lines matured (yellow ripeness) at higher temperature and some lines at lower temperature. To see if maturity temperature had any effect on dormancy, correlation coefficient of PHS indices and maturity day was calculated. A significant negative correlation was found between maturity day and GI (-0.421). This indicates that grains maturing at higher temperature are less dormant than those maturing at lower temperature. Mares (1993) found that lower temperature during grain maturation produced dormant grains than higher temperature during maturation. Similar result has been obtained by Nyachiro et al. (2002) and Mares et al. (2009).

Environmental effect and PHS

To see the influence of environmental conditions in PHS of wheat cultivars, various climatic parameters depicted in table (4) was used to determine the possible relationship with PHS indices. Results obtained showed that higher maximum temperature and higher minimum temperatures during the later stages of grain maturation is associated to higher GI value, indicating lower PHS resistance. Similarly, higher maximum temperature and higher minimum temperature after maturity resulted in lower FN and DI. This result is in consistence to the one reported by Strand (1989) and Mares (1993) that higher temperature after maturity decreased grain dormancy. Figure (7) shows the fluctuations in minimum and maximum temperature before maturity and harvest indicated by the arrows. This indicates that daily fluctuation in temperature during grain maturation can result in lower PHS tolerance. However, there is a conflicting report on the role of temperature in various studies. According to Auld and Paulsen (2003), environmental effect is smaller during the maturation period compared to post maturation and ripening. This is true for FN and DI in our study where climatic parameters showed significant correlation after maturity, but in case of GI index there was significant correlation both prior and post maturity. Mares (1993) and Thomason (2009.) found that lower temperatures during grain maturation produced slightly higher sprouting resistant grains than higher temperatures. Similarly, Nielsen et al. (1984) found that higher temperatures two week prior to maturity resulted in decreased tolerance to sprouting.

Likewise, higher precipitation during grain filling period resulted in lower GI and higher DI, which means increased PHS tolerance. In contrary, higher precipitation after maturity lead to higher GI and lower DI, meaning decreased PHS tolerance of the grains. This indicates that higher precipitation during grain filling period might be associated to higher PHS tolerance. However, this result is in contrary to the one obtained by Barnard and Smith (2009), where no significant correlation between rainfall and PHS was found. Also, our result suggests that higher rainfall and higher relative humidity after maturity can be associated with lower PHS tolerance. This could be partly because rainfall and high relative humidity after maturity may hinder the grain drying rate (Biddulph et al., 2005) thereby reducing dormancy.

In PHS prone areas, fungal infections, black points and other weather associated defects may affect the germination of grains irrespective of the typical germination pattern of a cultivar. The infection was also evident in the field in our study where some of the cultivars were severely affected. Although, great attention was made to exclude the affected grains for germination tests it is also possible that not-visible symptoms might be influencing the germination indices calculated in this study. Nevertheless, it is expected that a low level of infection will lead to low level of PHS for any given level of dormancy. This is partly because high black point infection is known to be associated with high alpha-amylase activity and therefore lower falling number (Biddulph et al., 2008).

Marker association studies

Earlier reports (Fofana et al., 2008; Ogbonnaya et al., 2007) have expressed a highly polymorphic nature of SSR markers in wheat. The result obtained in our study from a microsatellite analysis of 98 genotypes supported earlier studies. More than 90 alleles were detected from the 15 significant markers ($P<0.05$). Adapted lines showed a higher number of significant markers indicating that these lines carry majority of dormancy alleles. This was as expected because most of the Norwegian cultivars are thought to be less prone to sprouting due to the presence of dormancy genes. Also the higher number of significant markers obtained with GI indicates that phenotypic data based on germination ability coupled with marker based association studies could be a reliable method in evaluation of PHS in wheat.

Few important Norwegian cultivars were selected and a comparison was done with their marker alleles and PHS indices (table 15). The data showed that majority of them were less dormant and carried only one significant marker. Likewise, comparison of few best performing and worst performing cultivars (table 16) showed that best performing cultivars had higher number of significant markers and the worst performing cultivars had few or none of the significant markers. This illustrates the fact that seed dormancy is a quantitative trait governed by many genes (Osa et al., 2003).

Implications for breeding

PHS resistance is regarded as a complex trait that is controlled by different genes and is highly influenced by environmental factors, which makes assessment of PHS resistance much difficult. Three PHS indices (GI, FN, DI) were used to characterize marker allele and climatic data for PHS response. This study suggests that GI at maturity followed by comparing it with FN could be the better choice owing to the knowledge that GI reflects primary dormancy, whereas, FN reflects both primary as well as secondary dormancy. Since germination of seed is inversely linked to the dormancy of seed, GI could well predict the susceptibility of cultivars to PHS (Nyachiro et al., 2002).

The higher number of significant markers for GI for adapted cultivars (table 12) may indicate that Norwegian cultivars are more dormant compared to unadapted lines. However, analysis of selected important Norwegian cultivars (table 9) (table 15) showed lower dormancy. This might be because of the difference in maturation temperature for early maturing and late maturing lines (figure 8). In addition, the important Norwegian cultivars carried none or very few significant markers. This indicates the importance of selection of dormancy alleles and breeding in order to achieve PHS resistance in important Norwegian cultivars.

Most of the important Norwegian cultivars contained wmc650 marker, while the best performing cultivars had gpw4152, gwm155, hbe3, dupw4, wmc552, wmc153, and gwm938 in combination of 3 or more significant markers. Adapted lines (Paros/T9040, DH20097, Quarna) and unadapted lines (Frontana 95, Catbird-2, Ning-8343) are the best performing lines in all three PHS indices (GI, FN, DI) in this study, which could be useful as a potential sources of dormancy and used in breeding programs for improving tolerance to PHS.

Recently, a genotyping of Norwegian wheat lines by CAPs marker (Nakamura et al., 2011) was done (Lillemo, unpublished), which showed that the allele associated with dormancy was not present in any of the adapted spring wheat cultivars. Therefore, this could be a useful gene that could be crossed into Norwegian spring wheat cultivars to improve the level of dormancy.

The comparision of DI of 2010 with the historical averages (table 6) showed that this was an unusual year. In addition the adapted lines did not express higher level of dormancy compared to unadapted lines as was expected, which could be due to their early maturity day that corresponded with high temperature. This indicates that breeding decisions just on one year of data might be risky. In order to avoid this, testing over several years and different locations could be more appropriate and more reliable in dormancy assessment.

Conclusion

This study showed that different cultivars responded differently with regard to climatic characteristic at different stages of grain development. Variations that are caused by climatic factors have an effect in the study of PHS, and also create difficulty in selection of resistant varieties. Other limitations such as fungal infection might decrease the dormancy estimate and so immense care needs to be provided to avoid the possibility of infection.

GI index had a lower coefficient of variation and higher correlation of GI with FN was obtained. So, GI could be the better procedure for assessing PHS. The assessment of important Norwegian cultivars showed higher GI, lower FN and lower DI for these cultivars. Also, the significant markers that could be associated with dormancy were few in those cultivars. In General, some best performing adapted lines were Paros/T9040, DH20097 and Quarna and unadapted lines were Frontana (95), Catbird-2 and Ning-8343. Out of 25 markers used in this study only one marker (gpw4152) from chromosome 3D was found to be significant for all three PHS indices. So, this marker appears to be very useful in tracing alleles associated with PHS tolerance in other chromosomes.

It is clear that the polygenic control of PHS resistance in wheat restricts the chances of success for improvement of PHS resistance through the classical approach of plant breeding. As this trait is highly influenced by climatic factors, screening of cultivars and selection on the basis of phenotype is problematic. Therefore molecular markers linked to genes associated with PHS resistance could be a useful tool in marker assisted selection in order to develop the cultivars with resistance to PHS. A better understanding of genetic control of both seed dormancy and PHS resistance would be more helpful in the breeding program. Further work including greater marker density along with field experiments in different locations and different years could be helpful in PHS studies.

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Appendix

PHS and climatic data

line	Experiment	Group	GI_43	DI_1	DI_2	FN	WGP	Mean T 7_0 DBM	Mean T 14_8 DBM	Mean T 21_15 DBM
214	1	1	0.89	0.00	8.67	190	16.40	16.83	16.37	15.91
215	2	1	0.98	17.67	0.00	141	16.38	16.50	16.69	15.61
216	1	1	0.86	22.67	20.00	288	16.43	16.43	16.96	15.56
217	1	1	0.89	8.67	4.33	128	16.38	16.50	16.69	15.61
218	2	1	0.65	9.67	11.00	167	16.41	16.01	17.01	15.81
219	2	1	0.81	21.33	27.33	200	16.45	16.43	16.96	15.56
220	1	1	0.83	12.33	5.33	118	16.41	16.43	16.96	15.56
221	2	1	0.62	8.00	9.67	172	16.41	16.01	17.01	15.81
222	1	1	0.81	17.00	10.33	172	16.43	16.01	17.01	15.81
223	1	1	0.86	13.00	7.67	155	16.43	16.43	16.96	15.56
224	2	1	0.79	21.33	30.67	176	15.67	11.77	15.49	16.93
225	1	1	0.70	26.33	12.00	275	16.18	15.24	16.63	16.39
301	1	1	0.77	6.33	13.67	148	16.43	16.83	16.37	15.91
302	1	1	0.85	11.67	9.67	144	16.45	16.43	16.96	15.56
303	1	1	0.87	1.67	0.00	146	16.43	16.83	16.37	15.91
304	1	1	0.84	17.67	16.00	172	16.41	16.43	16.96	15.56
305	1	1	0.94	10.33	11.00	177	16.39	16.01	17.01	15.81
306	1	1	0.84	7.33	6.67	157	16.41	16.50	16.69	15.61
307	1	1	0.91	5.00	16.33	202	16.50	16.96	16.40	15.81
308	1	1	0.84	6.00	8.33	164	16.40	16.83	16.37	15.91
309	2	1	0.89	1.00	6.00	121	16.43	16.83	16.37	15.91
310	2	1	0.80	8.67	2.00	207	16.38	16.50	16.69	15.61
311	1	1	0.89	12.00	1.00	149	16.41	16.43	16.96	15.56
312	2	1	0.89	16.33	12.00	107	16.45	16.43	16.96	15.56
313	1	1	0.83	3.67	13.33	183	16.43	16.50	16.69	15.61
314	1	1	0.90	13.67	8.00	145	16.41	16.50	16.69	15.61
315	2	1	0.79	15.33	5.67	183	16.43	16.01	17.01	15.81
316	1	1	0.85	5.33	5.67	64	16.41	16.50	16.69	15.61
317	2	1	0.86	13.67	16.33	188	16.38	16.50	16.69	15.61
318	2	1	0.92	16.67	10.33	167	16.38	16.50	16.69	15.61
319	1	1	0.73	0.00	11.33	161	16.45	16.83	16.37	15.91
320	1	1	0.90	0.00	0.00	133	16.38	16.50	16.69	15.61
321	2	1	0.97	4.00	5.33	62	16.41	16.43	16.96	15.56
322	2	1	0.78	26.67	20.33	138	16.45	16.43	16.96	15.56
323	2	1	0.97	11.33	5.33	95	16.41	16.50	16.69	15.61

line	Experiment	Group	GI_43	DI_1	DI_2	FN	WGP	Mean T 7_0 DBM	Mean T 14_8 DBM	Mean T 21_15 DBM
324	2	1	0.53	40.00	49.00	269	16.41	16.01	17.01	15.81
325	1	1	0.94	13.00	7.33	112	16.38	16.50	16.69	15.61
401	2	1	0.95	4.67	8.33	150	16.40	16.83	16.37	15.91
402	2	1	0.90	19.33	18.33	190	16.41	16.43	16.96	15.56
403	2	1	0.90	14.33	12.00	172	16.41	16.43	16.96	15.56
404	2	1	0.90	8.33	19.00	187	16.41	16.01	17.01	15.81
405	2	1	0.85	18.00	23.00	164	16.43	16.01	17.01	15.81
406	2	1	0.92	14.67	7.67	189	16.43	16.43	16.96	15.56
407	2	1	0.81	10.67	13.67	175	16.41	16.01	17.01	15.81
408	2	1	0.71	29.67	14.67	189	16.41	16.01	17.01	15.81
409	1	1	0.81	22.67	16.33	166	16.41	16.01	17.01	15.81
410	1	1	0.65	19.67	15.00	201	16.35	15.49	16.93	16.11
411	2	1	0.93	19.00	8.67	157	16.31	16.01	17.01	15.81
412	2	1	0.92	5.00	4.00	123	16.31	16.01	17.01	15.81
413	1	1	0.79	10.00	18.33	152	16.39	16.01	17.01	15.81
414	1	1	0.77	32.33	30.00	217	16.39	16.01	17.01	15.81
415	1	1	0.80	6.33	4.33	126	16.31	16.01	17.01	15.81
416	2	1	0.87	8.33	7.00	52	16.31	16.01	17.01	15.81
417	2	1	0.90	16.00	7.33	124	16.41	16.01	17.01	15.81
418	1	1	0.94	17.67	16.67	66	16.41	16.01	17.01	15.81
419	2	1	0.53	23.67	8.67	248	16.41	16.01	17.01	15.81
420	2	1	0.80	19.33	10.33	125	16.41	16.01	17.01	15.81
421	2	1	0.87	7.00	12.00	149	16.41	16.01	17.01	15.81
422	2	1	0.82	12.67	17.00	198	16.43	16.01	17.01	15.81
423	1	1	0.81	6.00	7.67	128	16.41	16.01	17.01	15.81
424	2	1	0.93	7.00	*	192	16.43	16.50	16.69	15.61
425	2	1	0.77	13.67	*	110	16.43	16.43	16.96	15.56
501	1	1	0.86	10.67	6.33	168	16.43	16.43	16.96	15.56
502	1	1	0.89	18.67	20.67	158	16.43	16.43	16.96	15.56
503	2	1	0.89	6.33	4.33	192	16.43	16.83	16.37	15.91
504	1	1	0.88	15.33	16.67	214	16.43	16.43	16.96	15.56
505	2	1	0.73	13.33	19.00	216	16.39	16.01	17.01	15.81
506	1	1	0.90	4.33	*	186	16.43	16.01	17.01	15.81
507	2	1	0.84	7.33	8.33	186	16.48	16.96	16.40	15.81
508	1	1	0.72	30.33	*	296	16.41	16.01	17.01	15.81
509	1	1	0.87	8.33	*	238	16.41	16.01	17.01	15.81
510	1	1	0.58	22.00	11.67	359	16.43	16.01	17.01	15.81
511	1	1	0.87	15.67	0.00	128	16.45	16.96	16.40	15.81
512	2	2	0.82	4.33	6.00	141	16.45	16.83	16.37	15.91
513	2	2	0.81	*	0.00	159	16.30	15.49	16.93	16.11

line	Experiment	Group	GI_43	DI_1	DI_2	FN	WGP	Mean T 7_0 DBM	Mean T 14_8 DBM	Mean T 21_15 DBM
514	1	2	0.91	5.67	2.00	78	15.86	12.19	16.01	17.01
515	2	2	0.85	7.00	1.00	132	15.68	11.51	15.24	16.63
516	2	2	0.89	4.67	*	107	16.43	16.01	17.01	15.81
517	1	2	0.86	18.33	21.67	139	15.72	12.19	16.01	17.01
518	2	2	0.91	2.33	0.00	62	15.54	11.51	15.24	16.63
519	2	2	0.92	7.00	*	167	16.41	16.50	16.69	15.61
520	1	1	0.88	22.67	28.00	209	16.43	16.43	16.96	15.56
521	1	1	0.82	10.33	*	159	16.45	16.43	16.96	15.56
522	2	1	0.90	1.33	4.33	165	16.51	16.93	16.11	16.27
523	1	1	0.97	0.00	*	124	16.41	16.01	17.01	15.81
524	1	1	0.83	22.33	23.00	211	16.43	16.43	16.96	15.56
525	1	2	0.77	9.67	14.00	144	15.85	12.19	16.01	17.01
601	2	2	0.84	0.67	3.33	146	15.54	11.51	15.24	16.63
602	2	2	0.78	15.00	1.67	134	16.41	16.01	17.01	15.81
603	1	2	0.86	8.33	0.00	*	15.54	11.51	15.24	16.63
604	2	2	0.89	0.00	*	*	16.43	16.43	16.96	15.56
605	2	2	0.81	3.67	3.00	128	15.95	12.96	16.43	16.96
606	1	2	0.85	9.67	9.67	106	15.83	12.19	16.01	17.01
607	1	2	0.90	4.33	5.67	124	15.83	12.19	16.01	17.01
608	2	2	0.50	46.33	32.00	194	15.83	12.19	16.01	17.01
609	1	2	0.75	8.00	12.33	180	15.68	11.51	15.24	16.63
610	2	2	0.70	27.67	22.67	156	15.72	12.19	16.01	17.01
611	1	2	0.71	30.33	24.67	178	15.83	12.19	16.01	17.01
612	2	1	0.77	2.00	9.00	139	16.40	16.83	16.37	15.91
613	2	1	0.88	3.67	16.00	200	16.45	16.83	16.37	15.91
614	2	1	0.79	20.67	14.33	297	16.43	16.43	16.96	15.56
615	1	1	0.81	12.00	*	138	16.45	16.43	16.96	15.56
616	2	1	0.84	5.67	3.00	182	16.45	16.83	16.37	15.91
617	1	1	0.84	2.67	11.67	208	16.07	13.89	16.50	16.69
618	1	1	0.76	28.00	29.00	177	16.45	16.43	16.96	15.56
619	1	1	0.88	3.00	6.67	215	16.16	14.44	16.83	16.37
620	1	1	0.83	0.00	7.33	154	16.48	16.96	16.40	15.81
621	1	1	0.84	13.33	*	194	16.45	16.43	16.96	15.56
622	2	1	0.77	2.00	*	211	16.45	16.43	16.96	15.56
623	1	1	0.73	0.67	*	190	16.35	15.49	16.93	16.11
624	2	1	0.77	1.33	10.00	177	16.06	13.89	16.50	16.69
625	1	1	0.78	*	13.00	138	15.65	11.51	15.24	16.63
701	1	1	0.84	1.33	16.00	226	16.37	16.96	16.40	15.81
702	1	1	0.72	11.67	13.00	197	15.94	13.89	16.50	16.69
703	2	1	0.63	6.00	19.33	193	15.94	13.89	16.50	16.69

line	Experiment	Group	GI_43	DI_1	DI_2	FN	WGP	Mean T 7_0 DBM	Mean T 14_8 DBM	Mean T 21_15 DBM
704	2	1	0.94	6.33	10.33	148	14.73	16.83	16.37	15.91
705	2	1	0.83	0.00	*	282	16.35	14.77	16.96	16.40
706	1	1	0.79	12.00	11.00	237	16.16	14.44	16.83	16.37
707	1	1	0.92	4.67	14.00	177	16.15	14.44	16.83	16.37
708	2	1	0.78	5.67	17.00	210	16.07	13.89	16.50	16.69
709	2	1	0.74	0.67	*	208	16.35	15.49	16.93	16.11
710	1	1	0.59	12.33	37.00	267	16.05	13.89	16.50	16.69
711	2	1	0.82	6.67	0.00	190	16.12	14.77	16.96	16.40
712	2	1	0.82	23.00	19.00	187	16.43	16.43	16.96	15.56
713	1	1	0.85	12.33	12.67	171	16.14	14.44	16.83	16.37
714	1	1	0.94	5.33	*	237	16.35	14.77	16.96	16.40
715	1	2	0.60	61.67	21.33	294	15.83	12.19	16.01	17.01
716	2	2	0.50	49.33	0.67	246	15.83	12.19	16.01	17.01
717	1	2	0.56	48.67	42.00	243	15.62	11.77	15.49	16.93
718	2	2	0.62	18.67	26.00	171	15.83	12.19	16.01	17.01
719	1	2	0.64	27.67	28.67	178	15.62	11.77	15.49	16.93
720	1	2	0.66	9.67	20.67	162	16.43	16.43	16.96	15.56
721	2	2	0.86	1.00	8.67	136	16.50	16.96	16.40	15.81
722	1	2	0.89	0.00	*	149	16.35	15.49	16.93	16.11
723	1	2	0.54	33.33	15.00	187	15.54	11.51	15.24	16.63
724	2	2	0.87	18.67	1.33	170	16.43	16.43	16.96	15.56
725	2	2	0.65	7.00	10.67	243	16.07	13.89	16.50	16.69
801	2	2	0.89	1.67	8.67	156	16.48	16.96	16.40	15.81
802	1	2	0.91	1.67	1.33	189	16.05	13.89	16.50	16.69
803	2	2	0.98	5.00	11.67	154	16.44	16.63	16.39	16.11
804	2	1	0.93	0.67	0.00	109	16.48	16.96	16.40	15.81
805	2	1	0.92	4.67	0.00	192	16.51	16.93	16.11	16.27
806	2	1	0.90	13.00	*	195	16.45	16.43	16.96	15.56
807	2	1	0.95	5.00	*	112	16.43	16.50	16.69	15.61
808	2	2	0.79	9.67	*	223	16.41	16.01	17.01	15.81
809	1	2	0.87	0.00	0.67	121	16.05	13.89	16.50	16.69
810	1	2	0.84	0.33	0.00	62	15.94	13.89	16.50	16.69
811	1	2	0.88	0.00	3.33	137	15.62	11.77	15.49	16.93
812	1	2	0.86	0.33	0.00	91	15.54	11.51	15.24	16.63
813	2	2	0.85	9.00	0.00	161	15.62	11.77	15.49	16.93
814	1	2	0.50	38.33	10.67	192	15.54	11.51	15.24	16.63
815	2	1	0.75	1.67	6.33	114	16.07	13.89	16.50	16.69
816	1	1	0.70	21.00	43.00	155	16.06	13.89	16.50	16.69
817	2	1	0.58	32.33	31.33	193	15.68	11.51	15.24	16.63
818	1	2	0.84	4.67	0.67	142	15.54	11.51	15.24	16.63

line	Experiment	Group	GI_43	DI_1	DI_2	FN	WGP	Mean T 7_0 DBM	Mean T 14_8 DBM	Mean T 21_15 DBM
819	2	2	0.87	2.00	4.33	134	15.62	11.77	15.49	16.93
820	2	1	0.76	0.00	*	141	16.45	16.83	16.37	15.91
821	1	2	0.62	1.00	8.33	176	15.54	11.51	15.24	16.63
822	1	2	0.78	14.33	17.67	162	15.72	12.19	16.01	17.01

line	Max T WGP	Max T 7_0 DBM	Max T 14_8 DBM	Max T 21_15 DBM	Min T WGP	Min T 7_0 DBM	Min T 14_8 DBM	Min T 21_15 DBM
214	20.31	20.40	20.86	19.90	12.37	13.17	11.46	12.43
215	20.30	20.14	21.29	19.60	12.33	13.14	11.77	11.67
216	20.31	19.83	21.61	19.81	12.49	13.20	12.04	11.04
217	20.21	20.14	21.29	19.60	12.39	13.14	11.77	11.67
218	20.32	19.44	21.60	20.50	12.40	12.84	12.04	10.63
219	20.39	19.83	21.61	19.81	12.46	13.20	12.04	11.04
220	20.16	19.83	21.61	19.81	12.39	13.20	12.04	11.04
221	20.32	19.44	21.60	20.50	12.40	12.84	12.04	10.63
222	20.40	19.44	21.60	20.50	12.37	12.84	12.04	10.63
223	20.36	19.83	21.61	19.81	12.32	13.20	12.04	11.04
224	19.62	15.46	19.36	21.24	11.75	8.48	11.71	12.17
225	20.07	18.93	20.86	21.00	12.14	11.59	12.13	11.20
301	20.30	20.40	20.86	19.90	12.47	13.17	11.46	12.43
302	20.39	19.83	21.61	19.81	12.46	13.20	12.04	11.04
303	20.30	20.40	20.86	19.90	12.47	13.17	11.46	12.43
304	20.16	19.83	21.61	19.81	12.39	13.20	12.04	11.04
305	20.05	19.44	21.60	20.50	12.31	12.84	12.04	10.63
306	20.33	20.14	21.29	19.60	12.44	13.14	11.77	11.67
307	20.51	21.29	20.63	19.46	12.42	12.64	11.67	12.40
308	20.31	20.40	20.86	19.90	12.37	13.17	11.46	12.43
309	20.30	20.40	20.86	19.90	12.47	13.17	11.46	12.43
310	20.21	20.14	21.29	19.60	12.39	13.14	11.77	11.67
311	20.16	19.83	21.61	19.81	12.39	13.20	12.04	11.04
312	20.39	19.83	21.61	19.81	12.46	13.20	12.04	11.04
313	20.36	20.14	21.29	19.60	12.46	13.14	11.77	11.67
314	20.28	20.14	21.29	19.60	12.49	13.14	11.77	11.67
315	20.40	19.44	21.60	20.50	12.37	12.84	12.04	10.63
316	20.28	20.14	21.29	19.60	12.49	13.14	11.77	11.67
317	20.21	20.14	21.29	19.60	12.39	13.14	11.77	11.67
318	20.21	20.14	21.29	19.60	12.39	13.14	11.77	11.67
319	20.38	20.40	20.86	19.90	12.44	13.17	11.46	12.43
320	20.21	20.14	21.29	19.60	12.39	13.14	11.77	11.67

line	Max T WGP	Max T 7_0 DBM	Max T 14_8 DBM	Max T 21_15 DBM	Min T WGP	Min T 7_0 DBM	Min T 14_8 DBM	Min T 21_15 DBM
321	20.16	19.83	21.61	19.81	12.39	13.20	12.04	11.04
322	20.39	19.83	21.61	19.81	12.46	13.20	12.04	11.04
323	20.28	20.14	21.29	19.60	12.49	13.14	11.77	11.67
324	20.32	19.44	21.60	20.50	12.40	12.84	12.04	10.63
325	20.21	20.14	21.29	19.60	12.39	13.14	11.77	11.67
401	20.31	20.40	20.86	19.90	12.37	13.17	11.46	12.43
402	20.16	19.83	21.61	19.81	12.39	13.20	12.04	11.04
403	20.16	19.83	21.61	19.81	12.39	13.20	12.04	11.04
404	20.38	19.44	21.60	20.50	12.35	12.84	12.04	10.63
405	20.40	19.44	21.60	20.50	12.37	12.84	12.04	10.63
406	20.31	19.83	21.61	19.81	12.49	13.20	12.04	11.04
407	20.32	19.44	21.60	20.50	12.40	12.84	12.04	10.63
408	20.38	19.44	21.60	20.50	12.35	12.84	12.04	10.63
409	20.38	19.44	21.60	20.50	12.35	12.84	12.04	10.63
410	20.36	19.36	21.24	20.83	12.22	11.71	12.17	10.76
411	20.19	19.44	21.60	20.50	12.28	12.84	12.04	10.63
412	20.19	19.44	21.60	20.50	12.28	12.84	12.04	10.63
413	20.05	19.44	21.60	20.50	12.31	12.84	12.04	10.63
414	20.05	19.44	21.60	20.50	12.31	12.84	12.04	10.63
415	20.19	19.44	21.60	20.50	12.28	12.84	12.04	10.63
416	20.19	19.44	21.60	20.50	12.28	12.84	12.04	10.63
417	20.32	19.44	21.60	20.50	12.40	12.84	12.04	10.63
418	20.32	19.44	21.60	20.50	12.40	12.84	12.04	10.63
419	20.32	19.44	21.60	20.50	12.40	12.84	12.04	10.63
420	20.32	19.44	21.60	20.50	12.40	12.84	12.04	10.63
421	20.32	19.44	21.60	20.50	12.40	12.84	12.04	10.63
422	20.40	19.44	21.60	20.50	12.37	12.84	12.04	10.63
423	20.32	19.44	21.60	20.50	12.40	12.84	12.04	10.63
424	20.36	20.14	21.29	19.60	12.46	13.14	11.77	11.67
425	20.31	19.83	21.61	19.81	12.49	13.20	12.04	11.04
501	20.31	19.83	21.61	19.81	12.49	13.20	12.04	11.04
502	20.31	19.83	21.61	19.81	12.49	13.20	12.04	11.04
503	20.30	20.40	20.86	19.90	12.47	13.17	11.46	12.43
504	20.31	19.83	21.61	19.81	12.49	13.20	12.04	11.04
505	20.05	19.44	21.60	20.50	12.31	12.84	12.04	10.63
506	20.40	19.44	21.60	20.50	12.37	12.84	12.04	10.63
507	20.42	21.29	20.63	19.46	12.45	12.64	11.67	12.40
508	20.32	19.44	21.60	20.50	12.40	12.84	12.04	10.63
509	20.32	19.44	21.60	20.50	12.40	12.84	12.04	10.63
510	20.40	19.44	21.60	20.50	12.37	12.84	12.04	10.63

line	Max T WGP	Max T 7_0 DBM	Max T 14_8 DBM	Max T 21_15 DBM	Min T WGP	Min T 7_0 DBM	Min T 14_8 DBM	Min T 21_15 DBM
511	20.32	21.29	20.63	19.46	12.35	12.64	11.67	12.40
512	20.38	20.40	20.86	19.90	12.44	13.17	11.46	12.43
513	20.28	19.36	21.24	20.83	12.20	11.71	12.17	10.76
514	19.80	15.94	19.44	21.60	11.90	8.87	12.84	12.04
515	19.69	15.70	18.93	20.86	11.69	7.97	11.59	12.13
516	20.40	19.44	21.60	20.50	12.37	12.84	12.04	10.63
517	19.57	15.94	19.44	21.60	11.78	8.87	12.84	12.04
518	19.46	15.70	18.93	20.86	11.56	7.97	11.59	12.13
519	20.28	20.14	21.29	19.60	12.49	13.14	11.77	11.67
520	20.36	19.83	21.61	19.81	12.32	13.20	12.04	11.04
521	20.39	19.83	21.61	19.81	12.46	13.20	12.04	11.04
522	20.48	21.24	20.83	19.99	12.38	12.17	10.76	13.36
523	20.32	19.44	21.60	20.50	12.40	12.84	12.04	10.63
524	20.31	19.83	21.61	19.81	12.49	13.20	12.04	11.04
525	19.86	15.94	19.44	21.60	11.94	8.87	12.84	12.04
601	19.46	15.70	18.93	20.86	11.56	7.97	11.59	12.13
602	20.38	19.44	21.60	20.50	12.35	12.84	12.04	10.63
603	19.46	15.70	18.93	20.86	11.56	7.97	11.59	12.13
604	20.36	19.83	21.61	19.81	12.32	13.20	12.04	11.04
605	19.88	16.97	19.83	21.61	11.99	9.19	13.20	12.04
606	19.77	15.94	19.44	21.60	11.87	8.87	12.84	12.04
607	19.77	15.94	19.44	21.60	11.87	8.87	12.84	12.04
608	19.77	15.94	19.44	21.60	11.87	8.87	12.84	12.04
609	19.69	15.70	18.93	20.86	11.69	7.97	11.59	12.13
610	19.57	15.94	19.44	21.60	11.78	8.87	12.84	12.04
611	19.77	15.94	19.44	21.60	11.87	8.87	12.84	12.04
612	20.31	20.40	20.86	19.90	12.37	13.17	11.46	12.43
613	20.38	20.40	20.86	19.90	12.44	13.17	11.46	12.43
614	20.31	19.83	21.61	19.81	12.49	13.20	12.04	11.04
615	20.39	19.83	21.61	19.81	12.46	13.20	12.04	11.04
616	20.38	20.40	20.86	19.90	12.44	13.17	11.46	12.43
617	20.02	17.96	20.14	21.29	12.09	9.83	13.14	11.77
618	20.39	19.83	21.61	19.81	12.46	13.20	12.04	11.04
619	20.12	18.54	20.40	20.86	12.16	10.50	13.17	11.46
620	20.42	21.29	20.63	19.46	12.45	12.64	11.67	12.40
621	20.39	19.83	21.61	19.81	12.46	13.20	12.04	11.04
622	20.39	19.83	21.61	19.81	12.46	13.20	12.04	11.04
623	20.31	19.36	21.24	20.83	12.28	11.71	12.17	10.76
624	19.96	17.96	20.14	21.29	12.12	9.83	13.14	11.77
625	19.65	15.70	18.93	20.86	11.77	7.97	11.59	12.13

line	Max T WGP	Max T 7_0 DBM	Max T 14_8 DBM	Max T 21_15 DBM	Min T WGP	Min T 7_0 DBM	Min T 14_8 DBM	Min T 21_15 DBM
701	20.28	21.29	20.63	19.46	12.32	12.64	11.67	12.40
702	19.80	17.96	20.14	21.29	11.98	9.83	13.14	11.77
703	19.80	17.96	20.14	21.29	11.98	9.83	13.14	11.77
704	20.30	20.40	20.86	19.90	12.47	13.17	11.46	12.43
705	20.16	18.61	21.29	20.63	12.24	10.94	12.64	11.67
706	20.12	18.54	20.40	20.86	12.16	10.50	13.17	11.46
707	20.05	18.54	20.40	20.86	12.20	10.50	13.17	11.46
708	20.02	17.96	20.14	21.29	12.09	9.83	13.14	11.77
709	20.36	19.36	21.24	20.83	12.22	11.71	12.17	10.76
710	19.99	17.96	20.14	21.29	12.06	9.83	13.14	11.77
711	20.02	18.61	21.29	20.63	12.10	10.94	12.64	11.67
712	20.31	19.83	21.61	19.81	12.49	13.20	12.04	11.04
713	20.09	18.54	20.40	20.86	12.14	10.50	13.17	11.46
714	20.16	18.61	21.29	20.63	12.24	10.94	12.64	11.67
715	19.77	15.94	19.44	21.60	11.87	8.87	12.84	12.04
716	19.77	15.94	19.44	21.60	11.87	8.87	12.84	12.04
717	19.51	15.46	19.36	21.24	11.68	8.48	11.71	12.17
718	19.77	15.94	19.44	21.60	11.87	8.87	12.84	12.04
719	19.51	15.46	19.36	21.24	11.68	8.48	11.71	12.17
720	20.31	19.83	21.61	19.81	12.49	13.20	12.04	11.04
721	20.51	21.29	20.63	19.46	12.42	12.64	11.67	12.40
722	20.36	19.36	21.24	20.83	12.22	11.71	12.17	10.76
723	19.46	15.70	18.93	20.86	11.56	7.97	11.59	12.13
724	20.31	19.83	21.61	19.81	12.49	13.20	12.04	11.04
725	20.02	17.96	20.14	21.29	12.09	9.83	13.14	11.77
801	20.42	21.29	20.63	19.46	12.45	12.64	11.67	12.40
802	19.65	17.96	20.14	21.29	12.04	9.83	13.14	11.77
803	20.30	20.86	21.00	19.86	12.29	12.13	11.20	12.93
804	20.42	21.29	20.63	19.46	12.45	12.64	11.67	12.40
805	20.48	21.24	20.83	19.99	12.38	12.17	10.76	13.36
806	20.39	19.83	21.61	19.81	12.46	13.20	12.04	11.04
807	20.36	20.14	21.29	19.60	12.46	13.14	11.77	11.67
808	20.32	19.44	21.60	20.50	12.40	12.84	12.04	10.63
809	19.99	17.96	20.14	21.29	12.06	9.83	13.14	11.77
810	19.80	17.96	20.14	21.29	11.98	9.83	13.14	11.77
811	19.51	15.46	19.36	21.24	11.68	8.48	11.71	12.17
812	19.46	15.70	18.93	20.86	11.56	7.97	11.59	12.13
813	19.51	15.46	19.36	21.24	11.68	8.48	11.71	12.17
814	19.46	15.70	18.93	20.86	11.56	7.97	11.59	12.13
815	20.02	17.96	20.14	21.29	12.09	9.83	13.14	11.77

line	Max T WGP	Max T 7_0 DBM	Max T 14_8 DBM	Max T 21_15 DBM	Min T WGP	Min T 7_0 DBM	Min T 14_8 DBM	Min T 21_15 DBM
816	19.96	17.96	20.14	21.29	12.12	9.83	13.14	11.77
817	19.69	15.70	18.93	20.86	11.73	7.97	11.59	12.13
818	19.46	15.70	18.93	20.86	11.56	7.97	11.59	12.13
819	19.51	15.46	19.36	21.24	11.68	8.48	11.71	12.17
820	20.38	20.40	20.86	19.90	12.44	13.17	11.46	12.43
821	19.46	15.70	18.93	20.86	11.56	7.97	11.59	12.13
822	19.57	15.94	19.44	21.60	11.78	8.87	12.84	12.04

line	PP WGP	PP 7_0 DBM	PP 14_8 DBM	PP 21_15 DBM	RH WGP	RH 7_0 DBM	RH 14_8 DBM	RH 21_15 DBM
214	168.4	41	17.6	17.8	78.1	78.4	79.1	82.4
215	170.2	42.8	31	23.2	77.9	77.9	79.3	82.3
216	174.8	25.8	30.8	18.4	78.5	78.9	79.5	80.5
217	170.2	42.8	31	23.2	78.2	77.9	79.3	82.3
218	174.8	25.8	30.8	17.8	78.3	78.7	79.6	79.1
219	168.8	25.8	30.8	18.4	78.3	78.9	79.5	80.5
220	174.8	25.8	30.8	18.4	78.3	78.9	79.5	80.5
221	174.8	25.8	30.8	17.8	78.3	78.7	79.6	79.1
222	168.8	25.8	30.8	17.8	78.1	78.7	79.6	79.1
223	168.8	25.8	30.8	18.4	78.5	78.9	79.5	80.5
224	220.6	51.8	25	35.6	79.1	83.9	79.4	78.5
225	173.6	40.8	45.4	17.6	78.6	80.7	78.9	78.1
301	168.4	41	17.6	17.8	78.3	78.4	79.1	82.4
302	168.8	25.8	30.8	18.4	78.3	78.9	79.5	80.5
303	168.4	41	17.6	17.8	78.3	78.4	79.1	82.4
304	174.8	25.8	30.8	18.4	78.3	78.9	79.5	80.5
305	174.8	25.8	30.8	17.8	78.1	78.7	79.6	79.1
306	164.2	42.8	31	23.2	78.4	77.9	79.3	82.3
307	160.6	48.4	26.6	42	77.9	78.1	79.4	83.0
308	168.4	41	17.6	17.8	78.1	78.4	79.1	82.4
309	168.4	41	17.6	17.8	78.3	78.4	79.1	82.4
310	170.2	42.8	31	23.2	78.2	77.9	79.3	82.3
311	174.8	25.8	30.8	18.4	78.3	78.9	79.5	80.5
312	168.8	25.8	30.8	18.4	78.3	78.9	79.5	80.5
313	164.2	42.8	31	23.2	78.2	77.9	79.3	82.3
314	170.2	42.8	31	23.2	78.4	77.9	79.3	82.3
315	168.8	25.8	30.8	17.8	78.1	78.7	79.6	79.1
316	170.2	42.8	31	23.2	78.4	77.9	79.3	82.3
317	170.2	42.8	31	23.2	78.2	77.9	79.3	82.3

line	PP WGP	PP 7_0 DBM	PP 14_8 DBM	PP 21_15 DBM	RH WGP	RH 7_0 DBM	RH 14_8 DBM	RH 21_15 DBM
318	170.2	42.8	31	23.2	78.2	77.9	79.3	82.3
319	162.4	41	17.6	17.8	78.1	78.4	79.1	82.4
320	170.2	42.8	31	23.2	78.2	77.9	79.3	82.3
321	174.8	25.8	30.8	18.4	78.3	78.9	79.5	80.5
322	168.8	25.8	30.8	18.4	78.3	78.9	79.5	80.5
323	170.2	42.8	31	23.2	78.4	77.9	79.3	82.3
324	174.8	25.8	30.8	17.8	78.3	78.7	79.6	79.1
325	170.2	42.8	31	23.2	78.2	77.9	79.3	82.3
401	168.4	41	17.6	17.8	78.1	78.4	79.1	82.4
402	174.8	25.8	30.8	18.4	78.3	78.9	79.5	80.5
403	174.8	25.8	30.8	18.4	78.3	78.9	79.5	80.5
404	168.8	25.8	30.8	17.8	78.3	78.7	79.6	79.1
405	168.8	25.8	30.8	17.8	78.1	78.7	79.6	79.1
406	174.8	25.8	30.8	18.4	78.5	78.9	79.5	80.5
407	174.8	25.8	30.8	17.8	78.3	78.7	79.6	79.1
408	168.8	25.8	30.8	17.8	78.3	78.7	79.6	79.1
409	168.8	25.8	30.8	17.8	78.3	78.7	79.6	79.1
410	172.8	29.8	35.6	17.6	78.2	79.4	78.5	78.5
411	153.8	25.8	30.8	17.8	78.5	78.7	79.6	79.1
412	153.8	25.8	30.8	17.8	78.5	78.7	79.6	79.1
413	174.8	25.8	30.8	17.8	78.1	78.7	79.6	79.1
414	174.8	25.8	30.8	17.8	78.1	78.7	79.6	79.1
415	153.8	25.8	30.8	17.8	78.5	78.7	79.6	79.1
416	153.8	25.8	30.8	17.8	78.5	78.7	79.6	79.1
417	174.8	25.8	30.8	17.8	78.3	78.7	79.6	79.1
418	174.8	25.8	30.8	17.8	78.3	78.7	79.6	79.1
419	174.8	25.8	30.8	17.8	78.3	78.7	79.6	79.1
420	174.8	25.8	30.8	17.8	78.3	78.7	79.6	79.1
421	174.8	25.8	30.8	17.8	78.3	78.7	79.6	79.1
422	168.8	25.8	30.8	17.8	78.1	78.7	79.6	79.1
423	174.8	25.8	30.8	17.8	78.3	78.7	79.6	79.1
424	164.2	42.8	31	23.2	78.2	77.9	79.3	82.3
425	174.8	25.8	30.8	18.4	78.5	78.9	79.5	80.5
501	174.8	25.8	30.8	18.4	78.5	78.9	79.5	80.5
502	174.8	25.8	30.8	18.4	78.5	78.9	79.5	80.5
503	168.4	41	17.6	17.8	78.3	78.4	79.1	82.4
504	174.8	25.8	30.8	18.4	78.5	78.9	79.5	80.5
505	174.8	25.8	30.8	17.8	78.1	78.7	79.6	79.1
506	168.8	25.8	30.8	17.8	78.1	78.7	79.6	79.1
507	166.6	48.4	26.6	42	78.1	78.1	79.4	83.0

line	PP WGP	PP 7_0 DBM	PP 14_8 DBM	PP 21_15 DBM	RH WGP	RH 7_0 DBM	RH 14_8 DBM	RH 21_15 DBM
508	174.8	25.8	30.8	17.8	78.3	78.7	79.6	79.1
509	174.8	25.8	30.8	17.8	78.3	78.7	79.6	79.1
510	168.8	25.8	30.8	17.8	78.1	78.7	79.6	79.1
511	166.6	48.4	26.6	42	77.9	78.1	79.4	83.0
512	162.4	41	17.6	17.8	78.1	78.4	79.1	82.4
513	172.8	29.8	35.6	17.6	78.3	79.4	78.5	78.5
514	220.4	51.6	25.8	30.8	78.7	83.8	78.7	79.6
515	220.6	47.8	31	45.4	78.7	82.0	80.7	78.9
516	168.8	25.8	30.8	17.8	78.1	78.7	79.6	79.1
517	205.4	51.6	25.8	30.8	78.3	83.8	78.7	79.6
518	205.6	47.8	31	45.4	79.1	82.0	80.7	78.9
519	170.2	42.8	31	23.2	78.4	77.9	79.3	82.3
520	168.8	25.8	30.8	18.4	78.5	78.9	79.5	80.5
521	168.8	25.8	30.8	18.4	78.3	78.9	79.5	80.5
522	153.8	35.6	17.6	41.8	78.0	78.5	78.5	82.6
523	174.8	25.8	30.8	17.8	78.3	78.7	79.6	79.1
524	174.8	25.8	30.8	18.4	78.5	78.9	79.5	80.5
525	226.4	51.6	25.8	30.8	79.0	83.8	78.7	79.6
601	205.6	47.8	31	45.4	79.1	82.0	80.7	78.9
602	168.8	25.8	30.8	17.8	78.3	78.7	79.6	79.1
603	205.6	47.8	31	45.4	79.1	82.0	80.7	78.9
604	168.8	25.8	30.8	18.4	78.5	78.9	79.5	80.5
605	218	53.8	25.8	30.8	78.9	81.4	78.9	79.5
606	220.4	51.6	25.8	30.8	79.1	83.8	78.7	79.6
607	220.4	51.6	25.8	30.8	79.1	83.8	78.7	79.6
608	220.4	51.6	25.8	30.8	79.1	83.8	78.7	79.6
609	220.6	47.8	31	45.4	78.7	82.0	80.7	78.9
610	205.4	51.6	25.8	30.8	78.3	83.8	78.7	79.6
611	220.4	51.6	25.8	30.8	79.1	83.8	78.7	79.6
612	168.4	41	17.6	17.8	78.1	78.4	79.1	82.4
613	162.4	41	17.6	17.8	78.1	78.4	79.1	82.4
614	174.8	25.8	30.8	18.4	78.5	78.9	79.5	80.5
615	168.8	25.8	30.8	18.4	78.3	78.9	79.5	80.5
616	162.4	41	17.6	17.8	78.1	78.4	79.1	82.4
617	209.8	47.4	21.2	31	78.4	80.7	77.9	79.3
618	168.8	25.8	30.8	18.4	78.3	78.9	79.5	80.5
619	204.6	44	41	17.6	78.2	80.1	78.4	78.7
620	166.6	48.4	26.6	42	78.1	78.1	79.4	83.0
621	168.8	25.8	30.8	18.4	78.3	78.9	79.5	80.5
622	168.8	25.8	30.8	18.4	78.3	78.9	79.5	80.5

line	PP WGP	PP 7_0 DBM	PP 14_8 DBM	PP 21_15 DBM	RH WGP	RH 7_0 DBM	RH 14_8 DBM	RH 21_15 DBM
623	178.8	29.8	35.6	17.6	78.2	79.4	78.5	78.5
624	215.8	47.4	21.2	31	78.7	80.7	77.9	79.3
625	220.6	47.8	31	45.4	78.9	82.0	80.7	78.9
701	145.6	48.4	26.6	42	78.3	78.1	79.4	83.0
702	194.8	47.4	21.2	31	79.0	80.7	77.9	79.3
703	194.8	47.4	21.2	31	79.0	80.7	77.9	79.3
704	168.4	41	17.6	17.8	78.3	78.4	79.1	82.4
705	197.6	34	39.2	26.6	78.4	80.0	78.1	79.4
706	204.6	44	41	17.6	78.2	80.1	78.4	78.7
707	210.6	44	41	17.6	78.6	80.1	78.4	78.7
708	209.8	47.4	21.2	31	78.4	80.7	77.9	79.3
709	172.8	29.8	35.6	17.6	78.2	79.4	78.5	78.5
710	209.8	47.4	21.2	31	78.8	80.7	77.9	79.3
711	176.6	34	39.2	26.6	78.6	80.0	78.1	79.4
712	174.8	25.8	30.8	18.4	78.5	78.9	79.5	80.5
713	204.6	44	41	17.6	78.6	80.1	78.4	78.7
714	197.6	34	39.2	26.6	78.4	80.0	78.1	79.4
715	220.4	51.6	25.8	30.8	79.1	83.8	78.7	79.6
716	220.4	51.6	25.8	30.8	79.1	83.8	78.7	79.6
717	205.6	51.8	25	35.6	79.2	83.9	79.4	78.5
718	220.4	51.6	25.8	30.8	79.1	83.8	78.7	79.6
719	205.6	51.8	25	35.6	79.2	83.9	79.4	78.5
720	174.8	25.8	30.8	18.4	78.5	78.9	79.5	80.5
721	160.6	48.4	26.6	42	77.9	78.1	79.4	83.0
722	172.8	29.8	35.6	17.6	78.2	79.4	78.5	78.5
723	205.6	47.8	31	45.4	79.1	82.0	80.7	78.9
724	174.8	25.8	30.8	18.4	78.5	78.9	79.5	80.5
725	209.8	47.4	21.2	31	78.4	80.7	77.9	79.3
801	166.6	48.4	26.6	42	78.1	78.1	79.4	83.0
802	215.8	47.4	21.2	31	78.6	80.7	77.9	79.3
803	163.6	45.4	17.6	41.8	77.9	78.9	78.1	82.8
804	166.6	48.4	26.6	42	78.1	78.1	79.4	83.0
805	153.8	35.6	17.6	41.8	78.0	78.5	78.5	82.6
806	168.8	25.8	30.8	18.4	78.3	78.9	79.5	80.5
807	164.2	42.8	31	23.2	78.2	77.9	79.3	82.3
808	174.8	25.8	30.8	17.8	78.3	78.7	79.6	79.1
809	209.8	47.4	21.2	31	78.8	80.7	77.9	79.3
810	194.8	47.4	21.2	31	79.0	80.7	77.9	79.3
811	205.6	51.8	25	35.6	79.2	83.9	79.4	78.5
812	205.6	47.8	31	45.4	79.1	82.0	80.7	78.9

line	PP WGP	PP 7_0 DBM	PP 14_8 DBM	PP 21_15 DBM	RH WGP	RH 7_0 DBM	RH 14_8 DBM	RH 21_15 DBM
813	205.6	51.8	25	35.6	79.2	83.9	79.4	78.5
814	205.6	47.8	31	45.4	79.1	82.0	80.7	78.9
815	209.8	47.4	21.2	31	78.4	80.7	77.9	79.3
816	215.8	47.4	21.2	31	78.7	80.7	77.9	79.3
817	226.6	47.8	31	45.4	78.9	82.0	80.7	78.9
818	205.6	47.8	31	45.4	79.1	82.0	80.7	78.9
819	205.6	51.8	25	35.6	79.2	83.9	79.4	78.5
820	162.4	41	17.6	17.8	78.1	78.4	79.1	82.4
821	205.6	47.8	31	45.4	79.1	82.0	80.7	78.9
822	205.4	51.6	25.8	30.8	78.3	83.8	78.7	79.6

PHS and marker data

Plot no	sample ID	Group	GI	FN	DI_1	DI_2	barc125	barc170A	barc170B	gwm3
214	1005	1	0.89	173	.	8.67	.	114	195	96
215	1003	1	0.98	121	17.67	.	.	114	195	102
216	1011	1	0.86	264	22.67	20.00	160	114	195	96
217	1016	1	0.89	115	8.67	4.33	166	114	195	96
218	1173	1	0.65	168	9.67	11.00	160	114	195	96
219	1174	1	0.81	189	21.33	27.33	160	114	185	96
220	1178	1	0.83	148	12.33	5.33	160	114	195	94
222	1194	1	0.81	171	17.00	10.33	160	114	195	96
225	1305	1	0.70	291	26.33	12.00	166	114	195	96
302	1189	1	0.85	169	11.67	9.67	162	114	192	96
314	1307	1	0.90	124	13.67	8.00	166	114	195	96
316	1316	1	0.85	86	5.33	5.67	166	114	195	98
318	1327	1	0.92	158	16.67	10.33	166	114	195	98
321	1317	1	0.97	62	4.00	5.33	160	114	195	96
408	1184	1	0.71	199	29.67	14.67	160	114	195	100
424	1006	1	0.93	192	7.00	.	160	114	195	96
425	1009	1	0.77	137	13.67	.	160	115	195	96
504	1029	1	0.88	202	15.33	16.67	160	114	185	100
505	1031	1	0.73	239	13.33	19.00	162	114	.	94
506	1036	1	0.90	201	4.33	.	160	114	195	102
508	1043	1	0.72	290	30.33	.	.	114	.	94
509	1044	1	0.87	214	8.33	.	160	114	185	102
510	1045	1	0.58	371	22.00	11.67	162	114	.	94
511	1046	1	0.87	101	15.67	.	162	115	185	94
512	1048	2	0.82	145	4.33	6.00	.	114	182	102
513	1052	2	0.81	165	.	.	166	114	201	102
514	1050	2	0.91	62	5.67	2.00	166	114	195	96
515	1054	2	0.85	117	7.00	1.00	166	115	195	96
516	1058	2	0.89	96	4.67	.	166	114	182	96
517	1064	2	0.86	119	18.33	21.67	.	114	182	98
518	1066	2	0.91	62	2.33	.	164	114	182	102
519	1068	2	0.92	280	7.00	.	166	114	185	100
520	1032	1	0.88	198	22.67	28.00	.	115	195	98
521	1039	1	0.82	161	10.33	.	.	114	.	102
522	1075	1	0.90	151	1.33	4.33	160	114	195	102
523	1027	1	0.97	109	.	.	166	114	185	100
524	1038	1	0.83	201	22.33	23.00	166	114	195	100
525	1071	2	0.77	92	9.67	14.00	164	114	195	96

Plot no	sample ID	Group	GI	FN	DI_1	DI_2	barc125	barc170A	barc170B	gwm3
601	1073	2	0.84	121	0.67	3.33	168	114	.	102
602	1086	2	0.78	129	15.00	1.67	166	115	.	98
603	1121	2	0.86	.	8.33	.	166	115	201	102
604	1124	2	0.89	.	.	.	166	114	189	102
605	1127	2	0.81	.	3.67	3.00	166	114	182	96
606	1131	2	0.85	128	9.67	9.67	166	114	195	96
607	1134	2	0.90	73	4.33	5.67	166	114	189	102
608	1137	2	0.50	226	46.33	32.00	166	114	.	98
609	1141	2	0.75	195	8.00	12.33	.	114	.	96
610	1142	2	0.70	182	27.67	22.67	164	114	182	.
611	1145	2	0.71	193	30.33	24.67	.	115	195	96
612	1041	1	0.77	.	2.00	9.00	170	114	195	96
613	1169	1	0.88	188	3.67	16.00	166	114	195	96
614	1170	1	0.79	301	20.67	14.33	166	114	195	98
615	1171	1	0.81	219	12.00	.	160	114	192	96
616	1172	1	0.84	164	5.67	3.00	160	114	195	98
619	1175	1	0.88	196	3.00	6.67	160	114	195	96
620	1176	1	0.83	221	.	7.33	160	114	.	96
621	1177	1	0.84	171	13.33	.	166	114	195	102
623	1179	1	0.73	207	0.67	.	160	114	192	96
624	1180	1	0.77	196	1.33	10.00	160	114	195	96
625	1181	1	0.78	139	.	13.00	160	114	195	96
701	1182	1	0.84	203	1.33	16.00	166	114	195	102
702	1183	1	0.72	221	11.67	13.00	160	114	195	100
704	1185	1	0.94	220	6.33	10.33	166	114	185	100
705	1186	1	0.83	258	.	.	160	114	195	100
706	1187	1	0.79	212	12.00	11.00	166	114	185	100
707	1188	1	0.92	212	4.67	14.00	160	114	195	96
709	1190	1	0.74	227	0.67	.	160	114	195	96
710	1191	1	0.59	287	12.33	37.00	162	114	.	96
711	1192	1	0.82	173	6.67	.	160	114	195	94
712	1193	1	0.82	202	23.00	19.00	160	114	195	96
714	1195	1	0.94	232	5.33	.	166	114	185	100
715	1106	2	0.60	309	61.67	21.33	166	115	.	102
717	1102	2	0.50	262	49.33	0.67	168	115	.	96
719	1091	2	0.64	198	27.67	28.67	166	114	189	96
720	1079	2	0.66	118	9.67	20.67	166	115	.	.
721	1080	2	0.86	108	1.00	8.67	166	114	189	98
723	1114	2	0.54	187	33.33	15.00	168	114	182	96
724	1081	2	0.87	239	18.67	1.33	168	114	185	100

Plot no	sample ID	Group	GI	FN	DI_1	DI_2	barc125	barc170A	barc170B	gwm3
725	1082	2	0.65	266	7.00	10.67	166	114	185	100
801	1083	2	0.89	156	1.67	8.67	166	114	185	100
802	1084	2	0.91	189	1.67	1.33	166	114	185	98
803	1085	2	0.98	140	5.00	11.67	166	114	185	100
804	1020	1	0.93	96	0.67	.	166	114	185	100
805	1018	1	0.92	177	4.67	.	166	114	185	98
807	1152	1	0.95	101	5.00	.	160	114	195	98
808	1148	2	0.79	202	9.67	.	166	114	195	96
809	1158	2	0.87	83	.	0.67	168	114	195	96
810	1161	2	0.84	88	0.33	.	168	114	195	96
811	1164	2	0.88	89	.	3.33	166	115	195	96
812	1057	2	0.86	121	0.33	.	166	115	201	102
813	1060	2	0.85	133	9.00	.	166	115	.	96
814	1063	2	0.50	164	38.33	10.67	166	114	182	96
815	1116	1	0.75	136	1.67	6.33	160	115	195	96
816	1119	1	0.70	132	21.00	43.00	170	115	195	96
817	1120	1	0.58	229	32.33	31.33	160	114	185	96
818	1166	2	0.84	92	4.67	0.67	166	114	195	102
819	1168	2	0.87	82	2.00	4.33	166	114	189	102
820	1275	1	0.76	.	.	.	170	114	195	96

Plot no	Gwm 66A	Gwm 66B	VP1 A	Wmc 153	Wmc 307	Wmc 552	DuPW 4	Gpw 4152	Gwm 155	Gwm 938	Cfa 2193
214	.	.	257	.	.	173	309	294	162	153	236
215	.	161	257	.	.	.	309	294	169	153	214
216	.	161	257	.	.	.	309	294	169	218	236
217	.	166	297	.	.	.	309	.	167	.	236
218	106	158	257	199	168	180	309	294	161	218	231
219	106	157	257	199	168	180	213	296	161	218	231
220	108	.	297	199	168	176	215	294	161	155	231
222	108	158	297	199	168	180	309	294	161	218	231
225	106	149	297	199	170	178	213	294	160	.	231
302	.	163	257	199	168	180	213	296	161	.	236
314	106	149	257	199	168	.	213	294	160	218	236
316	.	149	257	199	168	180	213	294	160	.	236
318	106	149	257	.	168	173	309	294	162	.	214
321	106	.	297	199	168	180	213	294	.	218	231
408	108	149	257	199	168	180	309	294	161	.	231

Plot no	Gwm 66A	Gwm 66B	VP1 A	Wmc 153	Wmc 307	Wmc 552	DuPW 4	Gpw 4152	Gwm 155	Gwm 938	Cfa 2193
424	.	161	257	.	.	.	309	294	169	220	240
425	.	161	297	.	.	.	309	294	161	218	231
504	106	158	257	199	168	180	213	296	169	218	231
505	106	.	257	199	168	178	215	296	167	169	236
506	.	158	257	.	168	.	309	.	169	153	236
508	108	149	.	199	168	178	215	296	167	169	236
509	108	161	257	199	168	173	213	296	169	218	231
510	106	157	257	199	168	178	215	296	167	169	236
511	108	157	257	199	168	178	213	296	169	169	231
512	122	.	312	199	168	173	309	296	165	153	231
513	.	166	257	199	166	173	213	296	165	153	231
514	108	168	257	.	166	182	309	296	162	153	234
515	106	149	257	199	166	171	309	296	165	153	231
516	105	166	.	199	166	173	213	.	165	.	.
517	.	149	257	199	168	184	.	.	165	.	231
518	.	149	312	199	166	173	213	296	165	153	231
519	108	166	297	199	168	180	213	296	169	206	.
520	.	.	297	.	168	.	213	294	169	218	231
521	.	.	257	199	.	173	213	296	.	153	231
522	.	161	257	199	.	173	213	294	169	218	231
523	106	163	257	199	168	.	213	294	169	.	231
524	.	166	257	199	.	.	309	296	169	153	229
525	106	.	.	164	166	171	309	296	145	.	229
601	122	168	297	164	166	184	.	294	145	153	231
602	108	166	297	179	166	178	213	296	162	.	231
603	106	166	257	179	166	173	213	296	165	153	229
604	122	166	297	199	166	173	213	296	165	200	231
605	106	166	257	199	166	171	309	296	165	200	231
606	106	166	257	179	170	182	309	296	165	.	229
607	122	166	257	199	166	173	213	296	165	153	231
608	.	166	257	179	166	171	309	296	165	200	229
609	.	149	297	.	168	182	215	296	.	.	.
610	.	.	257	199	166	.	213	.	165	153	231
611	108	.	312	205	168	171	309	296	161	153	234
612	.	.	.	.	170	178	.	296	.	.	.
613	108	149	257	199	168	180	309	.	167	.	236
614	108	149	257	199	168	180	309	294	169	218	214
615	106	149	257	199	168	180	213	294	161	155	231
616	108	.	297	199	168	180	309	296	161	218	.
619	106	161	257	199	168	176	309	294	169	218	231

Plot no	Gwm 66A	Gwm 66B	VP1 A	Wmc 153	Wmc 307	Wmc 552	DuPW 4	Gpw 4152	Gwm 155	Gwm 938	Cfa 2193
620	.	157	257	199	168	180	215	294	169	155	214
621	108	166	.	199	168	173	309	294	169	153	214
623	.	.	257	199	168	180	309	294	161	218	214
624	.	161	257	199	168	.	309	294	161	218	.
625	108	161	297	199	168	.	309	294	169	218	236
701	108	166	257	199	.	173	309	294	169	153	231
702	108	149	257	199	168	180	309	294	161	.	231
704	108	166	297	199	168	180	213	296	169	206	214
705	.	158	.	199	168	180	213	294	161	206	236
706	106	166	257	199	168	180	213	296	161	206	231
707	.	161	.	.	168	180	309	294	162	153	.
709	108	.	297	199	168	180	309	294	161	169	231
710	106	163	257	199	168	176	215	296	169	169	231
711	108	161	297	199	168	180	309	294	161	218	231
712	106	.	297	199	168	180	309	294	161	220	236
714	.	166	297	199	168	180	213	296	169	206	214
715	106	166	257	199	.	184	215	296	.	.	.
717	106	168	297	.	168	.	.	.	145	.	231
719	106	166	297	179	170	180	213	296	162	200	229
720	108	166	.	.	168	180	213	296	162	200	234
721	108	166	297	179	168	178	213	296	162	200	231
723	105	168	297	205	170	184	213	296	161	.	231
724	.	157	257	199	168	180	213	294	161	206	231
725	.	147	257	199	168	180	213	294	169	.	231
801	106	157	257	199	170	180	213	294	169	206	231
802	106	.	257	199	.	178	213	294	169	206	231
803	.	157	257	199	168	180	213	294	169	206	231
804	.	166	257	.		.	213	294	169	206	231
805	.	166	257	.	.	.	213	294	169	206	231
807	.	149	297	199	168	180	309	294	161	.	.
808	106	147	.	199	166	.	309	296	165	153	231
809	105	.	297	164	166	171	309	296	145	153	229
810	108	168	297	164	166	171	309	296	145	153	229
811	108	166	312	199	168	171	309	296	165	153	231
812	106	166	257	179	166	173	213	296	165	153	229
813	106	147	297	199	.	171	213	296	165	153	231
814	106	166	257	205	166	171	309	296	161	200	229
815	.	161	297	199	168	180	309	294	161	218	231
816	108	.	257	199	170	176	213	296	169	220	231
817	106	161	297	199	170	176	309	296	162	.	240

Plot no	Gwm 66A	Gwm 66B	VP1 A	Wmc 153	Wmc 307	Wmc 552	DuPW 4	Gpw 4152	Gwm 155	Gwm 938	Cfa 2193
818	106	149	.	.	166	184	309	296	165	.	234
819	122	147	297	199	168	184	215	.	165	200	231
820	106	.	257	.	170	180	215	296	162	.	240

Plot no	Gwm 937	Wmc 650	CD 920298	Gwm 285	Gwm 894	Hbe 3	Gwm 637	Gwm 802	VP 1B	Wmc 513	Wmc 559
214	208	108	524	241	175	163	.	148	466	.	275
215	208	108	524	241	175	163	189	148	467	.	277
216	208	108	524	.	175	163	.	156	558	.	275
217	210	108	524	241	178	163	189	150	.	.	275
218	208	108	524	241	175	163	.	154	.	.	254
219	176	119	419	241	142	168	.	154	558	240	256
220	176	108	421	241	142	163	.	159	556	245	274
222	208	108	524	319	175	163	.	154	.	.	254
225	176	108	419	239	142	168	.	148	.	.	254
302	178	.	419	.	144	168	.	156	.	.	274
314	178	108	419	360	144	163	.	156	557	240	256
316	178	108	419	.	144	163	.	159	558	.	256
318	208	108	524	360	175	163	.	159	.	.	274
321	176	108	419	.	142	168	.	156	558	.	256
408	208	108	524	241	175	163	.	159	.	.	275
424	208	108	524	.	175	163	.	156	556	.	.
425	208	108	524	362	175	163	.	159	557	248	275
504	176	119	419	360	142	168	.	156	558	240	256
505	176	.	421	362	142	170	.	156	466	.	274
506	208	108	524	.	175	163	189	156	.	.	256
508	210	.	421	331	178	170	.	156	.	.	274
509	176	119	419	.	142	168	173	159	.	.	256
510	176	.	421	360	142	170	.	156	557	.	274
511	176	119	419	362	142	168	.	156	558	240	256
512	208	119	524	241	175	163	189	154	467	.	274
513	176	121	419	241	142	168	189	148	.	.	.
514	208	106	524	241	142	163	189	148	.	.	.
515	208	106	524	241	175	163	189	148	467	.	274
516	176	119	419	241	142	168	187	148	.	.	274
517	176	119	419	239	142	168	187	161	.	.	274
518	176	119	419	241	142	168	.	148	.	.	274

Plot no	Gwm 937	Wmc 650	CD 920298	Gwm 285	Gwm 894	Hbe 3	Gwm 637	Gwm 802	VP 1B	Wmc 513	Wmc 559
519	176	119	419	.	142	168	.	.	.	243	.
520	176	108	419	362	142	168	.	159	558	.	256
521	176	.	419	241	142	168	189	148	.	.	274
522	176	108	419	241	142	168	.	148	557	248	256
523	176	119	419	362	142	168	173	159	556	.	256
524	208	108	524	.	175	163	189	154	467	.	256
525	208	108	524	247	175	163	.	158	.	.	275
601	.	125	.	247	.	.	.	158	.	.	275
602	174	.	419	.	139	168	.	159	.	.	252
603	176	121	419	241	142	168	189	148	.	.	256
604	174	129	419	241	139	168	.	148	467	.	252
605	208	119	524	241	175	163	187	159	467	.	274
606	208	106	524	239	175	163	.	159	.	.	274
607	174	.	419	241	139	168	.	148	.	.	274
608	208	125	524	241	175	163	.	159	.	.	256
609	.	129	421	.	.	170	.	161	.	.	.
610	176	119	419	241	142	168	187	148	.	.	274
611	208	106	524	.	175	163	187	154	467	.	272
612	.	.	.	239	.	.	.	148	.	.	274
613	178	108	524	241	178	163	189	150	467	.	274
614	208	108	524	362	175	163	.	159	.	.	.
615	178	108	419	241	144	168	.	156	.	.	.
616	208	108	524	.	175	.	.	156	.	.	.
619	208	108	524	319	175	163	.	.	558	.	256
620	176	.	421	362	142	170	.	156	556	248	277
621	208	108	524	241	175	163	189	148	.	.	275
623	208	108	524	360	175	163	.	156	.	.	274
624	208	108	524	.	175	163	.	156	.	.	275
625	208	108	524	319	175	163	.	154	557	.	274
701	208	108	524	241	175	163	.	150	.	.	274
702	208	108	524	241	175	163	.	159	.	.	275
704	176	119	419	.	142	168	189	150	.	.	277
705	176	108	419	.	142	168	189	159	466	245	256
706	176	119	419	.	142	168	.	150	557	245	254
707	208	108	524	239	175	163	.	156	.	.	.
709	208	108	524	241	175	163	.	156	558	.	274
710	210	.	419	331	177	170	.	156	557	.	.
711	208	108	524	241	175	163	.	156	557	.	.
712	208	108	524	.	175	163	.	156	558	.	274
714	176	119	419	.	142	168	189	150	.	.	277

Plot no	Gwm 937	Wmc 650	CD 920298	Gwm 285	Gwm 894	Hbe 3	Gwm 637	Gwm 802	VP 1B	Wmc 513	Wmc 559
715	.	125	421	.	.	170	189	158	.	.	275
717	174	.	.	.	139	.	.	154	.	.	272
719	174	129	419	.	139	168	.	159	467	.	252
720	.	.	419	241	.	168	.	159	467	.	272
721	174	129	419	241	139	168	189	158	467	.	252
723	176	119	419	241	142	168	.	159	467	.	.
724	176	119	419	.	142	168	.	156	.	.	256
725	176	119	419	.	142	168	.	159	.	.	256
801	176	119	419	241	142	168	.	156	.	243	256
802	176	119	419	.	142	168	.	156	.	243	274
803	176	119	419	241	142	168	.	159	.	243	275
804	178	119	419	.	144	168	173	156	557	245	.
805	176	119	419	241	142	168	.	154	557	240	275
807	208	108	524	.	175	163	.	159	556	.	.
808	208	108	524	.	175	163	.	148	467	.	252
809	208	106	524	247	175	163	.	158	467	.	274
810	208	106	524	247	175	163	.	154	.	.	274
811	208	106	419	.	142	163	189	154	.	.	274
812	176	121	419	241	142	168	.	148	.	.	256
813	174	.	419	.	139	168	.	159	.	.	274
814	208	119	524	.	175	163	189	159	467	.	274
815	208	108	524	331	175	163	.	156	.	.	275
816	176	108	419	241	142	168	.	159	.	.	256
817	208	.	524	241	175	163	.	159	.	.	.
818	208	108	524	241	175	163	189	148	.	.	274
819	.	.	421	239	.	170	187	161	467	.	274
820	208	108	421	239	175	163	.	159	.	.	256

Maturity to harvest climatic data

		Maturity to 1st Harvest					1st Harvest to 2nd Harvest				
Plot no	Group	Mean T	Max T	Min T	RH	PP	Mean T	Max T	Min T	RH	PP
214	1	13.11	17.11	9.38	81.31	60.00	11.17	15.69	6.16	78.58	94.20
215	1	12.89	17.27	8.73	80.49	58.40	10.61	14.95	5.86	77.31	94.40
216	1	12.20	16.73	7.59	78.64	56.60	10.05	14.57	5.28	78.20	94.40
217	1	12.89	17.27	8.73	80.49	58.40	10.61	14.95	5.86	77.31	94.40
218	1	11.62	16.51	6.51	77.55	52.20	10.02	13.76	6.07	79.20	141.80
219	1	12.20	16.73	7.59	78.64	56.60	10.04	14.57	5.28	78.20	94.40
220	1	12.20	16.73	7.59	78.64	56.60	10.04	14.57	5.28	78.20	94.40
221	1	11.61	16.51	6.51	77.55	52.20	10.02	13.76	6.07	79.20	141.80
222	1	11.61	16.51	6.51	77.55	52.20	10.02	13.76	6.07	79.20	141.80
223	1	12.20	16.73	7.59	78.64	56.60	10.04	14.57	5.28	78.20	94.40
224	1	11.79	16.44	6.79	77.42	35.20	6.93	11.21	2.52	79.27	132.80
225	1	11.29	15.98	6.38	78.38	48.20	7.78	11.90	3.50	79.46	146.80
301	1	13.10	17.11	9.38	81.31	60.00	11.17	15.69	6.16	78.58	94.20
302	1	12.20	16.73	7.59	78.64	56.60	10.04	14.57	5.28	78.20	94.40
303	1	13.10	17.11	9.38	81.31	60.00	10.64	15.02	5.85	77.29	94.40
304	1	12.20	16.73	7.59	78.64	56.60	10.04	14.57	5.28	78.20	94.40
305	1	11.61	16.51	6.51	77.55	52.20	10.02	13.76	6.07	79.20	141.80
306	1	12.89	17.27	8.73	80.49	58.40	10.61	14.95	5.86	77.31	94.40
307	1	13.38	17.31	9.78	81.34	63.00	11.17	15.69	6.16	78.58	94.20
308	1	13.10	17.11	9.38	81.31	60.00	11.17	15.69	6.16	78.58	94.20
309	1	13.10	17.11	9.38	81.31	60.00	11.17	15.69	6.16	78.58	94.20
310	1	12.89	17.27	8.73	80.49	58.40	10.61	14.95	5.86	77.31	94.40
311	1	12.20	16.73	7.59	78.64	56.60	10.04	14.57	5.28	78.20	94.40
312	1	12.20	16.73	7.59	78.64	56.60	10.04	14.57	5.28	78.20	94.40
313	1	12.89	17.27	8.73	80.49	58.40	10.61	14.95	5.86	77.31	94.40
314	1	12.89	17.27	8.73	80.49	58.40	10.61	14.95	5.86	77.31	94.40
315	1	11.61	16.51	6.51	77.55	52.20	10.02	13.76	6.07	79.20	141.80
316	1	12.89	17.27	8.73	80.49	58.40	10.07	14.20	5.63	78.14	142.20
317	1	12.89	17.27	8.73	80.49	58.40	10.07	14.20	5.63	78.14	142.20
318	1	12.89	17.27	8.73	80.49	58.40	10.07	14.20	5.63	78.14	142.20
319	1	13.10	17.11	9.38	81.31	60.00	11.17	15.69	6.16	78.58	94.20
320	1	12.89	17.27	8.73	80.49	58.40	10.61	14.95	5.86	77.31	94.40
321	1	12.20	16.73	7.59	78.64	56.60	10.04	14.57	5.28	78.20	94.40
322	1	12.20	16.73	7.59	78.64	56.60	10.04	14.57	5.28	78.20	94.40
323	1	12.89	17.27	8.73	80.49	58.40	10.61	14.95	5.86	77.31	94.40
324	1	11.61	16.51	6.51	77.55	52.20	10.02	13.76	6.07	79.20	141.80

		Maturity to 1st Harvest					1st Harvest to 2nd Harvest				
Plot no	Group	Mean T	Max T	Min T	RH	PP	Mean T	Max T	Min T	RH	PP
325	1	12.89	17.27	8.73	80.49	58.40	10.61	14.95	5.86	77.31	94.40
401	1	13.10	17.11	9.38	81.31	60.00	11.17	15.69	6.16	78.58	94.20
402	1	12.20	16.73	7.59	78.64	56.60	10.04	14.57	5.28	78.20	94.40
403	1	12.20	16.73	7.59	78.64	56.60	10.04	14.57	5.28	78.20	94.40
404	1	11.61	16.51	6.51	77.55	52.20	10.02	13.76	6.07	79.20	141.80
405	1	11.61	16.51	6.51	77.55	52.20	10.02	13.76	6.07	79.20	141.80
406	1	12.20	16.73	7.59	78.64	56.60	10.04	14.57	5.28	78.20	94.40
407	1	11.61	16.51	6.51	77.55	52.20	10.02	13.76	6.07	79.20	141.80
408	1	11.61	16.51	6.51	77.55	52.20	10.02	13.76	6.07	79.20	141.80
409	1	11.61	16.51	6.51	77.55	52.20	10.02	13.76	6.07	79.20	141.80
410	1	11.45	16.21	6.39	78.02	52.20	9.93	13.68	6.03	79.36	141.80
411	1	11.61	16.51	6.51	77.55	52.20	10.02	13.76	6.07	79.20	141.80
412	1	11.61	16.51	6.51	77.55	52.20	10.02	13.76	6.07	79.20	141.80
413	1	11.61	16.51	6.51	77.55	52.20	10.02	13.76	6.07	79.20	141.80
414	1	11.61	16.51	6.51	77.55	52.20	10.02	13.76	6.07	79.20	141.80
415	1	11.61	16.51	6.51	77.55	52.20	10.02	13.76	6.07	79.20	141.80
416	1	11.61	16.51	6.51	77.55	52.20	10.02	13.76	6.07	79.20	141.80
417	1	11.61	16.51	6.51	77.55	52.20	10.02	13.76	6.07	79.20	141.80
418	1	11.61	16.51	6.51	77.55	52.20	10.02	13.76	6.07	79.20	141.80
419	1	11.61	16.51	6.51	77.55	52.20	10.02	13.76	6.07	79.20	141.80
420	1	11.61	16.51	6.51	77.55	52.20	10.02	13.76	6.07	79.20	141.80
421	1	11.61	16.51	6.51	77.55	52.20	10.02	13.76	6.07	79.20	141.80
422	1	11.61	16.51	6.51	77.55	52.20	10.02	13.76	6.07	79.20	141.80
423	1	11.61	16.51	6.51	77.55	52.20	10.02	13.76	6.07	79.20	141.80
424	1	12.89	17.27	8.73	80.49	58.40	*	*	*	*	*
425	1	12.20	16.73	7.59	78.64	56.60	*	*	*	*	*
501	1	12.20	16.73	7.59	78.64	56.60	10.04	14.57	5.28	78.20	94.40
502	1	12.20	16.73	7.59	78.64	56.60	10.04	14.57	5.28	78.20	94.40
503	1	13.10	17.11	9.38	81.31	60.00	11.17	15.69	6.16	78.58	94.20
504	1	12.20	16.73	7.59	78.64	56.60	10.04	14.57	5.28	78.20	94.40
505	1	11.61	16.51	6.51	77.55	52.20	10.02	13.76	6.07	79.20	141.80
506	1	11.61	16.51	6.51	77.55	52.20	*	*	*	*	*
507	1	13.38	17.31	9.78	81.34	63.00	11.17	15.69	6.16	78.58	94.20
508	1	11.61	16.51	6.51	77.55	52.20	*	*	*	*	*
509	1	11.61	16.51	6.51	77.55	52.20	*	*	*	*	*
510	1	11.61	16.51	6.51	77.55	52.20	10.02	13.76	6.07	79.20	141.80
511	1	13.26	17.31	9.45	80.93	63.20	11.16	15.64	6.18	78.66	94.20
512	2	13.00	17.12	9.05	80.87	60.20	11.16	15.64	6.18	78.66	94.20
513	2	11.44	16.21	6.39	78.02	52.20	9.93	13.68	6.03	79.36	141.80

		Maturity to 1st Harvest					1st Harvest to 2nd Harvest				
Plot no	Group	Mean T	Max T	Min T	RH	PP	Mean T	Max T	Min T	RH	PP
514	2	11.75	16.33	6.87	77.93	43.40	8.98	13.00	4.86	78.64	106.60
515	2	11.91	16.59	6.83	76.86	32.80	6.93	11.21	2.52	79.27	132.80
516	2	11.61	16.51	6.51	77.55	52.20	*	*	*	*	*
517	2	11.75	16.33	6.87	77.93	43.40	8.97	13.00	4.86	78.64	106.60
518	2	11.91	16.59	6.83	76.86	32.80	6.93	11.21	2.52	79.27	132.80
519	2	12.89	17.27	8.73	80.49	58.40	*	*	*	*	*
520	1	12.20	16.73	7.59	78.64	56.60	10.04	14.57	5.28	78.20	94.40
521	1	11.94	16.79	6.86	77.76	56.80	*	*	*	*	*
522	1	13.61	17.56	9.95	80.14	77.80	*	*	*	*	*
523	1	11.61	16.51	6.51	77.55	52.20	*	*	*	*	*
524	1	12.20	16.73	7.59	78.64	56.60	8.06	12.36	3.55	78.94	147.00
525	2	11.75	16.33	6.87	77.93	43.40	8.97	13.00	4.86	78.64	106.60
601	2	11.22	15.98	6.10	76.94	63.20	6.22	10.37	1.92	79.38	84.60
602	2	11.61	16.51	6.51	77.55	52.20	10.02	13.76	6.07	79.20	141.80
603	2	11.91	16.59	6.83	76.86	32.80	6.93	11.21	2.52	79.27	132.80
604	2	11.94	16.79	6.86	77.76	56.80	*	*	*	*	*
605	2	11.75	16.33	6.87	77.93	43.40	8.80	13.04	4.45	78.46	95.60
606	2	11.75	16.33	6.87	77.93	43.40	8.97	13.00	4.86	78.64	106.60
607	2	11.75	16.33	6.87	77.93	43.40	8.97	13.00	4.86	78.64	106.60
608	2	11.75	16.33	6.87	77.93	43.40	8.97	13.00	4.86	78.64	106.60
609	2	11.91	16.59	6.83	76.86	32.80	6.93	11.21	2.52	79.27	132.80
610	2	11.75	16.33	6.87	77.93	43.40	8.97	13.00	4.86	78.64	106.60
611	2	11.75	16.33	6.87	77.93	43.40	8.97	13.00	4.86	78.64	106.60
612	1	13.10	17.11	9.38	81.31	60.00	11.17	15.69	6.16	78.58	94.20
613	1	13.10	17.11	9.38	81.31	60.00	11.17	15.69	6.16	78.58	94.20
614	1	12.20	16.73	7.59	78.64	56.60	10.04	14.57	5.28	78.20	94.40
615	1	12.20	16.73	7.59	78.64	56.60	*	*	*	*	*
616	1	13.10	17.11	9.38	81.31	60.00	11.17	15.69	6.16	78.58	94.20
617	1	11.17	15.98	5.85	76.81	16.60	8.91	12.82	5.01	80.90	144.40
618	1	12.20	16.73	7.59	78.64	56.60	10.04	14.57	5.28	78.20	94.40
619	1	11.23	15.90	6.11	77.44	29.60	7.54	11.69	3.29	79.59	146.80
620	1	13.38	17.31	9.78	81.34	63.00	11.17	15.69	6.16	78.58	94.20
621	1	12.20	16.73	7.59	78.64	56.60	*	*	*	*	*
622	1	12.20	16.73	7.59	78.64	56.60	*	*	*	*	*
623	1	11.44	16.21	6.39	78.02	52.20	*	*	*	*	*
624	1	11.16	15.98	5.85	76.81	16.60	8.91	12.82	5.01	80.90	144.40
625	1	11.91	16.59	6.83	76.86	32.80	6.93	11.21	2.52	79.27	132.80
701	1	13.38	17.31	9.78	81.34	63.00	11.17	15.69	6.16	78.58	94.20
702	1	11.16	15.98	5.85	76.81	16.60	8.91	12.82	5.01	80.90	144.40

		Maturity to 1st Harvest					1st Harvest to 2nd Harvest				
Plot no	Group	Mean T	Max T	Min T	RH	PP	Mean T	Max T	Min T	RH	PP
703	1	11.16	15.98	5.85	76.81	16.60	8.91	12.82	5.01	80.90	144.40
704	1	13.10	17.11	9.38	81.31	60.00	11.17	15.69	6.16	78.58	94.20
705	1	11.17	16.02	6.00	77.59	32.40	*	*	*	*	*
706	1	11.23	15.90	6.11	77.44	29.60	7.54	11.69	3.29	79.59	146.80
707	1	11.23	15.90	6.11	77.44	29.60	7.54	11.69	3.29	79.59	146.80
708	1	11.16	15.98	5.85	76.81	16.60	8.91	12.82	5.01	80.90	144.40
709	1	11.44	16.21	6.39	78.02	52.20	*	*	*	*	*
710	1	11.16	15.98	5.85	76.81	16.60	8.91	12.82	5.01	80.90	144.40
711	1	11.17	16.02	6.00	77.59	32.40	*	*	*	*	*
712	1	12.20	16.73	7.59	78.64	56.60	10.04	14.57	5.28	78.20	94.40
713	1	11.23	15.90	6.11	77.44	29.60	7.54	11.69	3.29	79.59	146.80
714	1	11.17	16.02	6.00	77.59	32.40	*	*	*	*	*
715	2	11.75	16.33	6.87	77.93	43.40	8.97	13.00	4.86	78.64	106.60
716	2	11.75	16.33	6.87	77.93	43.40	8.97	13.00	4.86	78.64	106.60
717	2	11.79	16.44	6.79	77.42	35.20	8.97	13.00	4.86	78.64	106.60
718	2	11.75	16.33	6.87	77.93	43.40	8.97	13.00	4.86	78.64	106.60
719	2	11.79	16.44	6.79	77.42	35.20	8.97	13.00	4.86	78.64	106.60
720	2	12.20	16.73	7.59	78.64	56.60	10.04	14.57	5.28	78.20	94.40
721	2	13.38	17.31	9.78	81.34	63.00	11.17	15.69	6.16	78.58	94.20
722	2	11.44	16.21	6.39	78.02	52.20	*	*	*	*	*
723	2	11.91	16.59	6.83	76.86	32.80	6.93	11.21	2.52	79.27	132.80
724	2	12.20	16.73	7.59	78.64	56.60	8.06	12.36	3.55	78.94	147.00
725	2	11.16	15.98	5.85	76.81	16.60	8.91	12.82	5.01	80.90	144.40
801	2	14.40	18.04	11.02	81.55	52.20	11.13	15.61	6.33	79.25	110.20
802	2	11.16	15.98	5.85	76.81	16.60	8.91	12.82	5.01	80.90	144.40
803	2	14.45	18.06	11.19	81.51	62.00	*	*	*	*	*
804	1	13.38	17.31	9.78	81.34	63.00	11.17	15.69	6.16	78.58	94.20
805	1	14.71	18.27	11.47	80.33	66.80	*	*	*	*	*
806	1	12.20	16.73	7.59	78.64	56.60	*	*	*	*	*
807	1	12.89	17.27	8.73	80.49	58.40	*	*	*	*	*
808	2	11.61	16.51	6.51	77.55	52.20	*	*	*	*	*
809	2	11.16	15.98	5.85	76.81	16.60	8.91	12.82	5.01	80.90	144.40
810	2	11.18	15.82	6.28	78.07	79.00	8.05	11.96	3.99	78.29	47.40
811	2	11.79	16.44	6.79	77.42	35.20	8.97	13.00	4.86	78.64	106.60
812	2	11.91	16.59	6.83	76.86	32.80	6.93	11.21	2.52	79.27	132.80
813	2	11.79	16.44	6.79	77.42	35.20	8.97	13.00	4.86	78.64	106.60
814	2	11.91	16.59	6.83	76.86	32.80	6.93	11.21	2.52	79.27	132.80
815	1	11.16	15.98	5.85	76.81	16.60	8.91	12.82	5.01	80.90	144.40
816	1	11.16	15.98	5.85	76.81	16.60	8.91	12.82	5.01	80.90	144.40

		Maturity to 1st Harvest					1st Harvest to 2nd Harvest				
Plot no	Group	Mean T	Max T	Min T	RH	PP	Mean T	Max T	Min T	RH	PP
817	1	11.91	16.59	6.83	76.86	32.80	6.93	11.21	2.52	79.27	132.80
818	2	11.91	16.59	6.83	76.86	32.80	6.93	11.21	2.52	79.27	132.80
819	2	11.79	16.44	6.79	77.42	35.20	8.97	13.00	4.86	78.64	106.60
820	1	13.10	17.11	9.38	81.31	60.00	*	*	*	*	*
821	2	11.22	15.98	6.10	76.94	63.20	6.22	10.37	1.92	79.38	84.60
822	2	11.75	16.33	6.87	77.93	43.40	8.97	13.00	4.86	78.64	106.60

Cultivar descriptions

Plot no	Variety name	Pedigree	Origin	Habitat
214	Bjarne	SvB87293/Bastian	Norway	Spring
215	Bastian	Bajio 66/Runar/4/Yaktana//Norin10/Brevor /3/Møystad/5/ Rollo/Magnif/4/Sonora// TZPP/Nainari/3/Møystad	Norway	Spring
216	Zebra	Ralle/Dragon	sweden	Spring
217	Berserk	T3042/KN6//SW35128	Norway	Spring
218	NK01568 (Demonstrant)	T1005/NK93512	Norway	Spring
219	GN03509 (Krabat)	T1005/NK93512	Norway	Spring
220	GN05567 (Laban)	NK97510/SW39042	Norway	Spring
221	GN06600		Norway	Spring
222	GN04526	T1005/NK93501//SW35302	Norway	Spring
223	SW46051		Sweden	Spring
224	GN03597		Norway	Spring
225	GN06578	NK95571/SW37262//Avle	Norway	Spring
301	GN07501		Norway	Spring
302	SW51114	33120/449979//Anemos/37391	Sweden	Spring
303	Bjarne	SvB87293/Bastian	Norway	Spring
304	Zebra	Ralle/Dragon	sweden	Spring
305	Berserk	T3042/KN6//SW35128	Norway	Spring
306	NK01568 (Demonstrant)	T1005/NK93512	Norway	Spring
307	GNO3509	T1005/NK93512	Norway	Spring
308	GNO6600		Norway	Spring
309	GNO7501		Norway	Spring
310	GNO7548		Norway	Spring
311	GNO7560		Norway	Spring

Plot no	Variety name	Pedigree	Origin	Habitat
312	GNO7569		Norway	Spring
313	GNO7574		Norway	Spring
314	GNO8504	NK00517/NK98501	Norway	Spring
315	GNO8558		Norway	Spring
316	GNO8588	NK00517/NK98501	Norway	Spring
317	SW71142		Sweden	Spring
318	SW71144	Vinjett/449979//CanonM7M15S13N/Tjalve-2	Sweden	Spring
319	GNO7525		Norway	Spring
320	GNO8530		Norway	Spring
321	GNO8595	SW40330/NK99535	Norway	Spring
322	GNO9508		Norway	Spring
323	GNO9509		Norway	Spring
324	GNO9543		Norway	Spring
325	GNO9571		Norway	Spring
401	GNO9572		Norway	Spring
402	CHDII32105			Spring
403	GNO5575		Norway	Spring
404	GNO3597		Norway	Spring
405	GNO4526		Norway	Spring
406	SW46051		Sweden	Spring
407	SW51114	33120/449979//Anemos/37392	Sweden	Spring
408	GNO6510	T9040/WW29323//Avle	Norway	Spring
409	GNO6578	NK95571/SW37262//Avle	Norway	Spring
410	GNO6519		Norway	Spring
411	GNO8536		Norway	Spring
412	GNO8548		Norway	Spring
413	SW71030		Sweden	Spring
414	SW71139		Sweden	Spring
415	GNO9646		Norway	Spring

Plot no	Variety name	Pedigree	Origin	Habitat
416	GNO9648		Norway	Spring
417	SW81059		Sweden	Spring
418	SW81060		Sweden	Spring
419	SW81111		Sweden	Spring
420	SW81126		Sweden	Spring
421	SW81230		Sweden	Spring
422	SW81231		Sweden	Spring
423	SW81340		Sweden	Spring
424	Tjalve	Reno/Kolibri M//Drabant M1M2b	sweden	Spring
425	Avle	TW232-62/Kadett//Nemares	sweden	Spring
501	Bjarne	SvB87293/Bastian	Norway	Spring
502	Zebra	Ralle/Dragon	sweden	Spring
503	Bastian	Bajio 66/Runar/4/Yaktana//Norin10/Brevor /3/Møystad/5/ Rollo/Magnif/4/Sonora// TZPP/Nainari/3/Møystad	Norway	Spring
504	T9040	Reno/Genesee//Drabant	Norway	Spring
505	T9040 (1995)	Reno/Genesee//Drabant	Norway	Spring
506	NK93602	Yaktana/Rollo//Kalyansona/3/Sirius/Potam//Reno/6/ Sonora 64/TZPP//Nainari/3/Møystad/4/Runar/5/ Rollo/Magnif/4/Sonora 64/TZPP//Nainari/3 /Møystad	Norway	Spring
507	NK93602 (1995)	Yaktana/Rollo//Kalyansona/3/Sirius/Potam//Reno/6/ Sonora 64/TZPP//Nainari/3/Møystad/4/Runar/5/ Rollo/Magnif/4/Sonora 64/TZPP//Nainari/3 /Møystad	Norway	Spring
508	Paros		Germany	Spring
509	D99060	Paros/NK93602	Norway	Spring
510	D99014	Paros/T9040	Norway	Spring
511	D99159	T9040/Paros	Norway	Spring
512	Saar	Sonoita F81/Trap#1//Baviacora M92	Cimmyt	Spring
513	Milan	VS73.600/Maioral/3/Bobwhite//Yecora F70/Trifon	Cimmyt	Spring
514	Filin	F60314.76/Maioral//Ciano T79/3/ CMH73A.497/2*Hermosillo M77	Cimmyt	Spring

Plot no	Variety name	Pedigree	Origin	Habitat
515	Pfau-Milan-1	Hork/YMH//Kalyansona/Bluebird/3/Milan	Cimmyt	Spring
516	Dulus	Bobwhite/Neelkant//Ducula/3/Ducula	Cimmyt	Spring
517	205-Kauz(1)	Croc_1/Ae.squarrosa (205)//Kauz	Cimmyt	Spring
518	219-Seri(1)	Altar 84/Ae.squarrosa (219)//2*Seri M82	Cimmyt	Spring
519	219-Seri-Avle(1)	Altar 84/Ae.squarrosa (219)//2*Seri M82/3/Avle	Cimmyt	Spring
520	T10014	Yactana//Norin10/Brevor/3/Runar/4/SuperX/Runar/5/763/Runar//J03	Norway	Spring
521	DH 49-18 (1)	Bastian/Adder	Norway	Spring
522	NK93604-1	WW//M26/Runar/3/Runar//Møystad/Els	Norway	Spring
523	T2038	PC15-255/Runar/5/Sonora 64/TZPP// Nainari/3/Møystad/4/Runar	Norway	Spring
524	MS 273-150	Møystad/Sonora 64	Norway	Spring
525	Kariega-2	Agent/3*Anza//K4500.2/Sapsucker S	S. Africa	Spring
601	Avocet-YrA-1	Wagga Wagga 119/Wagga Wagga 15//Egret/3* Pinnacle//Anza/3/Egret	Australia	Spring
602	SH3-CBRD	SHA3/CBRD	Cimmyt	Spring
603	ONSCDH-01(1)	GONDO	Cimmyt	Spring
604	ONSCDH-02(1)	MILAN/SHA7	Cimmyt	Spring
605	ONSCDH-03(1)	CBRD/KAUZ	Cimmyt	Spring
606	ONSCDH-04(2)	R37/GHL121//KAL/BB/3/JUP/MUS/4/2*YMI #6/5/CBRD	Cimmyt	Spring
607	ONSCDH-05(2)	GUAM92//PSN/BOW	Cimmyt	Spring
608	ONSCDH-06(2)	NG8675/CBRD	Cimmyt	Spring
609	ONSCDH-07(3)	ALTAR 84/AE.SQUARROSA (224)//ESDA	Cimmyt	Spring
610	ONSCDH-08(1)	BCN*2//CROC_1/AE.SQUARROSA (886)	Cimmyt	Spring
611	ONSCDH-09(1)	MAYOOR//TK SN1081/AE.SQUARROSA (222)	Cimmyt	Spring
612	Naxos (x3)	Tordo/St.Mir808-Bastion//Minaret	Germany	Spring
613	NK01533	T3042/KN6//SW35128	Norway	Spring
614	BAJASS-5		Norway	Spring
615	NK00521	T3021/WW27377	Norway	Spring
616	NK01513	T1005/SPORT//T3042/KN6	Norway	Spring
617	NK01568 (Demonstrant)	T1005/NK93512	Norway	Spring

Plot no	Variety name	Pedigree	Origin	Habitat
618	GN03509	T1005/NK93512	Norway	Spring
619	GN03531	T1005/NK93501//SW35302	Norway	Spring
620	GN04537	NK93610/SW37097	Norway	Spring
621	GN05507	NK97537/SW37262	Norway	Spring
622	GN05567	NK97510/SW39043	Norway	Spring
623	SW45126	Bastian/38444//Nordjet	Sweden	Spring
624	SW46375	Vinjett/449980//CanonMB/449979	Sweden	Spring
625	GN03597	T1005/NK93501//SW35302	Norway	Spring
701	GN04528	NK95520/NK95515//BASTIAN	Norway	Spring
702	GN05580	T9040/WW29323//Avle	Norway	Spring
703	GN06510	T9040/WW29323//Avle	Norway	Spring
704	GN06539	Altar/Ae.squ//2*Seri/3/Avle	Norway	Spring
705	GN06557	NK97537/NK98524	Norway	Spring
706	GN06573	T9040/WW29323//SW37262/3/NK98524	Norway	Spring
707	SW51069	Lavett/Vin/3/Str872020/32294//Curry	Norway	Spring
708	SW51114	33120/449979//Anemos/37393	Sweden	Spring
709	Bombona	Bombona	Sweden	Spring
710	QUARNA	QUARNA	Swiss	Spring
711	GN03529	T1005/NK93501//SW35302	Norway	Spring
712	SW45204	31249/T.searsii(2S/2B)//Cur/3/382…	Sweden	Spring
713	GN04526	T1005/NK93501//SW35303	Norway	Spring
714	GN06530	Altar/Ae.squ//2*Seri/3/Avle	Norway	Spring
715	Frontana-1	Fronteira/Mentana	Brazil	Spring
716	Frontana-2	Fronteira/Mentana	Brazil	Spring
717	Nobeokabouzu M-1		China	Spring
718	Sumai 3 (Mhazy)		China	Spring
719	Sumai3(18-2)	Funo/Taiwan Xiaomai	China	Spring
720	CJ9306	Recurrent selection -many parents	China	Spring
721	CJ9403	Recurrent selection -many parents	China	Spring

Plot no	Variety name	Pedigree	Origin	Habitat
722	Saar	Sonoita F81/Trap#1//Baviacora M92	Cimmyt	Spring
723	Ning8343Pl4	Yang mai 3//Ning 701/Sumai 1/3/Aurora	China	Spring
724	512-21	Runar//Ning8343/Brakar	Norway	Spring
725	512-50	Runar//Ning8343/Brakar	Norway	Spring
801	512-54	Runar//Ning8343/Brakar	Norway	Spring
802	512-70	Runar//Ning8343/Brakar	Norway	Spring
803	512-87	Runar//Ning8343/Brakar	Norway	Spring
804	Runar	ELS/7*Rollo	Norway	Spring
805	Brakar - Pl.1	Sonora//TZPP/Nainari/3/Møystad/4/Møystad// Norrøna/ Kärn II/5/Yaktana//Norin 10/Brevor/3 /Rollo//Tammi/Kärn Kärn II/6/ELS//Tammi/Kärn II/ 3/Snøgg II/4/Bastion	Norway	Spring
806	Berserk -4	T3042/KN6//SW35128	Norway	Spring
807	Sport-2	CI5484/Pompe BM//Trippel/3/WW17269/4/WW19151	Sweden	Spring
808	AC_Somerset-1	AC Minto*2/ND643	Canada	Spring
809	CD87-3		Australia	Spring
810	Chara-3		Australia	Spring
811	Kukri-3		Australia	Spring
812	Bagula-Milan -2	Teeter/Junco//Milan	Cimmyt	Spring
813	Gondo -1	Golden Valley/Azteca 67//Musala/3/Dodo/4/ Bobwhite	Cimmyt	Spring
814	Catbird -2	Chuan mai 18/Bagula	Cimmyt	Spring
815	Vinjett	Tjalve M/Canon	Sweden	Spring
816	DH20070	NK93604/ARINA	Norway	Spring
817	DH20097	NK93604/ARINA	Norway	Spring
818	Naxos-2xSaar	Naxos/2*Saar	Norway	Spring
819	ONPMSYDER-05	ALTAR 84/AE.SQUARROSA (224)//2*YACO/3/KAUZ	Cimmyt	Spring
820	J03	landrace selection	Norway	Spring
821	Cameroon		Cameroon	Spring
822	SY1	SABUF/5/BCN/4/RABI//GS/CRA/3/AE.SQUARROSA (190)	Cimmyt	Spring