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Dormancy in Spring Wheat: Field and Greenhouse Trials

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Abstract

Resistance to preharvest sprouting is an important trait for Norwegian spring wheat cultivation. Sprouting in the field result in low quality grains which is unsuited for baking. Good dormancy after maturation is the most important component in preharvest sprouting resistance. This master thesis consist of three parts related to dormancy in Norwegian spring wheat. Part one is a compilation and data analysis of a long run trial with records of Dormancy of Norwegian varieties. Second part is an investigation in the use of greenhouse for screening for dormancy in spring wheat. The third part is an investigation in the use of artificial irrigation in the field to screen for dormancy by measuring sprouting damage.

A dataset from a long running trial from Vollebekk research farm in Ås was compiled and analyzed. The goal of the analysis was to assess the dormancy level of Norwegian varieties and the effect of climatic variables on these varieties. The Dormancy in the Norwegian varieties varied with growth season. A significant negative ($p < 0.05$) correlation between temperature in the 10 day period before yellow maturation and Dormancy Index measured 150° daydegrees and 450° daydegrees was found.

A collection of 16 varieties and breeding lines were grown in greenhouse under two temperature regimes. Germination rate was measured as germination index at maturity. In addition Dormancy index was measured at 150° daydegrees after yellow maturation. The temperatures in the greenhouse was very high due to lack of temperature control and the difference in temperature between the two regimes was low. Most of the genotypes did not induce dormancy, and had high germination rates. Th edormancy index failed to detect any differences between genotypes. The line T7347 and one of its parent Sirius showed high level of dormancy compared with the other genotypes. A significant effect of difference in the period before heading, but not of differences in the period from heading to maturation.

A collection of 156 genotypes consisting of varieties and lines relevant for Norwegian spring wheat breeding was grown at Vollebekk research farm in the 2012 growth season. Artificial irrigation simulating rain was applied for four weeks in the field around maturation. The field was severely sprouting damaged and most genotypes showed low falling number. The lines AC somerset, DH20097, Frontana, Paros, Paros/T9040, T10014 and the variety Zebra all relatively high falling numbers, which also had a record of high falling numbers from previous trials.

Sammendrag

Resistens mot aksgroing før høsting er en viktig egenskap for dyrking av vårhvete i Norge. Aksgroing fører til korn av lav kvalitet som er uegnet fro baking. God frøhvile etter modning er den viktigste komponenten i resistens mot aksgroing før høsting. Denne masteropggaven består av tre deler relatert til frøhvile i vårhvete. Del en er en sammenstening og dataanalyse av et flerårig forsøk med data på spiretreghet i norske markedssorter. Del to er et en undersøkelse i bruk av veksthus for identifisere frøhvile i vårhvete. Del tre består av undersøkelse i bruk av kunstig vanning i felt til å identifisere frøhvile ved å måle groskade.

Et datamateriale fra et flerårig feltforsøk på Vollebekk forskningsgård ble satt sammen og analysert. Målet med analysen var å undersøke frøhvilen i norske markedssorter av vårhvete og effekten av klimatiske variabler på frøhvile i disse sortene. Frøhvilen i de norsk sortene variarte med vekstsesongen. En signifikant negativ korrelasjon ($p < 0.05$) ble funnet mellom temperatur i perioden 10 dager før gulmodning og spiretreghetsindeks ved 150° og 450° døgngrader.

16 genotyper bestående av sorter og foredlingslinjer be dyrket i veksthus under to forskjellige temperaturregimer. Spireraten ble målt med spireindeks ved gulmodning. I tillegg ble spiretreghetsindeks målt 150° døgngrader etter gulmodning. Temperaturen i veksthuset var høy på grunn av mangel på temperaturkontroll. Differansen i temperatur mellom de to temperaturregimene var lav. De fleste genotypene fikk ikke indusert frøhvile og hadde høye spireindekser. Det var ingen forskjell i spiretreghetsindeks mellom genotypene. Foredlerlinjen T7347 og en av foreldrene Sirius hadde relativt høy frøhvile sammenlignet med de andre genotypene. Det ble funnet en signifikant effekt av temperaturforskjell i perioden før aksskyting.

156 genotyper bestående av sorter og foredlingslinjer med relevans for norsk vårhveteforedling ble dyrket i felt på Vollebekk forsøksgård i vekstsesongen 2012. Kunstig vanning for å simulere regn ble påført i 4 uker i perioden rundt gulmodning. Feltet fikk store mengder med aksgroing og de fleste genotypene hadde lave falltall. Linjene AC Somerset, DH20097, Frontana, Paros, Paros/T9040, T10014 og sorten Zebra hadde relativt høye falltall. Disse har hatt høye falltall i tidligere forsøk.

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Chapter 1

Introduction

Preharvest sprouting in wheat (Triticum *aestivum*) is a topic that is very broad and complex, but of great importance for agriculture, as it represent an economic loss for farmers. Preharvest sprouting is characterized by the event in which germination occurs before the crops have been harvested and the grains germinate while still in the head of the plant. This results in moderate yield losses and most importantly lower quality, which means that farmers will fetch a lower price for the grains. In its nature preharvest sprouting is not something that is erratic and sprouting damage vary greatly from year to year. The research that has been done on preharvest sprouting has been of utmost importance for the ability to grow baking quality wheat in Norway. With the introduction of preharvest sprouting resistant varieties the wheat acreage in Norway have increased from virtually non existent in 1965 to a level today where most of the wheat used for food are grown domestically. When the combine harvester was introduced in the 1950s the need for sprouting resistant cultivars became more important, as the grains needed to dry out before harvest, and thus needed to stay out in the field for a longer period. The wheat production in Norway dropped drastically as farmers started to grow barley instead. It was not until the 1970s, after the release of the varieties Reno and Runar which had good sprouting resistance along with improvements in other traits, that the wheat acreage in Norway started to increase (Lillemo and Diseth 2011). In the recent years Norway has had over 70 % of the wheat used for food grown domestically in good years. Some years this figure drops

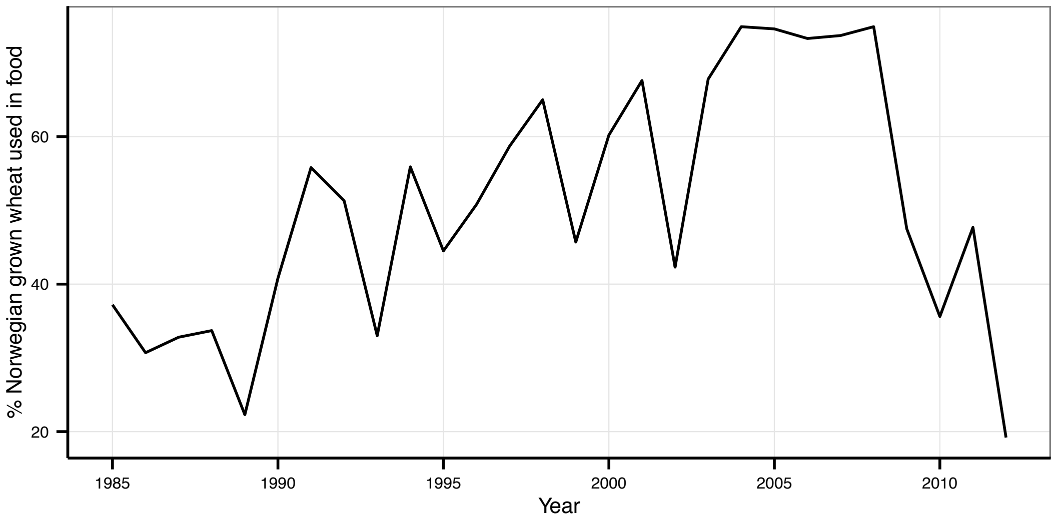


FIGURE 1.1: % of wheat sold for use as food in Norway that is grown domestically. (Norwegian Agricultural Authority 2013)

below 20 % (figure 1.1). Between 2004 and 2008 the % of Norwegian wheat was over 70 %, but dropped in 2009 and hit a low of 19 % in 2012. Preharvest sprouting damage is one of the explanations for this variability in the wheat supply. The harvest seasons in the most recent years in Norway have been dominated with wet weather and severe yield losses. In light of this there is some concerns whether the wheat varieties grown in Norway has the adequate level of resistance to preharvest sprouting. There is also great uncertainty related to climate changes and what implications a changing climate will have for Norwegian wheat growers. If the harvest seasons are getting wetter as a result of climate change, the current level of resistance to preharvest sprouting might not be sufficient. The resistance to preharvest sprouting is also influenced by the environment during the development of the plant and grains. A changing climate can render previously resistant varieties susceptible, as the plants are not receiving the right environment for induction of resistance to preharvest sprouting.

In breeding programs, testing for resistance to preharvest sprouting is typically performed at the more advanced stages of breeding programs. A reason for this is that there is a substantial amount of labor associated with testing for resistance to preharvest sprouting. In addition the large Genotype × Environment interaction associated with preharvest sprouting means that the testing must be performed over multiple years and locations to obtain reliable information on the inherent level of preharvest sprouting resistance. To improve the efficiency of the breeding program there is of interest to develop more reliable methods for screening for resistance to preharvest sprouting. This is also necessary for development of genetic markers which can be used in Marker Assisted Selection (MAS), which would enable breeders to select based on genotype without phenotyping. The amount work needed for developing markers increases as the complexity of the trait linked to the marker increases. Phenotyping complex trait like resistance to preharvest sprouting with a large amount of measurement errors would have large benefits of improved methods for phenotyping, both for screening directly in a breeding program and to develop markers for MAS.

Understanding the environmental effects on preharvest sprouting is also important in the question for developing improved methods for studying preharvest sprouting. A good knowledge of which environmental condition preharvest sprouting occurs, and under which conditions resistance to preharvest sprouting is expressed can give a basis for tuning parameters in tests and experiments with a goal of illuminate questions regarding preharvest sprouting. Knowledge of the environmental effects on preharvest sprouting can also be used to predict susceptibility in the field and give farmers a warning when sprouting in the field is likely to occur.

1.1 Background

There are many factors influencing preharvest sprouting, making it a complex topic. How susceptible a plant is to preharvest sprouting is the product of many factors. Lodging, disease level, temperature, rainfall, genetic composition, development stage, moisture and agronomic practices, to name a few important factors. In the theoretical background an overview of preharvest sprouting the emphasis will be on areas relevant for this thesis.

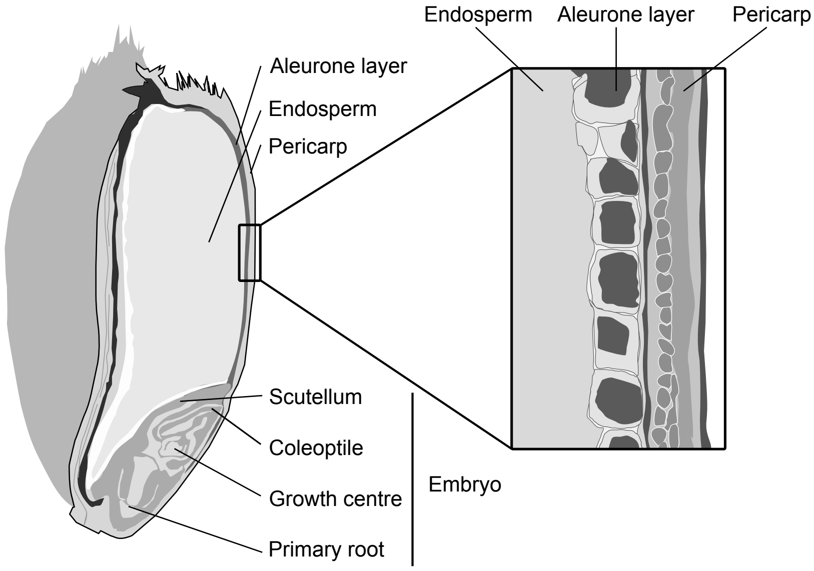


Figure 1.2: Drawing of a longitudinal bisected wheatgrain showing its main components. To the right is a magnification of the outer parts of the grain. Drawn from Macmasters et al. 1971.

1.1.1 The physiology of the wheat grain

The grain is the single unit in which the germination occurs, and an understanding of the physiology of the grain is necessary to explain the different mechanisms involved in germination. The mature grain (see figure 1.2) consists of an outer layer called the pericarp which surrounds the seed. The pericarp originates from the ovule which is maternal tissue. The seed consists of a seed coat (testa), the endosperm and the embryo. The endosperm comprises most of the seed and is for the most part starch and proteins, and serves as the primary source of nutrients for the germinating seed. The endosperm has an outer layer of cells called the aleurone layer which has important functions during germination. The aleurone layer is the only living part of the endosperm at maturity. The endosperm originates from a triple fusion during fertilization between two maternal cells and one fraternal from the pollen. The embryo consists of the primary root, the growth center, the scutellum which is situated closest to the endosperm and the epicotyle which is the first leaf to protrude the grain during germination. The embryo originates from a fusion between the egg and one cell from the pollen.

1.1.2 Germination

Germination occurs when a non-dormant seed is exposed to moisture and water enter in to the seed, a process called imbibition. Following the increased water content a biochemical cascade is set off which mobilizes nutrients for the growing embryo. Giberrelic acid (GA) is released from the scutellum and into the endosperm and aleurone layer. GA in turn activates synthesis and release of α-amylase and other digestive enzymes from the aleurone layer into the starchy endosperm. This in turn makes sugars and proteins available from the starchy endosperm to the embryo (Taiz and Zeiger 2010).

1.1.3 Dormancy and climate

For preharvest sprouting to occur there must be good conditions for sprouting in the field. Resistance to preharvest sprouting is a complex trait with many components. One of the most important components of this resistance is dormancy. Dormancy is characterized by an event where a seed do not to germinate when exposed to conditions that are normally favorable for germination for that type of seed. The dormancy is a feature of the grain. External factors that prevents the grain from germinating is not counted as dormancy J. M. Baskin and C. C. Baskin 2007. The dormancy of wheat is normally at its highest around yellow maturation and is gradually lost as the grain dries. This period of dormancy breakdown is called the after ripening period. This dormancy of a newly developed grain is known as primary dormancy. Sometimes grains that have lost the primary dormancy can regain dormancy. This is called secondary dormancy. Absisic acid (ABA) has been established as the main hormone controlling dormancy Gubler et al. 2005. In wheat the level of ABA rises rapidly towards maturation and it dropped when the grains dries out after maturation. King 1976.

The climatic factors during the development of the grains is highly influential on the level of dormancy at maturation. Climatic factors also affects the rate of dormancy loss after maturation. Several studies have been performed to elucidate the relationship

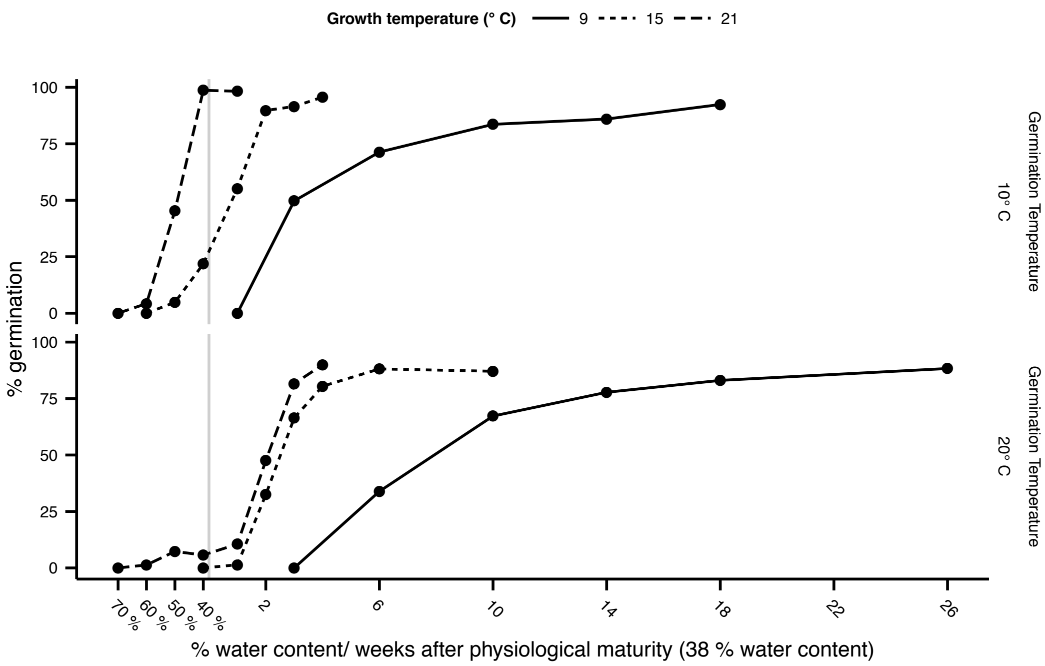


FIGURE 1.3: Plot adapted from figure 4 in Buraas and Skinnes 1985. The plot shows mean % germination from seven wheat genotypes grown at 9°, 15° and 21° C in phytotron. The seeds have been germinated at 10° C (upper panel) and 20° C (lower panel).

between weather and susceptibility to preharvest sprouting. In wheat temperature during the development is an important factor in determining the level of dormancy at maturity. A study by Erling Strand 1989 evaluated correlations between the level of dormancy after maturation and various climatic factors for different periods during the development. The study included three cultivars (Runar, Reno and Drabant) wich included observations from 20, 17 and 11 years of observations respectively. The study found that variation in temperature in the grain filling period had greatest influence on the level dormancy at harvest time. High precipitation and humidity before harvest increased dormancy, however the effect was dependent on the genotype. Buraas and Skinnes 1985 did a study with barley wheat and triticale grown in phytotron under controlled conditions. 7 wheat genotypes where included and grown at 9°, 15° and 21° C. Development under lower temperatures did increase the dormancy level after maturation (see figure 1.3). Also the level of dormancy was most pronounced when the germination temperature was high (20° C).

Walker-Simmons and Sesing 1990 showed that grains developed at 15° C had higher levels of dormancy than grains developed under 25° C. The same study showed that the ABA levels of the grains steadily increased during development under 15° C. For development under 20° C the ABA levels was initially high, but dropped rapidly towards maturation. T. B. Biddulph et al. 2005 found that drought during grain development increases the level of dormancy. Thomas B. Biddulph et al. 2007 Showed that constantly high temperatures along with moisture stress induced dormancy in a normally non-dormant genotype. Under certain conditions after-ripened grains become dormant again. Cold temperatures and high humidity after maturation can induce this secondary dormancy (Belderok and Habekotte 1980)

1.1.4 Measures of dormancy

There are several methods to assess dormancy of seeds. However only three methods relevant for this thesis will be discussed, namely the Dormancy Index, the Germination Index and the falling number test. The germination tests measures dormancy directly, while falling number test measures it indirectly by measuring sprouting damage.

The Dormancy Index was developed by E Strand 1965. It was developed as both a measure of dormancy and as a measure for determining the storage time needed for to remove dormancy of a grain sample. The the dormancy coincides with the number of days at 20° C before the dormancy of a sample is zero. The Dormancy Index is measured by germinating seeds at 10° C and 20° C and counting number of dormant seeds after 10 and 7 days respectively. The dormancy index is calculated with equation 1.1. The Dormancy index is used today in Norwegian breeding to evaluate the dormancy of Norwegian varieties. In Norwegian breeding the Dormancy Index is measured 150° and 450° day degrees after yellow maturation.

$$\text{DI} = \frac{2 \times (\%\text{ dormant seeds at }10^\circ) + \%\text{ dormant seeds at }20^\circ}{3} \tag{1.1}$$

The Germination Index index is a measure of germination where seeds that germinate early is given more weight than seeds that use long time to germinate. It measured by germinating seeds and counting number of germinated seeds each day for as long the test is going. The temperature for the germination test needs to be calibrated after what material that is being tested. The germination index is calculated with equation 1.2, where x_i is day $_i$, n_i is the number of germinated seeds at day$_i$ and $i = 1, 2, ..., i$. If all seeds germinate at day 1, the germination index is 1, and if all seeds are dormant at the end of the test the germination index is zero. A benefit of using the germination index compared with the dormancy index is that the former can differ between grain samples that germinate early or late in the test period. The Dormancy index measures germination at one point in time, and does not differ between a sample where all seeds germinated the first or last day of the test.

$$\mathrm{GI} = \frac{((x_i + 1) - 1 \times n_1 + (x_i + 1) - 2 \times n_2 + ... + 1 \times n_i)}{x_i \times \text{number of viable seeds in test}} \tag{1.2}$$

A indirect measure of sprouting damage is the Hagberg falling number (Hagberg 1960; Hagberg 1961) which indirectly measures α-amylase activity in a mixture of flour and water. The test is done by rapidly heating a mixture of flour and water until it gelatinize and release a plunger in to the sample. The shorter time the plunger uses to reach the bottom of the sample, the higher the α-amylase activity. This is because α-amylase breaks down the starch in the sample and makes it more liquid. Low α-amylase means there is less break down of starch and the sample becomes more viscous and the plunger uses longer time to reach the bottom. The activity of α-amylase is related to the amount of sprouting in the grain sample that the flour was milled from. Humphreys and Noll 2002 reported a correlation between sprouting score (1 = no sprouting visible on head, 9 = 90 % sprouting visible on head) and falling numbers of -0.63 in field grown wheat. A benefit by using falling number when screening for preharvest resistance is that high falling number is a quality trait which are a breeding goal in it self. In Norway the mills require a falling number above 200 to be classified as baking quality. A component of uncertainty when using falling number as a measurement of dormancy is that other factors influencing the falling number is confounded with dormancy. This could be useful when the goal is to select for resistance to preharvest sprouting, regardless of which trait that provides such resistance. Another source of uncertainty in falling number measurements is that differences in starch quality influences the falling number. As noted by Ringlund 1983 the α-amylase activity may be equal in samples, but the different qualities of starch can give different falling numbers.

1.2 Research questions

1. What can the dataset from the weather resistance trial reveal about dormancy in Norwegian varieties and the relation between dormancy and climatic variables around maturation?
2. Is greenhouse useful as a tool to screen for genotypes with good dormancy?
3. Can measurements of sprouting damage by falling number of wheat exposed to artificial weathering be used to screen for genotypes with good dormancy?

In this thesis the first research question was be addressed by compiling the data from the weather resistance trial and was merged with data on climatic variables. The relationship between climatic variables and Dormancy Index was evaluated based on correlations between the two. In addition the varieties will was ranked based on dormancy level over several years. The second research question was answered by growing a selection of 16 varieties and breeding lines in greenhouse at two different temperatures and measuring dormancy with Germination Index and Dormancy Index. The third research question was answered by growing a collection of 156 genotypes consisting of varieties and breeding lines in the field and irrigation was applied after maturation to simulate rain. The sprouting damage was assessed by measuring the falling number.

Chapter 2

Experiments and analysis

In this chapter the three parts of this thesis is presented. The first part is the analysis of the field trial. The second part is the report from on dormancy from the greenhouse trial. The third part is the report from falling numbers from the field trial. Each part is presented with methods, result and discussion relevant for each part. A separate discussion of three parts together is presented in chapter 3.

2.1 Data on Dormancy Index

Since the 1960s a long running trial called the weather resistance trial have been grown at Vollebekk research farm in Ås, Norway. In this trial several varieties have been grown in the field and the Dormancy Index have been recorded 150° and 450° day degrees after yellow maturation. The genotypes that was included in the trail was breeding lines which are of interest for Norwegian wheat breeding or varieties grown in Norway. The results from these trials have not been compiled and analyzed together in the recent years. A compilation of this data could give insights into the dormancy characteristics of modern Norwegian wheat varieties. In addition this data gives the opportunity to study how dormancy is related to climatic variables. Climatic data records are available from a weather station near the research farm. Erling Strand 1989 presented a study where the relation between climatic variables and Dormancy Index.

In the study a correlation between temperature around maturation and Dormancy Index was reported.

In this analysis the Dormancy Index data from the trials done at Vollebekk research farm will be compiled in to one dataset and then be analyzed with two goals in mind. One goal is to study the relationship between temperature and precipitation around maturation and the Dormancy Index at 150° and 450° day degrees for modern Norwegian varieties. The second goal is to estimate the dormancy of Norwegian varieties and possibly rank the varities.

2.1.1 Materials and methods

The dataset from the weather resistance-trial consists of observations of Dormancy Index of grains harvested 150° and 450° day degrees after yellow maturation. These two harvest times will hereafter be referenced to as 1. and 2. harvest time respectively. The trials were conducted at Vollebekk research farm, Ås. The genotypes included in the trials were various breeding lines and varieties relevant for Norwegian breeding. A subset of released Norwegian varieties was chosen to be included in the analysis. These varieties were also the varieties that was included in the trials for most years. Table 2.1 shows the varieties included and number of observations from each year. The maturation dates was determined as the date when the water content of the seeds were 38 %. The germination tests used for determining the Dormancy Index was performed by Kimen seed testing laboratory at Ås. The dataset is unpublished and was provided by Anne Kjersti Uhlen (personal communication).

The data preparation consisted of getting data on temperature and precipitation from all the years with data on Dormancy Index. For observations earlier than 2010 the dataset on Dormancy index included the harvest date, but did not include the date of maturity for each observation. This date had to be estimated. Once the estimated maturation date was available, climatic variables related to day of yellow maturation was calculated for each observation. The meteorological data was recorded on a weather

Table 2.1: Table showing the number of observations for the varieties included in the statistical analysis. Missing data is marked with "-".

Name	1995	1996	1997	1998	1999	2000	2001	2002	2003	2005	2006	2007	2008	2009	2010	2011	2012	Sum
Avle	1	1	1	-	1	1	1	1	1	1	-	2	1	-	1	-	2	15
Bastian	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	23
Berserk	-	-	-	-	-	-	-	1	1	2	1	1	2	2	3	2	1	16
Bjarne	-	-	-	1	1	1	1	1	1	1	1	2	2	2	3	2	4	23
Demonstrant	-	-	-	-	-	-	-	1	1	2	1	1	1	2	3	2	3	17
Krabat	-	-	-	-	-	-	-	-	-	1	1	1	2	2	2	2	3	14
Polkka	1	1	1	1	1	1	1	-	-	-	-	-	-	-	-	-	2	9
Vinjett	1	1	1	-	1	1	1	1	1	-	-	-	-	-	1	-	2	11
Zebra	-	1	2	1	1	1	2	1	1	1	1	2	2	2	3	2	3	26
Sum	4	5	6	4	6	6	7	7	7	9	6	11	12	12	18	12	22	154

station located approximately 1,6 km east of the research farm. Data on temperature and precipitation was downloaded from Norwegian Meteorological Institute 2013 and Bioforsk/Norwegian Meteorologaical Institute 2013 (which mirrors the data from Norwegian Meteorological Institute 2013). There was some periods with missing data from both sources. If data was missing from Norwegian Meteorological Institute 2013, it was complemented from Bioforsk/Norwegian Meteorologaical Institute 2013. The precipitation data was only available from 2010 from the meteorological institute, so the data on precipitation from 1995 to 2009 is from Bioforsk/Norwegian Meteorologaical Institute 2013. All the data is recordings from the same weather station.

Three variables related to the time of yellow maturation and the harvest time was calculated for temperature and precipitation (table 2.2). The mean temperature and total precipitation was calculated for the 10 day period before yellow maturation, the period between yellow maturation and 1. harvest time and the period between 1. and 2. harvest time. In the dataset the date of yellow maturity is missing from most of the observations. In order to investigate the correlations between climatic variables in relation to the date of yellow maturation, the date was estimated based on the assumption that the 1. harvest date is approximately 150 day degrees after yellow maturity. The date for yellow maturity was estimated to be the 1. date going backwards from the 1. harvest time to be over 150 day degrees. The calculations were conducted in R

Table 2.2: The description of the environmental variables calculated and which growth stage the variable is related to.

Variable	Description
tempYMmin10	Mean temperature in the period 10 days before (estimated) date of yellow maturity to yellow maturity.
tempYMtoHT1	Mean temperature in the period of yellow maturity to 1. harvest time.
tempHT1toHT2	Mean temperature in the period 1.harvest time and 2.harvest time.
precYMmin10	Total precipitation in the period 10 days before (estimated) date of yellow maturity to yellow maturity.
precYMtoHT1	Total precipitation in the period of yellow maturity to 1. harvesttime.
precHT1toHT2	Total precipitation in the period 1.harvest time and 2.harvest time.

(R Core Team 2013). The data on maturation from 2010 to 2012 was used to evaluate the quality of the data in relation to harvest dates.

To describe the dataset and the co-variablity among the climatic variables and the Dormancy Index a Pearson correlation coefficient (equation 2.1) was calculated for each pair of variable. In addition Pearson correlation coefficient was calculated for each variety for dormancy index at 1. and 2. harvest time and the climatic variables. Along with the coefficient a p-value for each estimate was calculated. Correlation coefficients and p-values were calculated with the R package Hmisc (Harrell Jr et al. 2013) For the correlation analysis all genotypes in table 2.1were included, except the variety Polkka. This gives 143 observations of 8 genotypes. A plot of the relation between the mean temperature in the 10 day period before yellow maturation and the Dormancy index at 1. and 2. harvest time for each variety was made to asses the structure of the relationship between temperature and Dormancy Index. A plot of the climatic variables was made to visually asses the in year variation of each climatic variable.

$$r = \frac{\sum_{i=1}^{n}(X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum_{i=1}^{n}(X_i - \bar{X})^2}\sqrt{\sum_{i=1}^{n}(Y_i - \bar{Y})^2}} \qquad \text{Pearson correlation coefficient} \qquad (2.1)$$

The overall level of Dormancy Index was estimated with a mixed effect model where the variety was treated as a fixed effect and the trial year was treated as a random effect. The analysis was performed in the statistical software R (R Core Team 2013 using the software package "lme4" (Bates et al. 2013). As the varieties was not included in the trials each year, two subsets of the dataset was analyzed separately. The subsets were chosen so that each variety had at least one observation in each year. The 1. subset consisted of the varieties that were included in the later years. This varieties included Krabat, Zebra, Bjarne, Bastian, Demonstrant and Berserk for the years 2005 and 2007 to 2012. The 2. subset consisted of the varieties included in the earlier years. The varieties were Avle, Vinjett and Polkka. Zebra and Bastian were also included to make comparisons between the two subsets possible. The years of the 2. subset was 1996, 1997, 1999 to 2001 and 2012.

2.1.2 Results

The correlations among the variables revealed that there was significant correlations between the climatic variables (table 2.3). The temperature variables were positively correlated. There was a negative correlation between temperature and precipitation. The correlation between Dormancy Index and climatic variables reveals that there is a significant negative correlation between temperature before yellow maturation and Dormancy Index both at 1. and 2. harvest time. For Dormancy Index at 2. harvest time there is negative correlation between temperature after maturation. In addition there is a positive correlation between precipitation after maturation and Dormancy Index at 2. harvest time. The Dormancy Index at the two harvest times are positively correlated.

The Pearson correlation coefficients for the dormancy index at 150° day degrees (1. harvest time) and the climatic variables in the time around maturation reveals that there is a negative correlation between temperature in the 10-day period before maturation and the dormancy index (table 2.4). This correlation is significant ($p < 0.05$) only for the varieties Berserk, Bjarne and Krabat. There is also a significant negative correlation between temperature from maturation to harvest and dormancy index for

Table 2.3: Table of correlations between the climatic variables of the different time periods and the dormancy index at the two harvest times. (Stars indicate significance, *: $p \leq 0.05$, **: $p \leq 0.01$ and ***: $p \leq 0.001$)

		Temperature			Precipitation			
		YMmin10	YMtoHT1	HT1toHT2	YMmin10	YMtoHT1	HT1toHT2	DI 1. HT
Temp	YMtoHT1	0.59 ***						
	HT1toHT2	0.60 ***	0.85 ***					
Prec	YMmin10	-0.26 **	-0.29 ***	-0.33 ***				
	YMtoHT1	-0.36 ***	-0.04	0.06	-0.10			
	HT1toHT2	-0.46 ***	-0.32 ***	-0.27 **	0.13	0.25 **		
	DI 1. HT	-0.36 ***	-0.09	-	-0.01	0.03	-	
	DI 2. HT	-0.47 ***	-0.26 **	-0.23 **	0.14	0.28 ***	0.45 ***	0.54 ***

the variety Krabat. There was no significant correlations between precipitation and dormancy index except for the varieties Vinjett. A plot of the dormancy index against the pre-maturation temperatures for each variety revealed the differences in variablity for the varieties (figure 2.2A). Berserk, Bjarne and Krabat, which had significant correlations between pre-maturation temperature and Dormancy Index, had a lower spread around the regression line than the varieties with no significant effects.

A plot (figure 2.1) of the climatic variables for each observation reveals that there is little in year variation compared with the between years variation. Temperature in the pre-maturation period and the period between maturation and 1. harvest time had the smallest variation. It is worth noting that the periods are not fixed in length, so the values for precipitation can not directly be compared. The period between 1. and 2. harvest times is longer than that of the period between maturation and 1. harvest time, so the former will have higher values than the latter.

The correlations between Dormancy Index at 450° day degrees (2. harvest time) after yellow maturation for the varieties is presented in table 2.4. There is a negative correlation between the pre-maturation temperatures and Dormancy Index at 2. harvest

TABLE 2.4: Table of Pearson correlation for Dormancy Index at 1. and 2. harvest time with temperature and precipitation. (Stars indicate significance, *: p ≤ 0.05, **: p ≤ 0.01 and ***: p ≤ 0.001)

	Temperature			Precipitation		
	YMmin10	YMtoHT1	HT1toHT2	YMmin10	YMtoHT1	HT1toHT2
1. harvest:						
Avle	-0.16	0.00	-	-0.22	-0.01	-
Bastian	-0.29	0.06	-	-0.18	0.08	-
Berserk	-0.58 *	-0.15	-	0.27	-0.09	-
Bjarne	-0.60 **	-0.19	-	-0.13	-0.06	-
Demonstrant	-0.37	-0.11	-	-0.27	0.21	-
Krabat	-0.60 *	-0.56 *	-	0.11	-0.08	-
Vinjett	-0.14	0.06	-	0.46	-0.68 *	-
Zebra	-0.29	-0.10	-	-0.19	0.01	-
2. harvest:						
Avle	-0.75 **	-0.62 *	-0.46	0.20	-0.05	0.43
Bastian	-0.54 **	-0.08	-0.15	0.00	0.44 *	0.44
Berserk	-0.77 ***	-0.35	-0.40	0.14	0.53 *	0.53 *
Bjarne	-0.31	-0.02	0.22	-0.06	0.20	0.12
Demonstrant	-0.59 *	-0.34	-0.25	0.12	0.28	0.49
Krabat	-0.68 **	-0.49	-0.47	0.12	0.24	0.33
Vinjett	-0.33	-0.58	-0.45	0.84 **	-0.33	0.56
Zebra	-0.55 **	-0.21	-0.16	0.14	0.40 *	0.74 ***

time. The correlations are significant ($p < 0.05$) for Avle, Bastian, Berserk, Demonstrant, Krabat and Zebra. There is a significant negative correlation between the mean temperature from yellow maturation to 1. harvest time for the variety Avle. There were no significant correlations between the mean temperature from 1. harvest time to 2. harvest time, although there was an indication of a negative relationship between the two variables. There was a significant positive correlation between precipitation in the pre-maturation period for the variety Vinjett. Bastian, Berserk and Zebra had significant positive correlation between precipitation and Dormancy Index in the period between 1. harvest time and 2. harvest time. Berserk and Zebra had a positive correlation between precipitation in the period from 1. harvest time to 2. harvest time and Dormancy Index. A plot of the Dormancy Index against the temperature in the pre-maturation period (figure 2.2B) reveals that there is less variability in Dormancy Index at the 2. harvest time than for the Dormancy Index at 1. harvest time. The overall Dormancy index was lower at 2. harvest time compared with 1. harvest time.

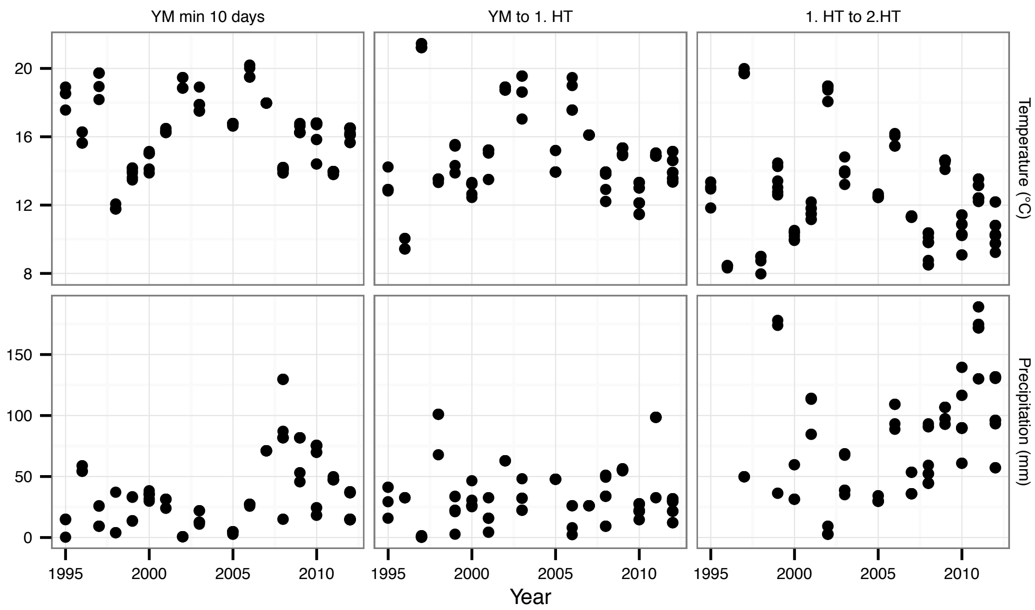


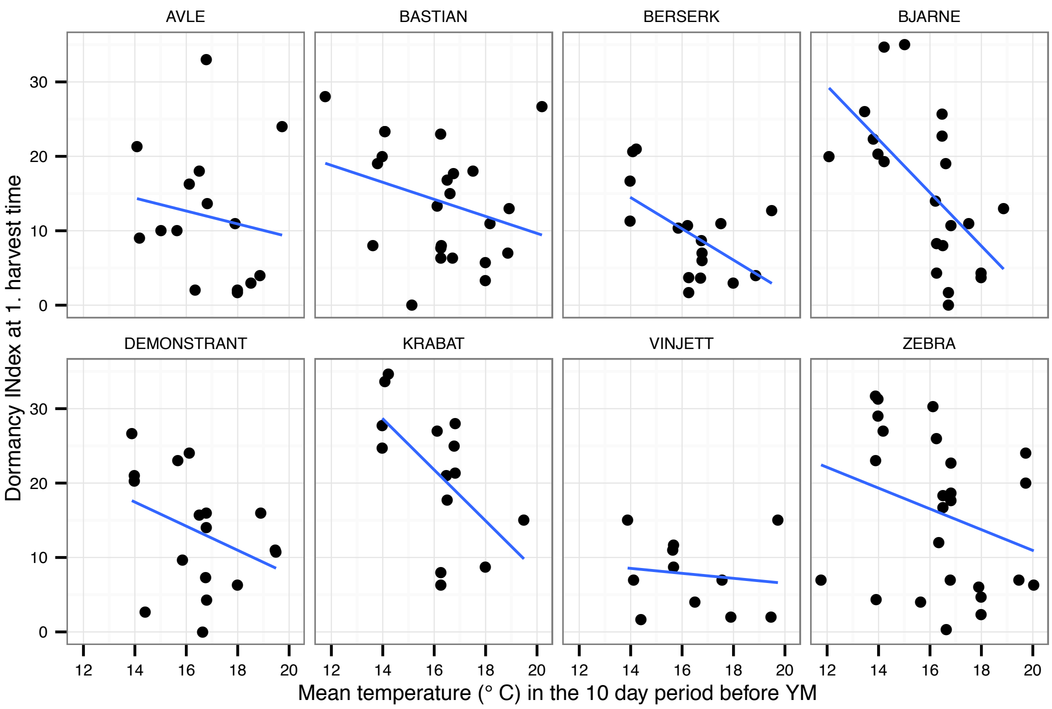
FIGURE 2.1: The values of the climatic variables mean temperature and precipitation for the three periods related to maturation and harvest times, plotted against year

TABLE 2.5: The mean DI adjusted for the yearly variation with 95 % confidence interval and number of observations. Data are from the years 2005 and 2007-2012 for the 1. subset. The 2. subset is data from the years 1996, 1997, 1999 to 2001 and 2012.

	1. HT			2. HT		
	DI	95 % CI	n	DI	95 % CI	n
1. subset:						
Krabat	20.85	± 4.92	13	24.96	± 5.64	13
Zebra	16.83	± 4.58	15	16.29	± 5.43	14
Bjarne	14.03	± 4.58	15	7.20	± 5.08	16
Bastian	13.75	± 4.92	13	9.15	± 5.64	13
Demonstrant	13.53	± 4.74	14	11.12	± 5.43	14
Berserk	9.36	± 4.92	13	13.10	± 5.64	13
2. subset:						
Zebra	19.59	± 4.39	10	14.54	± 4.50	10
Avle	12.48	± 5.24	7	12.00	± 5.38	7
Bastian	11.17	± 5.24	7	4.91	± 5.38	7
Vinjett	10.07	± 5.24	7	12.57	± 5.38	7
Polkka	8.01	± 5.24	7	2.81	± 5.38	7

The estimated mean Dormancy Index for 1. and 2. harvest time over all years is presented in table 2.5 for the two subsets of the dataset. For the varieties that were included in years 2005 and 2007 to 2012 the mean Dormancy Index at 1. harvest time varied

A:



B:

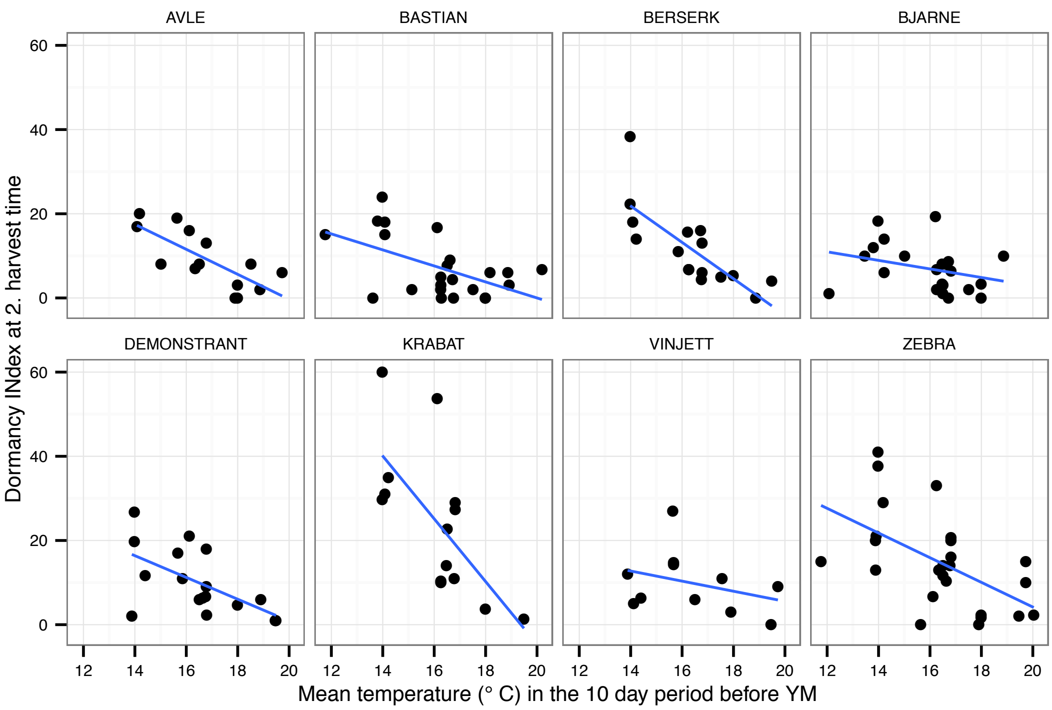


FIGURE 2.2: Shows the Dormancy Index at A: 1. harvest time, and B: 2. harvest time against the mean temperature 10 days before yellow maturation.

between 9.36 for Berserk and 20.85 for Krabat. The Dormancy Index at 2. harvest time varied from 7.2 for Bjarne and 24.96 for Krabat. Krabat and Berserk had an increase in Dormancy Index from 1. to 2. harvest time while Bjarne and Bastian decreased. Zebra and Demonstrant had a low difference in Dormancy Index between the two harvest times. Dormancy Index at 1. harvest time for the varieties that were included in the years 1997, 1999 to 2001 and 2012 varied between 8.01 for Polkka and 19.59 for Zebra. The Dormancy Index at 2. harvest time varied from 2.81 for Polkka to 14.54 for Zebra. Vinjett had an increase in Dormancy Index from 1. to 2. harvest time. Zebra, Bastian and Polkka decreased in Dormancy Index between the 1. and 2. harvest time. Avle was relatively stable in Dormancy between the two harvest times.

2.1.3 Discussion

The overall correlation between pre-maturation temperature and Dormancy Index was negative. These findings were consistent with earlier findings of lower temperarture before maturation gives a higher dormancy (Erling Strand 1989; Walker-Simmons and Sesing 1990). The positive relation between Dormancy Index at 2. harvest time and precipitation is possibly a result of induction of secondary dormancy when the grains have been exposed to high levels of precipitation. However the overall correlation between climatic variables and Dormancy Index ignores individual differences in correlation patterns between the genotypes. The correlations for dormancy index and climatic variables calculated for each variety reveals that the varieties have different responses.

In this data analysis where the aim is to study environmental effects on dormancy in relation to developmental stages of the grain, a source of error is to reliably estimate the dates of the developmental events. For this dataset the date of maturation was missing from most of the observations and had to be estimated. When comparing the observed date of maturation where available with the estimated date of maturity (figure 2.3A), there is some deviations. In this analysis the majority of the estimated date of maturation was 2-5 days later than the observed dates of maturation. Another source of

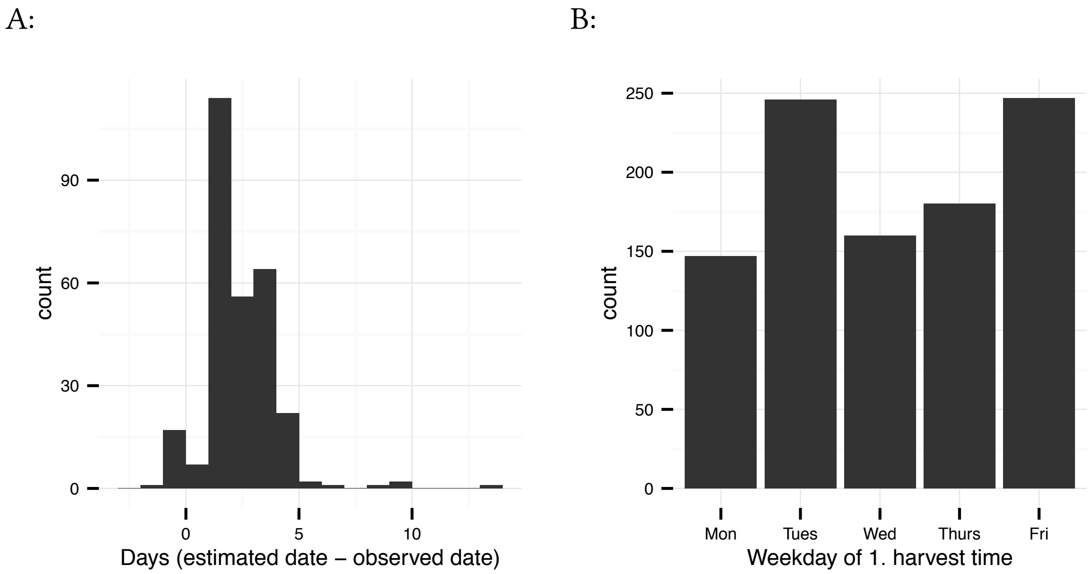


FIGURE 2.3: Overview of the harvest times for 2010 to 2012. A: displays a histogram of the difference in days between the estimated date of maturity and observed date of maturity. B: displays the weekday of the 1. harvest time. Note that no harvesting was performed in the weekends.

uncertainty regarding the maturation dates is that harvest was only performed during weekdays.

There are several challenges when studying dormancy in the field. As this analysis shows, the variation in climatic variables was greater between years than within the same year. In this study the varieties matured in a relatively short time period, limiting the in year variation of the environment. This makes the climate variables confounded with other unobserved variables for the year of the trials.

2.2 Greenhouse trial

The goal of this experiment is to examine the possibility of using greenhouse to discriminate between the inherent dormancy of different genotypes. The genotypes included in the experiment is a collection of varieties and lines which are of current interest for farmers and breeders. Based on earlier reports the genotypes varies on the level of dormancy. The genotypes of special interest are Saar, wich is known to have a very low level of dormancy and the line T7347 which is known to have a high level of dormancy. One of the parents of T7347, Sirius, is also included in the experiment. Bjarne is a currently used variety with a record of beeng relatively dormant.

TABLE 2.6: Table showing the genotypes included in the greenhouse trial.

Genotype	Comment	DI	GI
SHA3/CBRD			X
HAHN/PRL//AUS1408	Cimmyt line ONME4SP 160		X
Sirius	Parent of T7347, high dormancy		X
Saar	Low dormancy	X	X
T7347	High dormancy		X
Krabat		X	X
Bastian			X
Tjalve		X	X
Zebra		X	X
Naxos			X
TUI/RL4137	Cimmyt line ONME4SP 172		X
Demonstrant			X
Vinjett			X
Polkka		X	X
Avle			X
Bjarne		X	X

2.2.1 Materials and methods

16 genotypes was planted in pots in two growth rooms in greenhouse at the Centre for climate controlled plant research (SKP), Ås. The growthrooms were daylight rooms with heating to control temperature, and was cooled by venting through hatches in the roof. One of the rooms had insect nets covering the ventilation hatches which reduced the ventilation capacity of that room and led to higher temperatures than the other

room. The two rooms are hereafter referred to as high temperature room for the room with insect net, and low temperature room for the room with no insect net. The rooms were artificially lighted if the inbound radiation measured outside the greenhouse was below 200 W/m^2 from 6 am to 10 pm. Pots were placed on a table in a 8 x 18 grid in each of the rooms. The edge row was sown with Avle to control any edge effects. The two first and last rows on the short edge of the inner 6 x 16 grid consisted of 6 genotypes wich was used for determining the dormancy index. The remaining 6 x 12 grid consisted of 18 genotypes. One genotype was lost during the germination test, and was not included in the analysis. One of the pots in each block was a fill in sown with T7347, leaving a total of 16 genotypes included in the trial. The 6 x 12 grid was divided into four 6 x 3 grids making a complete replicate. The experiment was divided into two phases, were first phase was the period from sowing to heading. This phase was intended for obtaining plant material for stage two of the experiment. At 16th May 2012 most of the plants had reached the heading stage and phase 2 of the experiment was started. Half of the plants was moved from one room to the other to even out differences in growth conditions between the two rooms. At the same time the temperature settings was changed (figure 2.4). The temperature in the low temperature room was lowered to a daily mean of 10.7° C and the temperature in the high temperature room was raised to a mean of 14.7° C. The actual temperatures deviated from the set temperature as shown in figure 2.4. The plants were watered twice a week or when needed. Once a week the plants were watered with fertilizer. The date of heading for each pot was recorded. Heading was determined as the date when the first head of the plants in the pot was more than 50% visible. Heads used for determining germination index was harvested at yellow maturation and dried in a heating chamber for 48 hours at 30° C. After drying the seeds were stored in a deep freezer at -22° C until enough heads had been harvested. Yellow maturation date was determined as the date when the flag leaf and the upper bend of the straw lost its color and when the seeds were hard enough that a dent was left in the seed when pushed with the edge of the nail. This developmental signals varies much between the genotypes. Some plants were green while the head had lost all color and the seeds had dried. Others had lost all color in the plant while the grains still was soft and mealy. Heads for germination index was harvested

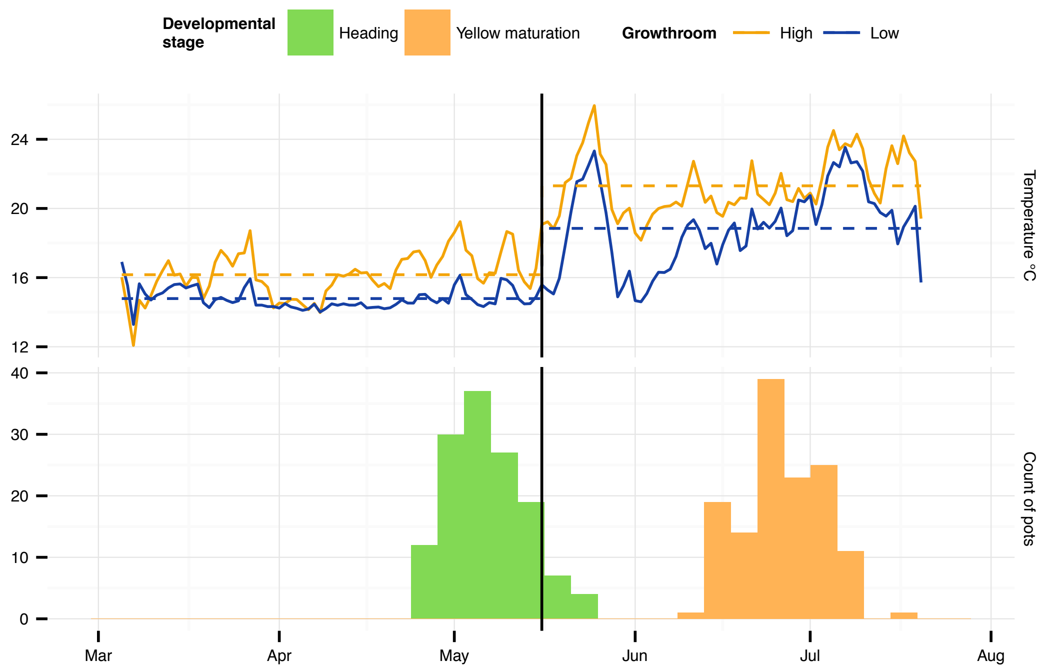


FIGURE 2.4: Upper panel: a plot of temperature in the two rooms in the greenhouse. Lower panel: a histogram of heading and yellow maturation. Shows the count of pots reaching heading and yellow maturation. The black vertical line shows the date (16th May 2012) on which the temperature setting was changed and half of the pots moved from one room to the other. The broken lines represents mean temperature before and after 16th May 2012.

150° daydegrees after yellow maturation. Up to four heads were harvested from each pot. The date of yellow maturation was recorded for each head, and four heads were harvested on the day that the mean daydegrees was 150° for the four heads. The first pots that were harvested was germinated immediately. There were some concerns about the temperature control during the germination tests and the germination tests were aborted. The rest of the heads were harvested at 150° daydegrees and frozen at -22° C until the problem was resolved and the germination test resumed.

Dormancy index was measured on 6 of the genotypes (see table 2.6). 50-100 seeds were laid out on 90 mm wetted filter paper on two petridishes, depending on how many heads available. The filters were wetted with 4 mL of tap water. The dishes were incubated at 20° and 10° C for 7 and 10 days respectively and the number of germinated seeds were counted. The remaining seeds were counted as dormant. The dormancy index was calculated with equation 2.2. The dormancy index gives the percentage of dormant seeds, with greater weight on seeds that are dormant at 10° C. An ANOVA-analysis was used to determine any effect of the temperature differences of the two rooms, and to detect differences in dormancy between the genotypes. The full model was used for the ANOVA:

$$\begin{aligned} DI_{ijkl} = \;& \mu + genotype_i + SH_j + HF_k + genotype : SH_{ij} + genotype : HF_{ik} + \\ & SH : HF_{jk} + genotype : SH : HF_{ijk} + \epsilon_{ijkl} \end{aligned}$$

where $\epsilon_{ijkl} \sim N(0, \sigma)$. *SH* denotes which room the plants was growing during sowing to heading, and *HF* denotes which room the plant was growing during heading to finish. The model includes the individual effects of the genotypes and interaction between the stages of the experiment and the total interactions.

$$\text{DI} = \frac{2 \times (\text{\% dormant seeds at } 10^{\circ}) + \text{\% dormant seeds at } 20^{\circ}}{3} \tag{2.2}$$

For the germination index test the seeds was hand threshed and laid out on a 90 mm filter paper on a petridish with 4 mL of tap water. There were up to 50 seeds laid out in one petridish when available. The seeds were incubated for 20 days at 15° C. The number of germinated seeds were counted each day and removed. After 20 days the seeds were incubated for 4 days at 4° C to break dormancy and then for 2 days at 15° C. Non-germinated seeds at this point was determined to be non-viable. The choice of 15° C as temperature for the germination index was based on the results from the dormancy index testing. The observed germination in the dormancy index test at 10° C was high, and at 20° C the germination was low. 15° C was therefore chosen to best differentiate between the germination index of the genotypes. The germination index was calculated with equation 2.3. This gives the proportion of germinated seeds, but weighted so seeds that germinate early contribute more. If all seeds germinate the first day, the germination index is 1. If no seeds germinate during the test the germination index is 0.

$$\text{GI} = \frac{(20 \times n_1 + 19 \times n_2 + \ldots + 1 \times n_{20})}{20 \times \text{ number of viable seeds}} \tag{2.3}$$

Table 2.7: ANOVA table of the dormancy indexes.

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Genotype	5	27.40	5.48	1.78	0.1575
growth1	1	0.07	0.07	0.02	0.8801
growth2	1	6.60	6.60	2.14	0.1569
Genotype:growth1	5	17.75	3.55	1.15	0.3624
Genotype:growth2	5	9.10	1.82	0.59	0.7074
growth1:growth2	1	0.04	0.04	0.01	0.9097
Genotype:growth1:growth2	5	21.48	4.30	1.39	0.2636
Residuals	23	70.92	3.08		

n_i is the number of germinated seeds at day i and $i = 1, 2, \ldots, 20$. An ANOVA was used to determine differences between genotypes and the inviromental effects before and after heading. The model that was used was the same model as for the dormancy index:

$$\begin{aligned} GI_{ijkl} = \; & \mu + genotype_i + SH_j + HF_k + genotype : SH_{ij} + genotype : HF_{ik} + \\ & SH : HF_{jk} + genotype : SH : HF_{ijk} + \epsilon_{ijkl} \end{aligned}$$

where $\epsilon_{ijkl} \sim N(0, \sigma)$.

2.2.2 Results

The results from germination test for the dormancy indexes was that there was almost no germination under 20° C, while almost complete germination under 10° C. This lead to all germination indexes beeing between 27 and 35 (see figure 2.6). One observation was removed from the analysis under suspicion of beeing freeze damaged during storage before the germination test. The results from the ANOVA of the dormancy indexes (table 2.7) showed no significant effects of genotype or differences in growth conditions during the experiment.

The ANOVA (table 2.8) from the germination index measurements showed significant ($p<0.05$) effects of environmental differences during sowing to heading, but the effect of environmental differences from heading to harvest was not significant. There was significant differences between the genotypes and a significant interaction between

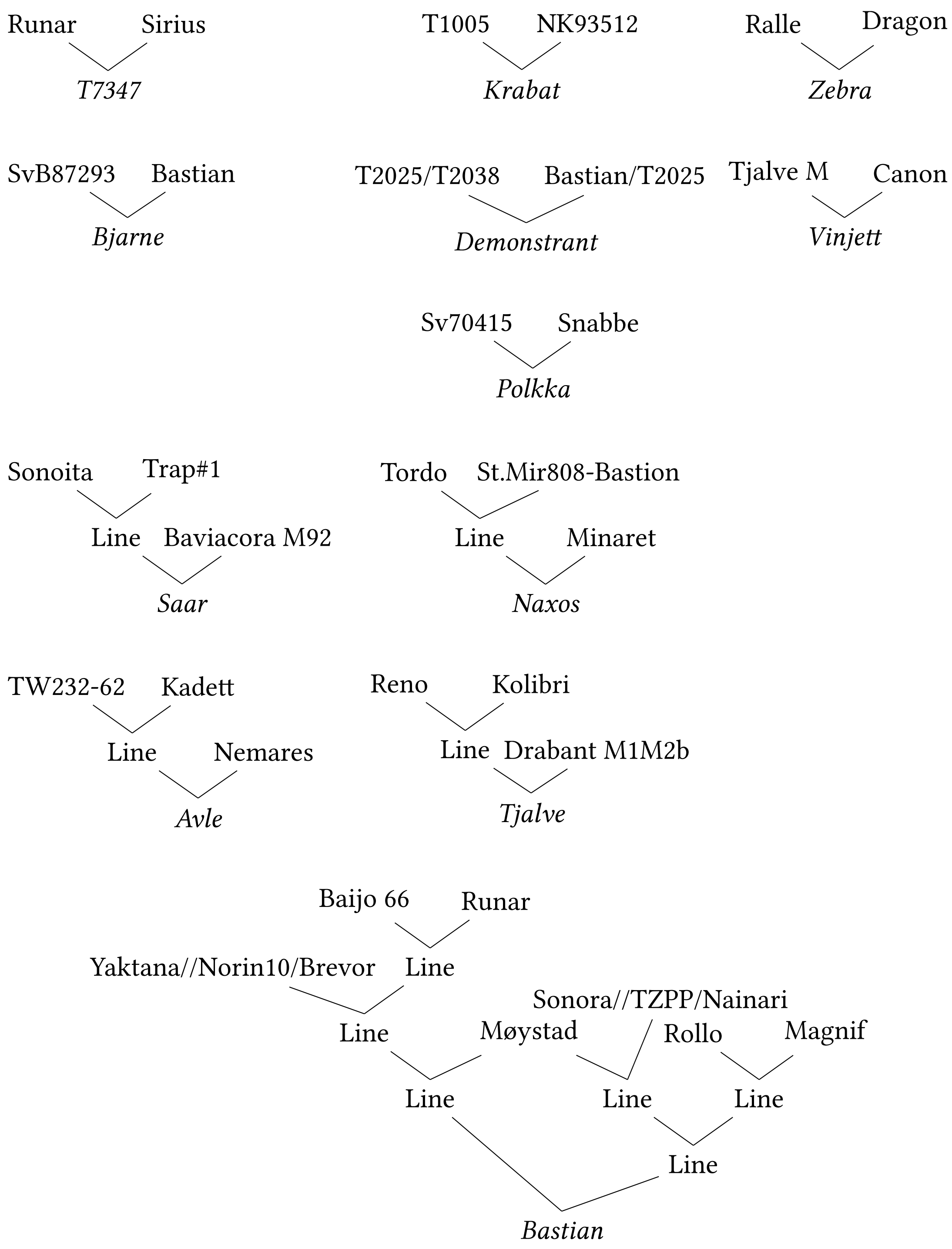


Figure 2.5: Pedigree of some of the genotypes included in the greenhouse trial.

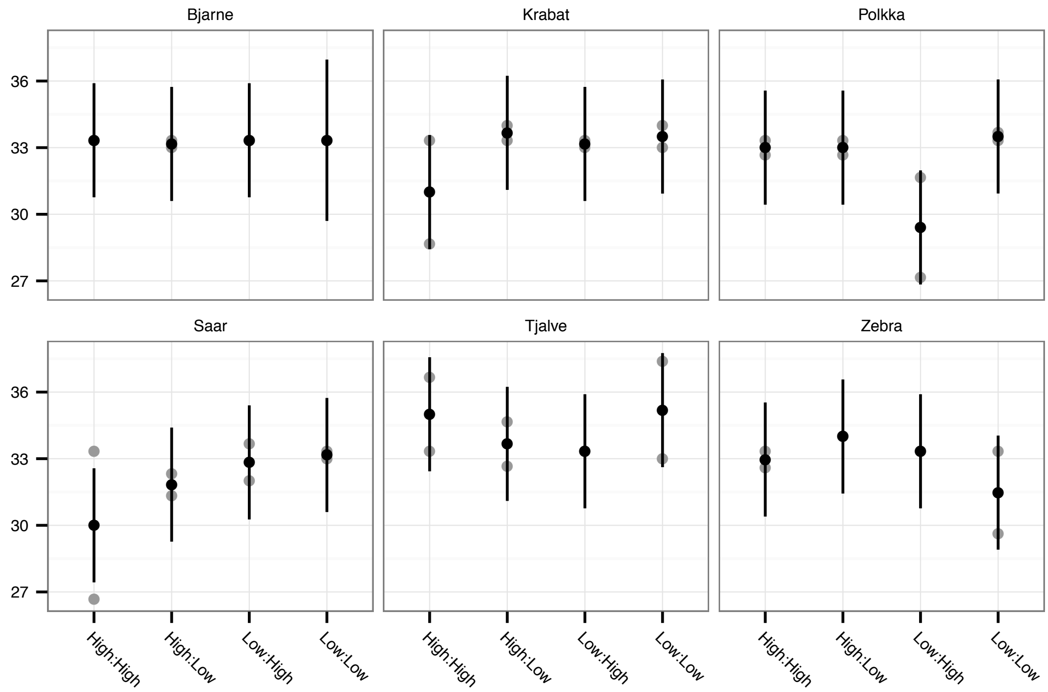


FIGURE 2.6: The mean dormancy index with 95 % confidence interval of the 6 genotypes. Shown as grey dots is the actual observations. The x axis shows wich room the samples were grown during the experiment. High/High and Low/Low indicates that the plants were grown in the high or low temperature room from sowing to harvest and where High/Low and Low/High indicates that the plants were moved from one room to the other after heading.

TABLE 2.8: ANOVA table of germination indexes.

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Genotype	15	4.26	0.28	58.14	0.0000
growth1	1	0.52	0.52	106.69	0.0000
growth2	1	0.00	0.00	0.62	0.4326
Genotype:growth1	15	0.68	0.05	9.28	0.0000
Genotype:growth2	15	0.11	0.01	1.44	0.1568
growth1:growth2	1	0.03	0.03	5.92	0.0178
Genotype:growth1:growth2	15	0.08	0.01	1.10	0.3717
Residuals	64	0.31	0.00		

the first and second stage of the experiment. There was also significant interaction between the first growth stage and genotype. However there was no significant effect of the second growth stage and interaction between the second growth stage and genotype. Also, there was no significant 3rd order interaction between the stages and genotype. In figure 2.7 the mean germination index for all the genotypes are presented. Some of the genotypes showed little dormancy regardless of environmental differences and germinated readily under all conditions. Bjarne, Naxos, Sirius, and T7347 had clearly lower germination rate when grown under colder temperatures from sowing to heading. Avle, Demonstrant and Zebra showed a slightly lower germination when grown under lower temperatures during the whole experiment.

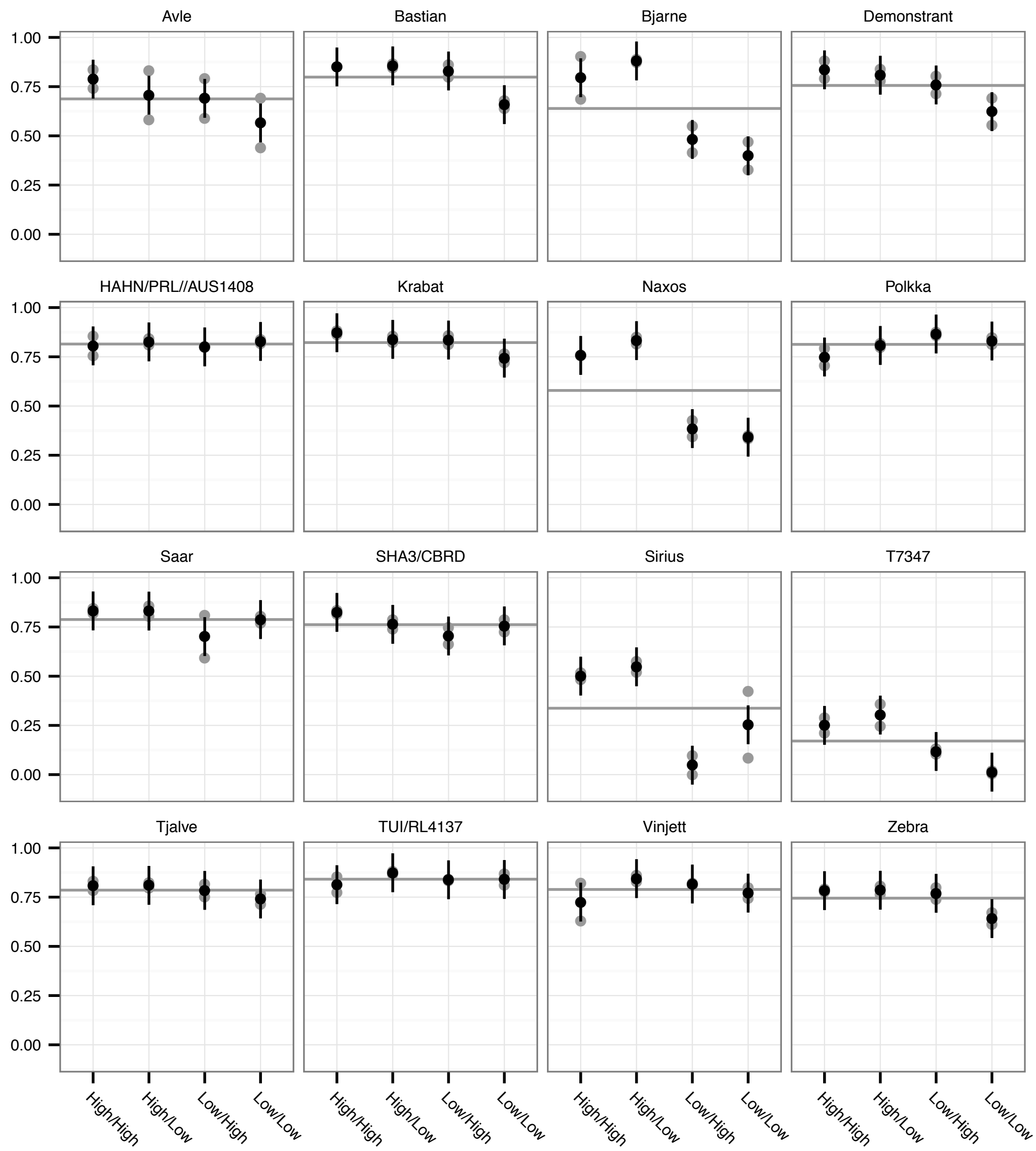


FIGURE 2.7: The mean Germination index with 95 % confidence interval for each genotype and combination of The treatments are the temperature before heading and after heading. The x axis shows which room the samples were grown during the experiment. High/High and Low/Low indicates that the plants were grown in the high or low temperature room from sowing to harvest and where High/Low and Low/High indicates that the plants were moved from one room to the other after heading.

2.2.3 Discussion

The genotypes separates into four groups based on which temperature combination dormancy was induced. One group is non dormant regardless of which room it was grown. Another group of Bastian, Zebra and Demonstrant have a slightly lower germination rate when only grown in the low temperature room. The third, consisting of Bjarne and Naxos, have high germination rate when grown in the high temperature room during the first stage of the experiment, but have a lower germination rate when grown in the low temperature room during the first stage. The fourth group, consisting of Sirius and T7347, have lower germination rate compared with the other genotypes both when grown in the low and high temperature room during the first stage. T7347 is known from Buraas and Skinnes 1985 to have high dormancy. Sirius is one of the parents of T7347, and is likely the source of the dormancy. One of the predecessors of Bjarne is Runar (see figure 2.5), the other parent of T7347. This is known to have a medium level of dormancy (Buraas and Skinnes 1985). One of the parents of Naxos (see figure 2.5) is Tordo, which is reported as a source of tolerance to PHS by gibberellin insensitivity by the gene Gai3 (Derera et al. 1976)

The relatively high temperatures in the greenhouse during the development of the plants can explain the uniform response of the genotypes. The lack of any significant differences in dormancy index between the genotypes is likely due to the high temperatures in the greenhouse. When there is no germination at 20° C and full germination at 10° C the dormancy index is 33, which is the case for all the samples in this experiment. This germination response related to high and low temperatures is expected when the wheat has been developed under high temperatures. The experiment from Buraas and Skinnes 1985 showed that phytotron grown wheat that was developed under 21° C had no dormancy when germinated at 10° C and high dormancy when germinated at 20° C (see figure 1.3 at page 6). This is the same response as seen on the dormancy index of the greenhouse experiment. Another explanation for the uniform response on dormancy index is the selection of genotypes that was used for determining dormancy index. Except for Bjarne, none of the genotypes are known to have very high levels of dormancy. In addition, none of this genotypes did show any response on the germination index related to temperature differences during the growth, except Bjarne.

The result of the germination index test showed that some of the genotypes responded to differences in temperature in the period from sowing to heading. The genotypes did not respond to differences in growth temperatures in the period from heading to yellow maturation. This is not what would be expected, as the grainfilling period is known to be the most sensitive for inducing dormancy. One possible explanation for this response is that the plants reached yellow maturation at different times depending on which room they were grown in. At the end of the experiment there was an increase in temperature. This increase happened after the plants in the high temperature room were harvested, but before all of the plants in the low temperature room were harvested. In figure 2.8 the mean date of yellow maturation of the heads in each pot is plotted against the mean temperature in the 10-day period before yellow maturation. This reveals that the spikes that were harvested at a later time in the experiment experienced a higher temperature before yellow maturation than plants that were in the high temperature room. However it is not evident that this could explain why the expected effect of temperature in the development stages closer to maturation did not appear in this experiment. Some of the lowest germination index was measured on the later dates when the temperature was at its highest. This experiment was carried out on an assumption that the environment in the grainfilling period is the most important for determining the level of dormancy, while in this experiment environmental differences in the period before grainfilling had the greatest effect on dormancy at yellow maturation.

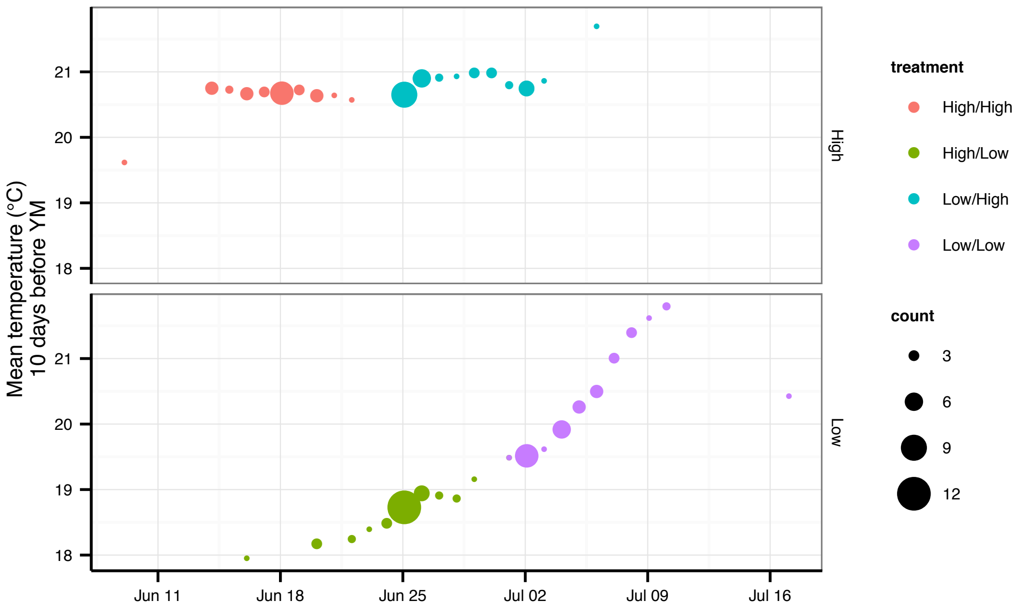


Figure 2.8: The mean dates of yellow maturation of the heads for the different pots. The size of the circle indicates number of pots that reached yellow maturation of that day. Position on the y-axis represents the mean temperature in the period 10 days before yellow maturation to yellow maturation.

2.3 Field trial

A challenge when measuring falling number of field-grown wheat to asses the level of tolerance to PHS in a genotype, is the chance of non-dormant seeds escaping germination due to dry weather. A solution to this is to apply irrigation in the field after yellow maturation to promote germination in non-dormant seeds. This experiment consisted of varieties and advanced breeding lines with relevance for Norwegian spring-wheat breeding that was grown in the the field at Vollebekk research farm in Ås. A mist irrigation system was installed in the field providing wetting of the heads in the after-ripening period. The falling number were measured after the plants had been weathered. The goal of this experiment was to examine the use of falling number of grains that were exposed to artificial wetting after maturation to evaluate resistance to PHS-damage. The results from the experiment can make the basis for development of a method for screening for high falling numbers after artificial weathering. Another goal of this experiment was to identify sources of dormancy that can be utilized in breeding and research on PHS-resistance. The results from the experiment is discussed in the light of three trials from previous years where falling numbers have been measured. Two master theses (Dahal 2012 and Tayor 2010) provided the data for comparisons. In addition, a dataset with falling numbers of Norwegian varieties grown at various location and years, performed by Bioforsk and Norsk Landbruksrådgivning, was used to compare the results from the Norwegian varieties included in the trial. The data is an unpublished compilation provided by Morten Lillemo (personal communication).

2.3.1 Material and methods

156 genotypes were sown on 3rd May 2012 at Vollebekk Research Farm in Ås. The experimental design was an alpha lattice design (Patterson and Williams 1976) with two replicates, consisting of 8 blocks with 20 plots in each block, totaling 320 plots. This experimental design has the benefit if being able to be analyzed as a random complete block design (RCBD), ignoring the block effects if the block effects are small and treat the whole relicate as a block. The blocks consisted of rows of 20 genotypes and a plot

on each side was sown with Bastian. The design ensured that two genotypes never were in the same block more than once. The plot size was 1.5 m x 0.75 m (D-plot). A 1.5 m wide path was made between the rows. The heading date was recorded and was defined as the date when more than 50 % of the head was visible on more than 50 % of the straws. The date of yellow maturation was recorded and defined as the date when more than 50 % of the straws had lost the green color on the uppermost internode and above. The field was sprayed twice with Proline® fungicide round the time of flowering to protect against Fusarium. A mist irrigation system was installed and started when the first plots reached yellow maturation. The mist irrigation consisted of sprinklers with a spraying radius of approximately 9 meters. The sprinklers were placed in a grid 9 meters apart so the water spray would reach the neighboring sprinklers, ensuring that all plants were reached by the spray. The plants was irrigated for 10 minutes every hour between 4 pm and 9 pm. The mist irrigation was active from 15th August 2012 to 1st September 2012 and from 7th September 2012 to 14th September 2012. The plots where harvested with a combine harvester on 19th September 2012. The seeds were stored in nets and dried at 30° C for two days.

The 2012 growth season was without any major deviations from the normal temperature or precipitation, except for a hot period in May (Figure 2.9). The temperature was slightly on the low side of the normal temperature during the grain filling period. There was some precipitation in the period when the mist irrigation was active.

The grains where cleaned and a 100 g sample from each plot was milled with a Perten laboratory mill. The water content of the flour was measured the day before the falling number test. The water content was measured by measuring the difference in weight after drying them overnight on 110° C in a heating chamber. Based on the water content, one sample of flour was weighed on a laboratory scale. The measured amount of flour was calculated based on the water content of the flour using the equation $g_{sample} = \frac{595}{100-\%wc}$. A sample of 15 % water content should weigh 7 grams. The sample was placed in a test tube and filled with 25 ml of filtered water and shaken vigorously until all flour had dispersed in the water. The sample was placed in a Perten Falling Number 1700 machine and the automated program for measuring falling number was started. The machine heated the sample in a boiling water bath while mixing the

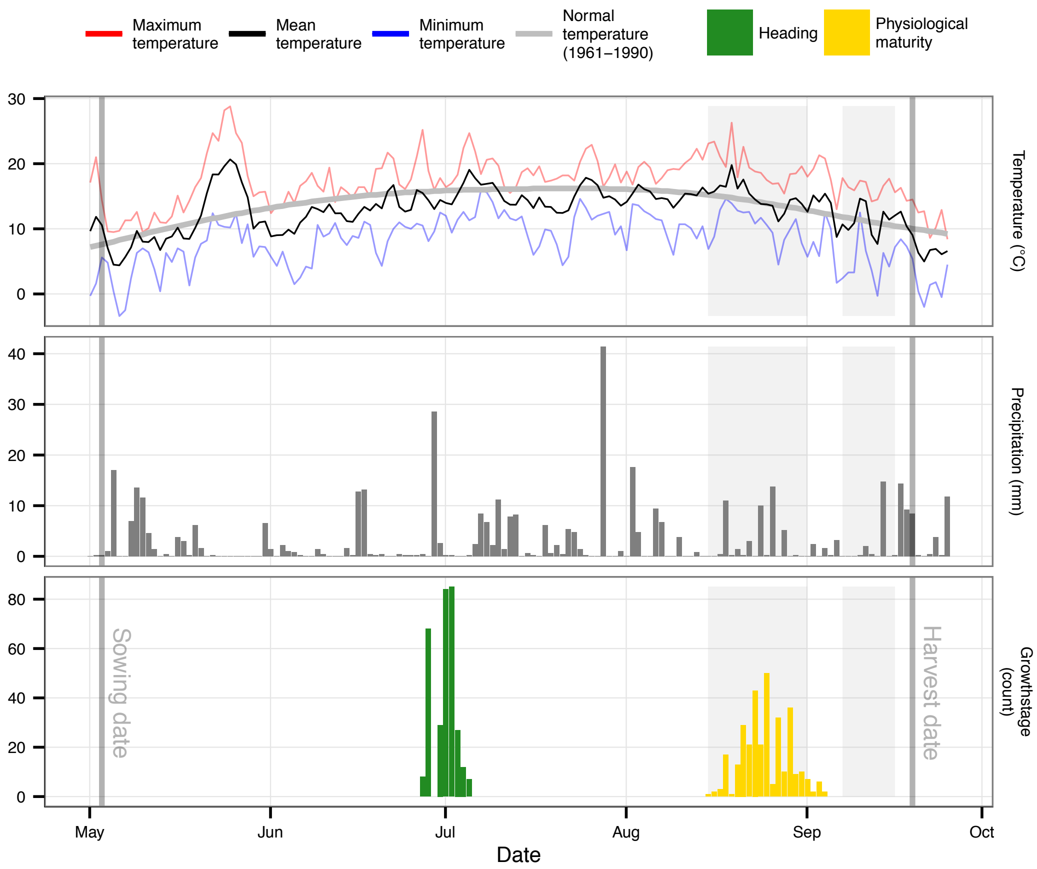


FIGURE 2.9: The daily temperature and precipitation during the 2012 growth season at Vollebekk research farm, Ås. The top panel displays daily mean, minimum, maximum and the normal temperature in ℃ between 1961 and 1990. The middle panel displays daily precipitation in mm. The bottom panel displays the daily count of plots reaching heading and yellow maturation. The shaded gray area indicates the periods where the mist irrigation was active.

sample for one minute. A plunger was automatically dropped into the sample and the time in seconds until the plunger reached the bottom of the tube was measured. The falling number is defined as 60 (mixing time in seconds) + the time in seconds from the plunger is dropped until it reaches the bottom of the tube. If the plunger used less than 2 seconds to drop to the bottom of the tube, the falling number was set to 62. The experiment was analyzed as RCBD using a linear model. Observations with a falling number of 62 was removed from the analysis. This was done to keep the assumptions of normality and homoscedasticity of the model. The model incorporated genotype and replicate as explanatory variables (equation 2.4).

$$\text{Falling number}_{ij} = \mu + \text{genotype}_i + \text{replicate}_j + \epsilon_{ij} \quad (2.4)$$

μ is the overall mean falling number of the experiment, genotype_i is the deviation from the mean for genotype_i, replicate_j is the deviation from the mean for replicate_j and ϵ_{ij} is the error for each observation. The error ϵ_{ij} is assumed to be independent, normally distributed $\sim N(0, \sigma)$.

2.3.2 Results

103 of the 156 genotypes had a falling number of 62 for at least one replicate. The estimated falling number of the genotypes that had a falling number over 62 for all replicates is shown in 2.10 on page 38. HAHN/PRL//AUS1408 and GN07580 was the only genotypes with a mean falling number higher than 200. Of the Norwegian varieties only Zebra had a mean falling number above 100.

A plot of the date of yellow maturation and the measured falling number (figure 2.11A) shows no clear trend in falling numbers in relation to yellow maturation date. The genotypes with high falling numbers was not among the particularly late or early genotypes. The genotypes matured in a period between 15th August 2012 and 4th September 2012. A plot of temperature in the 10-day period before yellow maturation and falling numbers (figure 2.11B) reveals that the genotypes with high falling numbers have higher temperatures in the period before maturation. The mean temperature in the period before maturation ranged from 13.6° to 16.4° C.

A comparison of the falling numbers from this trial and falling numbers from previous trials (figure 2.12) shows that the top genotypes from the 2012 trial almost consistently is among the better performing genotypes from the trials from 2009 and 2011. The 2010 season at Vollebekk was a particularly wet harvest season, wich is reflected in the lower falling numbers of that year.

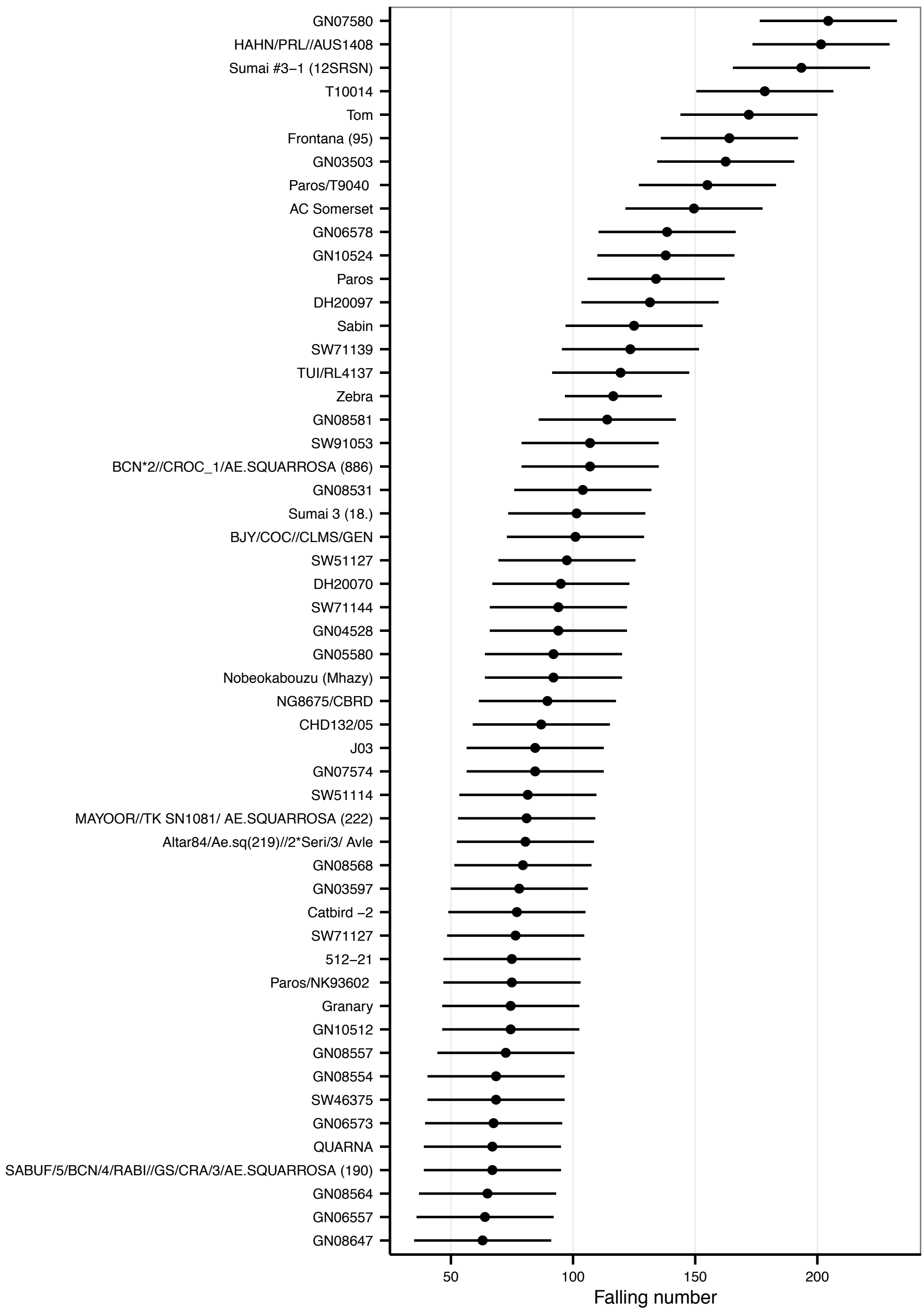


Figure 2.10: Plot of expected mean falling number with a 95 % confidence interval for the 53 genotypes with highest mean falling number.

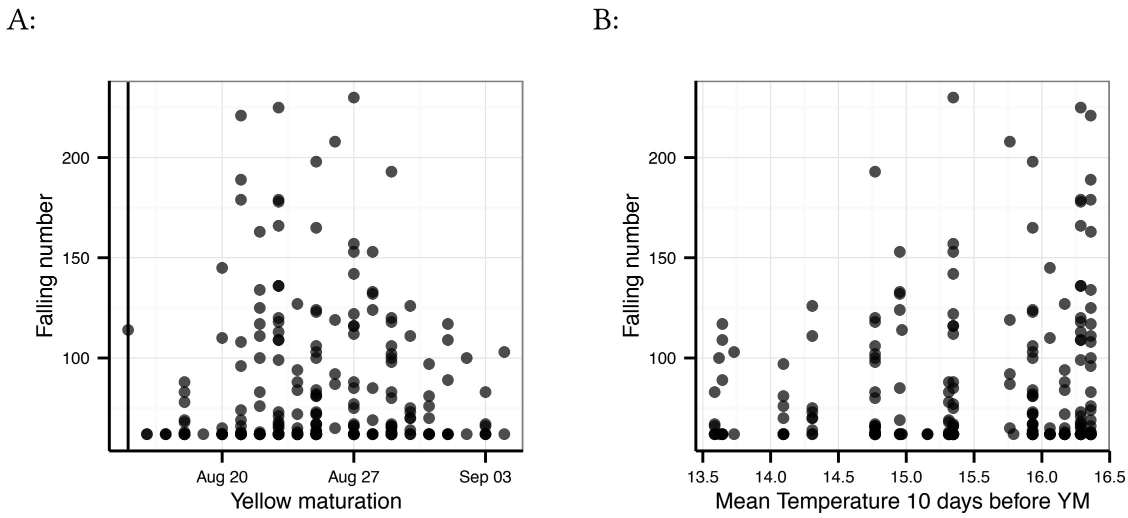


FIGURE 2.11: A: Date of yellow maturation and falling number for each plot. The black vertical line marks the date when the mist irrigation was activated. B: Mean temperature in the period 10 days before yellow maturation.

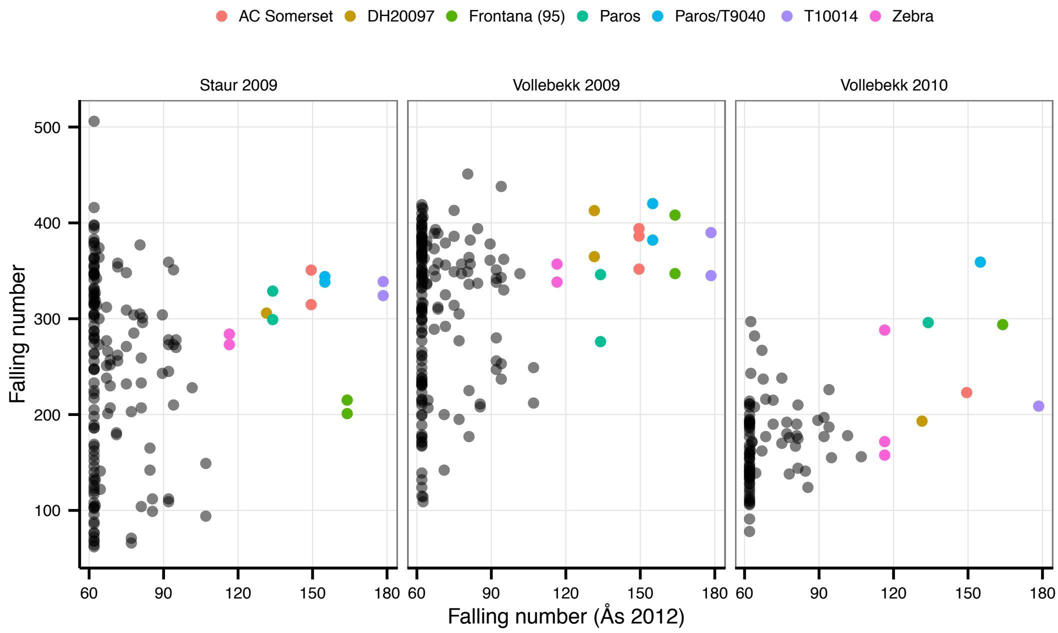


FIGURE 2.12: The mean falling number for the genotypes from the 2012 trial in Ås compared with earlier trials where falling numbers were measured. Not all genotypes included 2012 was measured in the other trials. The seven genotypes with highest mean falling number in 2012 are highlighted with colors. The data from 2009 are from Tayor 2010. Data from 2010 are from Dahal 2012.

2.3.3 Discussion

As the overall falling numbers were low and likely the result of severe PHS, it was impossible to compare the genotypes that were sprouting damaged. Only 53 of the 156 genotypes had falling numbers over 62 in all replicates. Some of these genotypes have been reported in literature as having good tolerance to PHS or have a pedigree with genotypes that are reported as sources of tolerance to PHS. Others have had high falling numbers in other trials. The lines HAHN/PRL//AUS1408, Frontana and TUI/RL4137 have been reported in literature as beeng sources of tolerance tp PHS. HAHN/PRL//AUS1408 is interesting as the parent AUS1408 is reported as a source for tolerance to PHS (Derera 1989). Frontana is reported as a source of tolerance to PHS both by having low α-amylase synthesis and by having a high level of dormancy (Derera 1989). The parent RL4137 in the line TUI/RL4137 is reported as a dormant genotype (Derera 1989) and is a major source of PHS tolerance in Canadian wheat varities (DePauw et al. 2009). When compared with the trials from Tayor 2010 and Dahal 2012 the genotypes Frontana, DH20097, AC Somerset, Paros, Paros/T9040, T10014 and Zebra were among the genotypes with higher falling numbers both in this trial and the trials from 2009 and 2010 (figure 2.12). This strengthens these genotypes standings as promising sources for tolerance to PHS. As these genotypes had high falling numbers relative to the growth season both in the 2012 trial with artificial field weathering and in 2010 with heavy rains indicates that these genotypes have the ability to produce high falling numbers even under conditions with high precipitation after maturation. Of the Norwegian varieties only Zebra had a falling number greater than 100 in the 2012 trial and was among the better in the trials from 2009 and 2010. Bioforsk and Norsk landbruksrådgivning measures the falling number of the Norwegian marked varieties and the most advanced lines each year in multiple fields as a part of the official variety testing. A compilation of this data provided by Morten Lillemo (personal communication) is used as a basis for comparison of the Norwegian varieties included in the trial. The falling numbers from the variety testing is presented in figure 2.13. In these trials Zebra did not have as great reduction in falling numbers in years where falling numbers was lower in general than the other varieties tested (see figure 2.13). This suggests that Zebra may have a higher tolerance to germination in years with

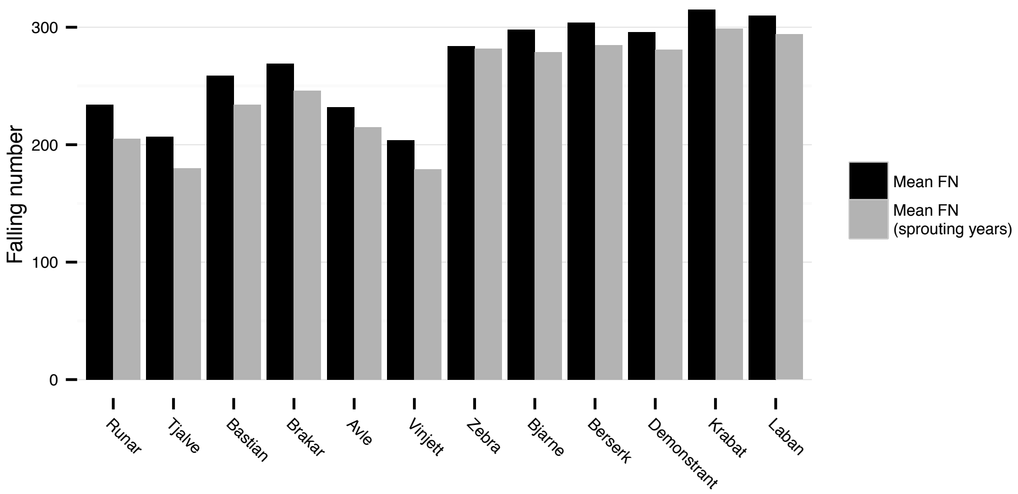


FIGURE 2.13: The falling numbers of Norwegian cultivars tested in field through the variety testing program by Bioforsk and Norsk Landbruksrådgivning. Black bars shows the mean falling number of years the variety was included in the test. Grey bars shows the mean falling number of years with sprouting. The varieties are ordered after year of release, with th earliest release on the left. Sprouting years are years with at least one variety with falling number 250 or lower. The data was provided by Morten Lillemo (personal communication)

high risk of PHS. The case may also be that Zebra has a more stable falling number regardless of sprouting level. The larger reduction in falling numbers in years with sprouting among the other varieties suggests that these varieties have another type of response when exposed to germination favoring conditions.

A limitation to field experiments and to this experiment in particular is the uneven exposure to environmental factors in relation to the date of maturation. A genotype which mature early would have been exposed to more precipitation and possibly low (germination inducing) temperatures in the period between yellow maturation and harvest, than a later maturing genotype. In addition, differences in temperature in the period before germination influences the level of dormancy at maturation. In this experiment the mist irrigation started at the date when the first plot reached yellow maturation. As there was a substantial difference in maturation dates between the genotypes, the number of days of exposure to mist irrigation after yellow maturation varied between 7 and 24 days. This variability in relation to the date of maturity makes it difficult to make comparisons between genotypes directly. However when plotting falling number on the date of yellow maturation (figure 2.11A) there is no apparent trend of higher falling numbers for the late maturing genotypes. This supports the notion that the observed differences in falling number in this experiment is due to genotypic differences. The differences in falling numbers observed in this experiment is also confirmed by the experiments from 2009 and 2010.

On the question on artificial weathering with mist irrigation as a tool for screening genotypes for high falling numbers, this experiment highlight the need for further refinement of the method. The overall low falling numbers measured in the experiment suggests that the level of artificial weathering in this experiment was too high for ranking the intermediate PHS-tolerant genotypes. Only the most resistant genotypes were identified in this experiment. If this experiment was to be conducted again, the level of artificial weathering should be adjusted to a lower level. There is also a need for controlling the variability related to different development rates of various genotypes. In an experiment as this where the harvest date is fixed to one date while the maturity date varies with the genotype, there is introduced a great amount of uncertainty on the ranking of the genotypes. When using this method for screening there is a risk of selection against early genotypes with good properties of PHS-resistance because they receives more artificial weathering than late genotypes. Late maturing susceptible genotypes in turn can falsely be selected on the bases of high falling number because of lower exposure to artificial weathering. A possible modification to the experimental setup is to harvest plots by hand on fixed dates after maturity. This would ensure that the artificial weathering would be equal for all plots after maturation. However the natural environmental influences would still vary with the earliness of the genotypes. This would also be true for the amount of artificial weathering received before maturation for the later maturing genotypes.

Chapter 3

Discussion

An objective of this thesis was to evaluate the dormancy in Norwegian varieties. When the results from all three parts of the thesis are viewed together, the variety Zebra is standing out as one of the better. It was the only variety that withstood the heavy artificial weathering of the field trial. The analysis of the historical revealed that Zebra was had overall good dormancy compared with the other varieties, and had a relatively stable dormancy between 1. and 2. harvest time. The question is whether there is differences in the stability of dormancy in the varieties. Though the results from this thesis can not answer this, there are some hints in that direction. When the results from this thesis is compared with data on falling numbers from previous years.

One goal of this thesis was to evaluate the dormancy characteristics of Norwegian spring wheat varieties based on the weather resistance trials from Vollebekk research farm. So what implications have these results for Norwegian spring wheat breeding in the future? One of the biggest challenges of our time is that of the current climate changes. The exact consequences of climate change is not clear with many scenarios, but it is not hard to envision types of climate change where dormancy is becoming more important for wheat growing in Norway. The results from this analysis rises the question if the current varieties have good enough dormancy to meet the challenges of climate change. The result for the analysis of the data from the weather resistance trials suggests that the dormancy in the current Norwegian varieties influenced by the climactic conditions during the grain development. Especially temperature plays an important part in this, with higher temperatures correlating with lower dormancy. In a climate change scenario with increased temperatures during the grain development there is a greater risk of higher frequency of seasons where the Norwegian varieties is having low dormancy and be susceptible to preharvest sprouting. If the harvest season then is wet, there is a higher risk of sprouting damage. Another aspect of an increased temperature and possible longer growing season is that sowing is started earlier in the spring. A possible problem with this agricultural practice is that the temperature sensitive stages of the grainfilling period then comes at an earlier and warmer time in the growth season, which in turn might give a lower level of dormancy. To meet these challenges, a future breeding goal might be to incorporate a type of dormancy which is less dependent on temperature. The question then arises if there is sources of a dormancy of this type. At least one promising source was confirmed, namely the line T7347,which showed a high level of dormancy in the greenhouse trial despite development under high temperatures. This could provide dormancy that are present over a wider temperature range, but more trials is needed to to evaluate the usefulness of this source.

The other main goal of this thesis was to evaluate two methods for measuring dormancy, either directly by measuring germination of greenhouse grown wheat or indirectly by measuring sprouting damage in artificially irrigated field grown wheat. If better dormancy should become a higher priority in Norwegian breeding, there is a question if the current methods for assessing dormancy could be improved. The results from the greenhouse experiment showed that there is a potential for using greenhouse in evaluation of dormancy. A prerequisite for the success of this method relies on the ability to accurately control the temperatures in the greenhouse. The experiments performed in this thesis was not designed to evaluate the relationship between dormancy in greenhouse and overall performance in the field. More experiments and trials designed to verify the relation between greenhouse dormancy and long run field dormancy are needed. The results from the field experiment left little doubt about the use of artificial irrigation could simulate a rainy harvest season, and thus give good conditions for selecting genotypes with good dormancy. More research is needed to fine tune this method. A possible future implementation of artificial irrigation could be to use it in dry years with little precipitation to avoid high falling numbers in non-dormant genotypes. As falling number testing is already a part of the screening in Norwegian breeding, this could be a feasible improvement of the screening process.

Chapter 4

Conclusion

The dormancy of the current Norwegian cultivars varies with climatic conditions in the time period around maturation. The analysis of the historical data on dormancy index found significant correlation between temperature in the last period before maturation.

The greenhouse trials identified the line T7347 a dormant genotype, which showed high levels of dormancy in conditions where the Norwegian varieties did not show high levels of dormancy. This line could be an interesting source of dormancy, and should be included in future trials. This line could also be an interesting research object for studying dormancy in spring wheat.

The field trial with artifcial weathering confirmed that the genotypes AC somerset, DH20097, Frontana, Paros, Paros/T9040, T10014 and the variety Zebra had high falling numbers even when exposed to heavy irrigation in the after ripening period.

More research needs to be done on the use of greenhouse as a tool for screening for dormancy. The results from this theses can be used as knowledge for further development of the method. The temperature control needs to be improved.

Artificial field weathering proved to be very effective as a tool for screening for high falling number. In this trial the irrigation exposure was to high to be able to asses the sprouting resistance level for most varieties. This method needs refinement to find the right level of artificial irrigation.

In light of possible higher risk of preharvest sprouting, the results from this thesis raises the question of weather current Norwegian varieties have the right level of dormancy. This thesis points out that there is interesting variation in the breeding material that can contribute to improved dormancy. This thesis also provides knowledge for future improvements of the methods used in dormancy breeding and research.

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Appendix A

Historic Data

	Year	Variety	Date 1.HT	Date 2.HT	DI 1.HT	DI 2.HT	date YM	YM min 10	YM to HT1	HT1 to HT2	YM min 10	YM to HT1	HT1 to HT2
1	1995	Avle	Sep 05	Sep 13	3.00	8.00	Aug 25	18.52	12.91	12.94	15.00	41.40	-
2	1995	Bastian	Sep 01	Sep 14	13.00	3.00	Aug 22	18.92	14.23	13.35	0.40	16.00	-
3	1995	Polkka	Sep 05	Sep 14	4.00	0.00	Aug 25	18.52	12.91	13.07	15.00	41.40	-
4	1995	Vinjett	Sep 07	Sep 18	7.00	11.00	Aug 27	17.55	12.82	11.84	14.80	29.60	-
5	1996	Avle	Sep 18	Oct 10	10.00	19.00	Sep 03	15.64	9.43	8.45	54.60	32.80	-
6	1996	Bastian	Sep 16	Oct 07	8.00	0.00	Sep 01	16.28	10.06	8.43	58.80	32.80	-
7	1996	Polkka	Sep 16	Oct 10	0.00	2.00	Sep 01	16.28	10.06	8.49	58.80	32.80	-
8	1996	Vinjett	Sep 18	Oct 14	11.00	27.00	Sep 03	15.64	9.43	8.33	54.60	32.80	-
9	1996	Zebra	Sep 18	Oct 10	4.00	0.00	Sep 03	15.64	9.43	8.45	54.60	32.80	-
10	1997	Avle	Aug 18	Aug 29	24.00	6.00	Aug 11	19.73	21.24	19.72	9.20	0.20	49.80
11	1997	Bastian	Aug 13	Aug 27	11.00	6.00	Aug 07	18.17	21.47	19.99	26.20	1.40	49.80
12	1997	Polkka	Aug 15	Aug 27	11.00	0.00	Aug 09	18.94	21.47	19.77	25.80	1.40	49.80
13	1997	Vinjett	Aug 18	Aug 29	15.00	9.00	Aug 11	19.73	21.24	19.72	9.20	0.20	49.80
14	1997	Zebra	Aug 18	Aug 29	20.00	15.00	Aug 11	19.73	21.24	19.72	9.20	0.20	49.80
15	1997	Zebra	Aug 18	Aug 29	24.00	10.00	Aug 11	19.73	21.24	19.72	9.20	0.20	49.80
16	1998	Bastian	Sep 18	Oct 12	28.00	15.00	Sep 07	11.76	13.54	8.72	4.20	101.20	-
17	1998	Bjarne	Sep 21	Oct 15	20.00	1.00	Sep 10	12.07	13.34	7.97	37.40	68.00	-
18	1998	Polkka	Sep 18	Oct 09	2.00	0.00	Sep 07	11.76	13.54	8.99	4.20	101.20	-
19	1998	Zebra	Sep 18	Oct 09	7.00	15.00	Sep 07	11.76	13.54	8.99	4.20	101.20	-
20	1999	Avle	Sep 08	Oct 01	9.00	20.00	Aug 30	14.18	15.47	12.77	33.20	22.40	-
21	1999	Bastian	Aug 31	Sep 20	8.00	0.00	Aug 21	13.62	13.89	14.27	14.00	33.40	36.40
22	1999	Bjarne	Sep 02	Sep 20	26.00	10.00	Aug 23	13.46	14.32	14.46	13.60	33.80	36.20
23	1999	Polkka	Sep 06	Sep 27	11.00	0.00	Aug 28	13.99	15.53	13.43	14.00	21.40	173.80
24	1999	Vinjett	Sep 10	Oct 01	15.00	12.00	Sep 01	13.88	15.55	12.59	33.40	3.00	-
25	1999	Zebra	Sep 08	Sep 29	27.00	29.00	Aug 30	14.18	15.47	13.03	33.20	22.40	178.00

	Year	Variety	Date 1.HT	Date 2.HT	DI 1.HT	DI 2.HT	date YM	YM min 10	YM to HT1	HT1 to HT2	YM min 10	YM to HT1	HT1 to HT2
26	2000	Avle	Sep 01	Sep 22	10.00	8.00	Aug 21	15.02	13.25	10.40	35.40	26.00	31.40
27	2000	Bastian	Aug 31	Sep 22	0.00	2.00	Aug 20	15.14	13.32	10.52	38.40	46.80	31.40
28	2000	Bjarne	Sep 01	Sep 25	35.00	10.00	Aug 21	15.02	13.25	10.20	35.40	26.00	31.60
29	2000	Polkka	Sep 01	Sep 22	3.00	0.00	Aug 21	15.02	13.25	10.40	35.40	26.00	31.40
30	2000	Vinjett	Sep 04	Sep 28	7.00	5.00	Aug 24	14.12	12.64	9.94	31.80	25.20	59.60
31	2000	Zebra	Sep 06	Sep 28	23.00	13.00	Aug 25	13.89	12.44	10.00	29.80	30.80	59.60
32	2001	Avle	Aug 30	Sep 28	2.00	7.00	Aug 21	16.35	15.06	11.49	31.40	4.60	114.00
33	2001	Bastian	Aug 29	Sep 26	23.00	2.00	Aug 20	16.25	15.22	11.82	31.60	16.00	113.60
34	2001	Bjarne	Sep 05	Sep 28	8.00	1.00	Aug 25	16.50	13.50	11.15	24.00	32.80	84.60
35	2001	Polkka	Aug 29	Sep 24	8.00	0.00	Aug 20	16.25	15.22	12.19	31.60	16.00	113.40
36	2001	Vinjett	Sep 05	Sep 28	4.00	6.00	Aug 25	16.50	13.50	11.15	24.00	32.80	84.60
37	2001	Zebra	Aug 30	Sep 28	12.00	13.00	Aug 21	16.35	15.06	11.49	31.40	4.60	114.00
38	2001	Zebra	Aug 29	Sep 26	26.00	33.00	Aug 20	16.25	15.22	11.82	31.60	16.00	113.60
39	2002	Avle	Aug 13	Aug 28	4.00	2.00	Aug 05	18.86	18.73	18.86	0.60	63.00	2.80
40	2002	Bastian	Aug 13	Aug 27	7.00	6.00	Aug 05	18.86	18.73	18.96	0.60	63.00	2.60
41	2002	Berserk	Aug 13	Aug 27	4.00	0.00	Aug 05	18.86	18.73	18.96	0.60	63.00	2.60
42	2002	Bjarne	Aug 13	Aug 27	13.00	10.00	Aug 05	18.86	18.73	18.96	0.60	63.00	2.60
43	2002	Demonstrant	Aug 15	Aug 28	11.00	1.00	Aug 08	19.46	18.93	18.74	0.80	63.00	2.60
44	2002	Vinjett	Aug 15	Sep 02	2.00	0.00	Aug 08	19.46	18.93	18.06	0.80	63.00	9.20
45	2002	Zebra	Aug 15	Sep 02	7.00	2.00	Aug 08	19.46	18.93	18.06	0.80	63.00	9.20
46	2003	Avle	Aug 15	Sep 02	11.00	0.00	Aug 07	17.90	18.62	13.89	12.60	32.20	39.00
47	2003	Bastian	Aug 13	Aug 29	18.00	2.00	Aug 06	17.51	19.55	14.83	22.00	22.40	67.60
48	2003	Berserk	Aug 13	Sep 02	11.00	5.00	Aug 06	17.51	19.55	13.99	22.00	22.40	68.60
49	2003	Bjarne	Aug 13	Sep 02	11.00	2.00	Aug 06	17.51	19.55	13.99	22.00	22.40	68.60
50	2003	Demonstrant	Aug 19	Sep 05	16.00	6.00	Aug 11	18.90	17.04	13.22	11.20	48.20	35.20
51	2003	Vinjett	Aug 15	Sep 02	2.00	3.00	Aug 07	17.90	18.62	13.89	12.60	32.20	39.00

	Year	Variety	Date 1.HT	Date 2.HT	DI 1.HT	DI 2.HT	date YM	YM min 10	YM to HT1	HT1 to HT2	YM min 10	YM to HT1	HT1 to HT2
52	2003	Zebra	Aug 15	Sep 02	6.00	0.00	Aug 07	17.90	18.62	13.89	12.60	32.20	39.00
53	2005	Avle	Sep 01	Sep 23	33.00	13.00	Aug 22	16.78	13.95	12.51	5.00	47.80	30.00
54	2005	Bastian	Aug 29	Sep 19	15.00	9.00	Aug 19	16.62	15.21	12.66	2.80	48.00	34.20
55	2005	Berserk	Sep 01	Sep 19	7.00	13.00	Aug 22	16.78	13.95	12.46	5.00	47.80	30.00
56	2005	Berserk	Sep 01	Sep 19	6.00	6.00	Aug 22	16.78	13.95	12.46	5.00	47.80	30.00
57	2005	Bjarne	Aug 29	Sep 19	19.00	8.00	Aug 19	16.62	15.21	12.66	2.80	48.00	34.20
58	2005	Demonstrant	Sep 01	Sep 23	16.00	9.00	Aug 22	16.78	13.95	12.51	5.00	47.80	30.00
59	2005	Demonstrant	Sep 01	Sep 23	14.00	18.00	Aug 22	16.78	13.95	12.51	5.00	47.80	30.00
60	2005	Krabat	Sep 01	Sep 19	25.00	11.00	Aug 22	16.78	13.95	12.46	5.00	47.80	30.00
61	2005	Zebra	Sep 01	Sep 23	18.00	14.00	Aug 22	16.78	13.95	12.51	5.00	47.80	30.00
62	2006	Bastian	Aug 08	Aug 30	26.70	6.70	Aug 01	20.19	19.48	16.20	25.60	2.20	93.40
63	2006	Berserk	Aug 15	Sep 05	12.70	4.00	Aug 07	19.49	17.58	15.46	27.20	26.00	109.20
64	2006	Bjarne	-	Sep 01	-	1.70	-	-	-	-	-	-	-
65	2006	Demonstrant	Aug 15	Sep 05	10.70	1.00	Aug 07	19.49	17.58	15.46	27.20	26.00	109.20
66	2006	Krabat	Aug 15	Sep 05	15.00	1.30	Aug 07	19.49	17.58	15.46	27.20	26.00	109.20
67	2006	Zebra	Aug 10	Aug 30	6.30	2.30	Aug 03	20.04	19.00	16.06	27.40	8.20	89.00
68	2007	Avle	Aug 24	Sep 21	2.00	0.00	Aug 15	17.99	16.12	11.30	71.20	26.20	35.80
69	2007	Avle	Aug 24	Sep 21	1.70	3.00	Aug 15	17.99	16.12	11.30	71.20	26.20	35.80
70	2007	Bastian	Aug 24	Sep 21	3.30	0.00	Aug 15	17.99	16.12	11.30	71.20	26.20	35.80
71	2007	Bastian	Aug 24	Sep 21	5.70	0.00	Aug 15	17.99	16.12	11.30	71.20	26.20	35.80
72	2007	Berserk	Aug 24	Sep 25	3.00	5.30	Aug 15	17.99	16.12	11.38	71.20	26.20	53.60
73	2007	Bjarne	Aug 24	Sep 21	4.30	3.30	Aug 15	17.99	16.12	11.30	71.20	26.20	35.80
74	2007	Bjarne	Aug 24	Sep 21	3.70	0.00	Aug 15	17.99	16.12	11.30	71.20	26.20	35.80
75	2007	Demonstrant	Aug 24	Sep 27	6.30	4.70	Aug 15	17.99	16.12	11.27	71.20	26.20	53.60
76	2007	Krabat	Aug 24	Sep 25	8.70	3.70	Aug 15	17.99	16.12	11.38	71.20	26.20	53.60
77	2007	Zebra	Aug 24	Sep 21	4.70	2.30	Aug 15	17.99	16.12	11.30	71.20	26.20	35.80

	Year	Variety	Date 1.HT	Date 2.HT	DI 1.HT	DI 2.HT	date YM	YM min 10	YM to HT1	HT1 to HT2	YM min 10	YM to HT1	HT1 to HT2
78	2007	Zebra	Aug 24	Sep 25	2.30	1.70	Aug 15	17.99	16.12	11.38	71.20	26.20	53.60
79	2008	Avle	Sep 04	Sep 30	21.33	17.00	Aug 25	14.08	13.83	9.81	81.80	33.80	44.60
80	2008	Bastian	Sep 04	Sep 30	23.33	18.00	Aug 25	14.08	13.83	9.81	81.80	33.80	44.60
81	2008	Bastian	Sep 04	Sep 30	23.33	15.00	Aug 25	14.08	13.83	9.81	81.80	33.80	44.60
82	2008	Berserk	Sep 02	Sep 26	21.00	14.00	Aug 23	14.22	13.95	10.38	129.60	9.20	52.20
83	2008	Berserk	Sep 04	Sep 30	20.67	18.00	Aug 25	14.08	13.83	9.81	81.80	33.80	44.60
84	2008	Bjarne	Sep 02	Sep 26	34.67	6.00	Aug 23	14.22	13.95	10.38	129.60	9.20	52.20
85	2008	Bjarne	Sep 02	Sep 26	19.33	14.00	Aug 23	14.22	13.95	10.38	129.60	9.20	52.20
86	2008	Demonstrant	Sep 12	Oct 07	26.67	2.00	Aug 31	13.88	12.23	8.49	15.00	51.00	90.80
87	2008	Krabat	Sep 02	Sep 30	34.67	35.00	Aug 23	14.22	13.95	10.12	129.60	9.20	59.40
88	2008	Krabat	Sep 04	Sep 30	33.67	31.00	Aug 25	14.08	13.83	9.81	81.80	33.80	44.60
89	2008	Zebra	Sep 09	Oct 07	4.33	21.00	Aug 29	13.91	12.91	8.75	87.20	49.60	93.40
90	2008	Zebra	Sep 12	Oct 07	31.67	20.00	Aug 31	13.88	12.23	8.49	15.00	51.00	90.80
91	2009	Bastian	Aug 17	Sep 08	6.30	5.00	Aug 08	16.26	15.34	14.62	81.80	55.80	106.80
92	2009	Bastian	Aug 17	Sep 10	7.70	3.00	Aug 08	16.26	15.34	14.62	81.80	55.80	107.00
93	2009	Berserk	Aug 17	Sep 08	1.70	6.70	Aug 08	16.26	15.34	14.62	81.80	55.80	106.80
94	2009	Berserk	Aug 17	Sep 08	3.70	6.70	Aug 08	16.26	15.34	14.62	81.80	55.80	106.80
95	2009	Bjarne	Aug 17	Sep 08	4.30	2.00	Aug 08	16.26	15.34	14.62	81.80	55.80	106.80
96	2009	Bjarne	Aug 17	Sep 08	8.30	6.70	Aug 08	16.26	15.34	14.62	81.80	55.80	106.80
97	2009	Demonstrant	Aug 21	Sep 10	4.30	2.30	Aug 11	16.79	14.98	14.49	45.80	56.60	92.80
98	2009	Demonstrant	Aug 20	Sep 10	0.00	6.30	Aug 10	16.64	14.90	14.64	53.20	54.80	97.40
99	2009	Krabat	Aug 17	Sep 08	6.30	10.30	Aug 08	16.26	15.34	14.62	81.80	55.80	106.80
100	2009	Krabat	Aug 17	Sep 08	8.00	10.00	Aug 08	16.26	15.34	14.62	81.80	55.80	106.80
101	2009	Zebra	Aug 20	Sep 10	0.30	10.30	Aug 10	16.64	14.90	14.64	53.20	54.80	97.40
102	2009	Zebra	Aug 21	Sep 15	7.00	-	Aug 11	16.79	14.98	14.08	45.80	56.60	92.80
103	2010	Avle	Sep 03	-	13.67	-	Aug 22	16.82	12.12	-	75.40	21.80	-

	Year	Variety	Date 1.HT	Date 2.HT	DI 1.HT	DI 2.HT	date YM	YM min 10	YM to HT1	HT1 to HT2	YM min 10	YM to HT1	HT1 to HT2
104	2010	Bastian	Sep 01	Sep 28	17.67	0.00	Aug 21	16.75	13.01	10.86	75.70	27.40	89.50
105	2010	Bastian	Aug 31	Sep 24	6.33	4.33	Aug 20	16.72	13.32	11.44	70.10	27.70	60.90
106	2010	Berserk	Sep 01	Sep 28	8.67	4.33	Aug 21	16.75	13.01	10.86	75.70	27.40	89.50
107	2010	Berserk	Sep 07	Oct 06	10.33	11.00	Aug 25	15.85	11.44	10.22	24.30	22.30	116.50
108	2010	Berserk	Aug 31	Sep 24	3.67	16.00	Aug 20	16.72	13.32	11.44	70.10	27.70	60.90
109	2010	Bjarne	Aug 31	Sep 24	0.00	8.67	Aug 20	16.72	13.32	11.44	70.10	27.70	60.90
110	2010	Bjarne	Aug 31	Sep 28	1.67	0.00	Aug 20	16.72	13.32	10.89	70.10	27.70	89.70
111	2010	Bjarne	Sep 03	Oct 01	10.67	6.33	Aug 22	16.82	12.12	10.29	75.40	21.80	90.00
112	2010	Demonstrant	Sep 07	Oct 06	9.67	11.00	Aug 25	15.85	11.44	10.22	24.30	22.30	116.50
113	2010	Demonstrant	Sep 01	Sep 28	7.33	6.67	Aug 21	16.75	13.01	10.86	75.70	27.40	89.50
114	2010	Demonstrant	Sep 10	Oct 13	2.67	11.67	Aug 28	14.40	11.48	9.10	18.50	14.50	139.70
115	2010	Krabat	Sep 03	Oct 01	21.33	27.33	Aug 22	16.82	12.12	10.29	75.40	21.80	90.00
116	2010	Krabat	Sep 03	Oct 01	28.00	29.00	Aug 22	16.82	12.12	10.29	75.40	21.80	90.00
117	2010	Vinjett	Sep 10	Oct 13	1.67	6.33	Aug 28	14.40	11.48	9.10	18.50	14.50	139.70
118	2010	Zebra	Sep 03	Oct 01	22.67	20.00	Aug 22	16.82	12.12	10.29	75.40	21.80	90.00
119	2010	Zebra	Sep 03	Oct 01	17.67	16.00	Aug 22	16.82	12.12	10.29	75.40	21.80	90.00
120	2010	Zebra	Sep 03	Oct 01	18.67	20.67	Aug 22	16.82	12.12	10.29	75.40	21.80	90.00
121	2011	Bastian	Aug 30	Sep 15	20.00	24.00	Aug 20	13.98	14.86	13.15	47.30	98.60	130.10
122	2011	Bastian	Aug 26	Sep 15	19.00	18.30	Aug 17	13.80	15.05	13.54	49.90	32.80	189.30
123	2011	Berserk	Aug 30	Sep 15	11.30	22.30	Aug 20	13.98	14.86	13.15	47.30	98.60	130.10
124	2011	Berserk	Aug 30	Sep 21	16.70	38.30	Aug 20	13.98	14.86	12.43	47.30	98.60	171.90
125	2011	Bjarne	Aug 30	Sep 21	20.30	18.30	Aug 20	13.98	14.86	12.43	47.30	98.60	171.90
126	2011	Bjarne	Aug 26	Sep 15	22.30	12.00	Aug 17	13.80	15.05	13.54	49.90	32.80	189.30
127	2011	Demonstrant	Aug 30	Sep 21	21.00	19.70	Aug 20	13.98	14.86	12.43	47.30	98.60	171.90
128	2011	Demonstrant	Aug 30	Sep 23	20.30	26.70	Aug 20	13.98	14.86	12.22	47.30	98.60	174.70
129	2011	Krabat	Aug 30	Sep 15	24.70	60.00	Aug 20	13.98	14.86	13.15	47.30	98.60	130.10
130	2011	Krabat	Aug 30	Sep 21	27.70	29.70	Aug 20	13.98	14.86	12.43	47.30	98.60	171.90

	Year	Variety	Date 1.HT	Date 2.HT	DI 1.HT	DI 2.HT	date YM	YM min 10	YM to HT1	HT1 to HT2	YM min 10	YM to HT1	HT1 to HT2
131	2011	Zebra	Aug 30	Sep 21	31.30	41.00	Aug 20	13.98	14.86	12.43	47.30	98.60	171.90
132	2011	Zebra	Aug 30	Sep 23	29.00	37.70	Aug 20	13.98	14.86	12.22	47.30	98.60	174.70
133	2012	Avle	Sep 06	Oct 04	16.30	16.00	Aug 26	16.12	13.57	9.75	36.70	21.60	130.40
134	2012	Avle	Sep 03	Sep 28	18.00	8.00	Aug 24	16.51	13.91	10.27	15.00	30.10	93.50
135	2012	Bastian	Sep 03	Oct 04	16.80	7.70	Aug 24	16.51	13.91	10.22	15.00	30.10	131.60
136	2012	Bastian	Sep 06	Oct 04	13.30	16.70	Aug 26	16.12	13.57	9.75	36.70	21.60	130.40
137	2012	Berserk	Aug 28	Sep 20	10.70	15.70	Aug 19	16.22	15.13	12.18	14.80	29.50	57.30
138	2012	Bjarne	Aug 30	Sep 28	25.70	3.30	Aug 20	16.47	14.62	10.82	14.70	31.90	96.10
139	2012	Bjarne	Aug 30	Sep 28	22.70	8.00	Aug 20	16.47	14.62	10.82	14.70	31.90	96.10
140	2012	Bjarne	Sep 03	Oct 04	-	3.00	Aug 24	16.51	13.91	10.22	15.00	30.10	131.60
141	2012	Bjarne	Aug 28	Sep 20	14.00	19.30	Aug 19	16.22	15.13	12.18	14.80	29.50	57.30
142	2012	Demonstrant	Sep 03	Oct 04	15.70	6.00	Aug 24	16.51	13.91	10.22	15.00	30.10	131.60
143	2012	Demonstrant	Sep 07	-	23.00	17.00	Aug 27	15.67	13.35	-	37.80	12.10	-
144	2012	Demonstrant	Sep 06	-	24.00	21.00	Aug 26	16.12	13.57	-	36.70	21.60	-
145	2012	Krabat	Aug 30	Sep 28	21.00	14.00	Aug 20	16.47	14.62	10.82	14.70	31.90	96.10
146	2012	Krabat	Sep 06	Oct 08	27.00	53.70	Aug 26	16.12	13.57	9.25	36.70	21.60	130.90
147	2012	Krabat	Sep 03	Oct 04	17.70	22.70	Aug 24	16.51	13.91	10.22	15.00	30.10	131.60
148	2012	Polkka	Aug 30	Sep 28	2.00	6.00	Aug 20	16.47	14.62	10.82	14.70	31.90	96.10
149	2012	Polkka	Aug 28	Sep 20	23.00	11.70	Aug 19	16.22	15.13	12.18	14.80	29.50	57.30
150	2012	Vinjett	Sep 07	-	11.70	14.30	Aug 27	15.67	13.35	-	37.80	12.10	-
151	2012	Vinjett	Sep 07	-	8.70	14.70	Aug 27	15.67	13.35	-	37.80	12.10	-
152	2012	Zebra	Sep 06	Oct 04	30.30	6.70	Aug 26	16.12	13.57	9.75	36.70	21.60	130.40
153	2012	Zebra	Sep 03	Oct 04	18.30	14.00	Aug 24	16.51	13.91	10.22	15.00	30.10	131.60
154	2012	Zebra	Sep 03	Sep 28	16.70	11.70	Aug 24	16.51	13.91	10.27	15.00	30.10	93.50

Appendix B

Greenhouse Dormancy Index

				10° C		10° C		
	Name	phase 1	phase 2	Germinated	Total	Germinated	Total	Dormancy Index
1	Bjarne	High	High	50	50	0	50	33.33
2	Bjarne	High	High	50	50	0	50	33.33
3	Bjarne	High	Low	50	50	0	50	33.33
4	Bjarne	High	Low	100	100	1	100	33.00
5	Bjarne	Low	High	48	50	0	50	33.33
6	Bjarne	Low	High	49	50	0	50	33.33
7	Bjarne	Low	Low	42	99	0	100	-
8	Bjarne	Low	Low	49	50	0	50	33.33
9	Krabat	High	High	42	50	0	50	33.33
10	Krabat	High	High	50	50	0	50	28.67
11	Krabat	High	Low	100	100	0	100	33.33
12	Krabat	High	Low	98	100	0	100	34.00
13	Krabat	Low	High	98	100	0	100	33.33
14	Krabat	Low	High	97	100	1	100	33.00
15	Krabat	Low	Low	93	100	0	100	34.00
16	Krabat	Low	Low	98	100	1	100	33.00
17	Polkka	High	High	51	52	1	50	32.67
18	Polkka	High	High	50	50	0	50	33.33
19	Polkka	High	Low	50	50	0	50	33.33
20	Polkka	High	Low	50	50	1	50	32.67
21	Polkka	Low	High	96	97	14	97	27.15
22	Polkka	Low	High	20	20	0	20	31.67
23	Polkka	Low	Low	98	99	1	100	33.67
24	Polkka	Low	Low	98	100	0	100	33.33
25	Saar	High	High	45	50	2	50	33.33

				10° C		10° C		
	Name	phase 1	phase 2	Germinated	Total	Germinated	Total	Dormancy Index
26	Saar	High	High	99	100	10	100	26.67
27	Saar	High	Low	96	100	2	100	32.33
28	Saar	High	Low	49	50	3	50	31.33
29	Saar	Low	High	84	100	1	100	33.67
30	Saar	Low	High	86	100	4	100	32.00
31	Saar	Low	Low	44	50	0	50	33.33
32	Saar	Low	Low	91	100	1	100	33.00
33	Tjalve	High	High	98	99	0	100	33.33
34	Tjalve	High	High	18	20	0	20	36.67
35	Tjalve	High	Low	47	50	0	50	34.67
36	Tjalve	High	Low	48	50	0	50	32.67
37	Tjalve	Low	High	49	50	0	50	33.33
38	Tjalve	Low	High	88	100	0	100	33.33
39	Tjalve	Low	Low	85	99	0	100	37.37
40	Tjalve	Low	Low	97	100	1	100	33.00
41	Zebra	High	High	40	45	1	45	32.59
42	Zebra	High	High	47	50	0	50	33.33
43	Zebra	High	Low	98	100	0	100	34.00
44	Zebra	High	Low	99	100	0	100	34.00
45	Zebra	Low	High	44	50	0	50	33.33
46	Zebra	Low	High	42	50	0	50	33.33
47	Zebra	Low	Low	80	98	2	100	29.61
48	Zebra	Low	Low	88	100	0	100	33.33

Appendix C

Greenhouse Germination Index

	Name	phase 1	phase 2	Block	Germination Index
1	Avle	High	High	1	0.74
2	Avle	High	High	2	0.83
3	Avle	High	Low	3	0.58
4	Avle	High	Low	4	0.83
5	Avle	Low	High	3	0.59
6	Avle	Low	High	4	0.79
7	Avle	Low	Low	1	0.69
8	Avle	Low	Low	2	0.44
9	Bastian	High	High	1	0.85
10	Bastian	High	High	2	0.85
11	Bastian	High	Low	3	0.84
12	Bastian	High	Low	4	0.87
13	Bastian	Low	High	3	0.86
14	Bastian	Low	High	4	0.80
15	Bastian	Low	Low	1	0.68
16	Bastian	Low	Low	2	0.64
17	Bjarne	High	High	1	0.69
18	Bjarne	High	High	2	0.90
19	Bjarne	High	Low	3	0.87
20	Bjarne	High	Low	4	0.89
21	Bjarne	Low	High	3	0.55
22	Bjarne	Low	High	4	0.41
23	Bjarne	Low	Low	1	0.47
24	Bjarne	Low	Low	2	0.33
25	Demonstrant	High	High	1	0.79
26	Demonstrant	High	High	2	0.88
27	Demonstrant	High	Low	3	0.78

	Name	phase 1	phase 2	Block	Germination Index
28	Demonstrant	High	Low	4	0.84
29	Demonstrant	Low	High	3	0.71
30	Demonstrant	Low	High	4	0.80
31	Demonstrant	Low	Low	1	0.69
32	Demonstrant	Low	Low	2	0.55
33	HAHN/PRL//AUS1408	High	High	1	0.76
34	HAHN/PRL//AUS1408	High	High	2	0.85
35	HAHN/PRL//AUS1408	High	Low	3	0.81
36	HAHN/PRL//AUS1408	High	Low	4	0.84
37	HAHN/PRL//AUS1408	Low	High	3	0.80
38	HAHN/PRL//AUS1408	Low	High	4	0.80
39	HAHN/PRL//AUS1408	Low	Low	1	0.82
40	HAHN/PRL//AUS1408	Low	Low	2	0.84
41	Krabat	High	High	1	0.86
42	Krabat	High	High	2	0.88
43	Krabat	High	Low	3	0.86
44	Krabat	High	Low	4	0.82
45	Krabat	Low	High	3	0.86
46	Krabat	Low	High	4	0.81
47	Krabat	Low	Low	1	0.72
48	Krabat	Low	Low	2	0.77
49	Naxos	High	High	1	0.76
50	Naxos	High	High	2	0.76
51	Naxos	High	Low	3	0.82
52	Naxos	High	Low	4	0.85
53	Naxos	Low	High	3	0.43
54	Naxos	Low	High	4	0.34
55	Naxos	Low	Low	1	0.35
56	Naxos	Low	Low	2	0.33
57	Polkka	High	High	1	0.71
58	Polkka	High	High	2	0.79
59	Polkka	High	Low	3	0.82
60	Polkka	High	Low	4	0.80
61	Polkka	Low	High	3	0.86
62	Polkka	Low	High	4	0.88
63	Polkka	Low	Low	1	0.85
64	Polkka	Low	Low	2	0.81
65	Saar	High	High	1	0.82
66	Saar	High	High	2	0.84
67	Saar	High	Low	3	0.86
68	Saar	High	Low	4	0.81
69	Saar	Low	High	3	0.59

	Name	phase 1	phase 2	Block	Germination Index
70	Saar	Low	High	4	0.81
71	Saar	Low	Low	1	0.81
72	Saar	Low	Low	2	0.77
73	SHA3/CBRD	High	High	1	0.81
74	SHA3/CBRD	High	High	2	0.83
75	SHA3/CBRD	High	Low	3	0.74
76	SHA3/CBRD	High	Low	4	0.79
77	SHA3/CBRD	Low	High	3	0.66
78	SHA3/CBRD	Low	High	4	0.75
79	SHA3/CBRD	Low	Low	1	0.79
80	SHA3/CBRD	Low	Low	2	0.72
81	Sirius	High	High	1	0.52
82	Sirius	High	High	2	0.48
83	Sirius	High	Low	3	0.52
84	Sirius	High	Low	4	0.57
85	Sirius	Low	High	3	0.00
86	Sirius	Low	High	4	0.10
87	Sirius	Low	Low	1	0.42
88	Sirius	Low	Low	2	0.08
89	T7347	High	High	1	0.21
90	T7347	High	High	2	0.29
91	T7347	High	Low	3	0.36
92	T7347	High	Low	4	0.25
93	T7347	Low	High	3	0.10
94	T7347	Low	High	4	0.13
95	T7347	Low	Low	1	0.02
96	T7347	Low	Low	2	0.01
97	Tjalve	High	High	1	0.83
98	Tjalve	High	High	2	0.78
99	Tjalve	High	Low	3	0.80
100	Tjalve	High	Low	4	0.82
101	Tjalve	Low	High	3	0.82
102	Tjalve	Low	High	4	0.75
103	Tjalve	Low	Low	1	0.77
104	Tjalve	Low	Low	2	0.71
105	TUI/RL4137	High	High	1	0.77
106	TUI/RL4137	High	High	2	0.85
107	TUI/RL4137	High	Low	3	0.87
108	TUI/RL4137	High	Low	4	0.88
109	TUI/RL4137	Low	High	3	0.83
110	TUI/RL4137	Low	High	4	0.84
111	TUI/RL4137	Low	Low	1	0.81

	Name	phase 1	phase 2	Block	Germination Index
112	TUI/RL4137	Low	Low	2	0.87
113	Vinjett	High	High	1	0.63
114	Vinjett	High	High	2	0.82
115	Vinjett	High	Low	3	0.83
116	Vinjett	High	Low	4	0.86
117	Vinjett	Low	High	3	0.82
118	Vinjett	Low	High	4	0.81
119	Vinjett	Low	Low	1	0.80
120	Vinjett	Low	Low	2	0.74
121	Zebra	High	High	1	0.79
122	Zebra	High	High	2	0.78
123	Zebra	High	Low	3	0.76
124	Zebra	High	Low	4	0.81
125	Zebra	Low	High	3	0.74
126	Zebra	Low	High	4	0.80
127	Zebra	Low	Low	1	0.61
128	Zebra	Low	Low	2	0.67

Appendix D

Falling Number

	Name	Rep	Block	Plot	Heading	YM	Falling number
1	Sabin	1	1	1	Jun 30	Aug 22	134
2	Bjarne/LW91W86	1	1	2	Jul 05	Aug 30	62
3	GN07581	1	1	3	Jun 28	Aug 24	65
4	Pfau/Milan	1	1	4	Jul 02	Aug 25	62
5	Zebra	1	1	5	Jul 01	Aug 22	125
6	NK93602 (1995)	1	1	6	Jul 02	Aug 22	62
7	Avans	1	1	7	Jul 01	Aug 25	72
8	Scirocco	1	1	8	Jun 28	Aug 25	100
9	512-50	1	1	9	Jul 01	Aug 24	63
10	Chara	1	1	10	Jul 02	Aug 31	62
11	R37/GHL121//KAL/BB/3/ JUP/MUS/4/2*YMI #6/5/CBRD	1	1	11	Jul 01	Aug 31	62
12	Sumai 3 (18.)	1	1	12	Jul 03	Aug 26	119
13	GN08564	1	1	13	Jul 02	Aug 30	64
14	SW44333	1	1	14	Jul 02	Sep 01	62
15	Polkka	1	1	15	Jul 02	Aug 22	62
16	512-70	1	1	16	Jun 28	Aug 23	62
17	QUARNA	1	1	17	Jul 01	Aug 23	68
18	RB07	1	1	18	Jun 28	Aug 31	62
19	Møystad	1	1	19	Jul 02	Aug 24	62
20	Vinjett	1	1	20	Jul 02	Aug 29	62
21	GN10524	1	2	1	Jun 28	Aug 23	166
22	Nanjing 7840 - Pl.4	1	2	2	Jul 03	Aug 25	62
23	SW44431	1	2	3	Jul 01	Aug 29	66
24	GN09572	1	2	4	Jul 01	Aug 20	62
25	GN03529	1	2	5	Jul 03	Aug 29	100
26	Kariega	1	2	6	Jun 28	Aug 23	62

	Name	Rep	Block	Plot	Heading	YM	Falling number
27	GN08504	1	2	7	Jul 01	Aug 24	88
28	NK93604	1	2	8	Jun 28	Aug 18	62
29	Kukri	1	2	9	Jul 04	Aug 29	62
30	MS 273-150	1	2	10	Jul 01	Aug 18	62
31	BCN*2//CROC_1/ AE.SQUARROSA (886)	1	2	11	Jul 03	Aug 30	111
32	GN05507	1	2	12	Jul 01	Aug 24	62
33	GN08534	1	2	13	Jul 02	Aug 26	65
34	GN05580	1	2	14	Jul 04	Sep 01	117
35	SW71237	1	2	15	Jul 02	Aug 29	62
36	GN08568	1	2	16	Jul 02	Sep 01	89
37	GN07501	1	2	17	Jul 02	Aug 29	62
38	T9040 (1995)	1	2	18	Jun 28	Aug 27	75
39	GN07580	1	2	19	Jul 02	Aug 27	230
40	DH 49-18 Bastian/Adder	1	2	20	Jun 28	Aug 18	62
41	GN09584	1	3	1	Jul 01	Aug 27	62
42	SW51114	1	3	2	Jul 01	Aug 26	87
43	GN07525	1	3	3	Jul 02	Aug 25	62
44	Polkka	1	3	4	Jul 02	Aug 19	62
45	CHD132/05	1	3	5	Jun 30	Aug 21	74
46	SW91053	1	3	6	Jul 02	Aug 21	96
47	Sport	1	3	7	Jul 02	Aug 17	62
48	Bjarne	1	3	8	Jul 02	Aug 20	62
49	GN08533	1	3	9	Jul 02	Aug 29	62
50	J03	1	3	10	Jul 03	Aug 18	88
51	Naxos/2*Saar	1	3	11	Jul 02	Aug 29	62
52	SW71127	1	3	12	Jul 01	Aug 29	65
53	AC Somerset	1	3	13	Jul 02	Aug 22	163
54	Bastian	1	3	14	Jul 01	Aug 16	62
55	GN05567	1	3	15	Jul 02	Aug 21	62
56	DH20070	1	3	16	Jul 02	Aug 15	114
57	GN06573	1	3	17	Jul 02	Aug 18	68
58	GN03509	1	3	18	Jul 03	Aug 28	62
59	SW71139	1	3	19	Jul 02	Aug 25	123
60	GN08595	1	3	20	Jul 03	Aug 29	62
61	Bombona	1	4	1	Jul 02	Aug 29	66
62	Nobeokabouzu (Mhazy)	1	4	2	Jun 30	Aug 23	109
63	GN10510	1	4	3	Jun 28	Aug 18	62
64	SW45204	1	4	4	Jul 01	Aug 25	62
65	GN03597	1	4	5	Jul 03	Aug 29	83
66	CJ9306	1	4	6	Jun 28	Aug 22	63
67	Zebra	1	4	7	Jul 02	Aug 24	127

	Name	Rep	Block	Plot	Heading	YM	Falling number
68	Avle	1	4	8	Jul 02	Aug 25	62
69	GN06557	1	4	9	Jul 01	Aug 23	65
70	NK01513	1	4	10	Jul 02	Aug 21	62
71	Norrøna	1	4	11	Jul 01	Aug 18	62
72	TJALVE/Purpur seed	1	4	12	Jul 03	Aug 25	62
73	GN06600	1	4	13	Jul 03	Aug 20	62
74	GN05589	1	4	14	Jul 04	Aug 24	62
75	T9040	1	4	15	Jul 04	Aug 21	62
76	GN04526	1	4	16	Jul 03	Aug 25	62
77	Dulus	1	4	17	Jul 03	Aug 18	62
78	Saar	1	4	18	Jun 28	Aug 24	62
79	GN08554	1	4	19	Jul 03	Aug 31	70
80	CJ9403	1	4	20	Jun 28	Aug 25	62
81	SW51069	1	5	1	Jul 01	Aug 21	62
82	GN05551	1	5	2	Jul 01	Aug 21	62
83	DH20097	1	5	3	Jul 01	Aug 20	145
84	Paros/NK93602	1	5	4	Jul 02	Aug 22	83
85	CBRD/KAUZ	1	5	5	Jul 02	Aug 27	62
86	Milan	1	5	6	Jul 02	Aug 27	62
87	ALTAR 84/ AE.SQUARROSA (224)// ESDA	1	5	7	Jul 01	Aug 26	92
88	CD87	1	5	8	Jun 28	Aug 25	62
89	GN08557	1	5	9	Jul 04	Aug 24	72
90	Saar	1	5	10	Jul 01	Aug 23	62
91	512-54	1	5	11	Jul 03	Aug 23	62
92	SABUF/5/BCN/4/RABI// GS/CRA/3/ AE.SQUARROSA (190)	1	5	12	Jul 03	Aug 20	65
93	NK01568	1	5	13	Jul 03	Aug 23	62
94	GN08596	1	5	14	Jul 05	Aug 24	62
95	Altar84/Ae.sq(219)//2*Seri/3/ Avle	1	5	15	Jul 02	Aug 18	83
96	GN07548	1	5	16	Jul 01	Aug 23	62
97	MILAN/SHA7	1	5	17	Jul 03	Aug 29	80
98	Dragon	1	5	18	Jul 02	Aug 27	62
99	512-87	1	5	19	Jul 01	Aug 23	62
100	T2038	1	5	20	Jun 28	Aug 20	62
101	BJY/COC//CLMS/GEN	1	6	1	Jun 28	Aug 22	100
102	Berserk -4	1	6	2	Jul 02	Aug 23	62
103	C80.1/3*QT4522//2*ATTILA	1	6	3	Jul 02	Aug 27	62
104	GN07574	1	6	4	Jul 02	Aug 25	106
105	Frontana (95)	1	6	5	Jul 01	Aug 26	208
106	Brakar - Pl.1	1	6	6	Jul 01	Aug 21	62
107	SHA3/CBRD	1	6	7	Jul 01	Aug 25	62

	Name	Rep	Block	Plot	Heading	YM	Falling number
108	NG8675/CBRD	1	6	8	Jul 02	Aug 23	113
109	HAHN/PRL//AUS1408	1	6	9	Jul 01	Aug 23	225
110	GN04537	1	6	10	Jul 02	Aug 21	62
111	Paros/T9040	1	6	11	Jul 03	Aug 27	157
112	GONDO	1	6	12	Jul 05	Aug 27	62
113	ONPMSYDER-05	1	6	13	Jul 03	Aug 27	62
114	GN08588	1	6	14	Jul 02	Aug 27	62
115	GN06578	1	6	15	Jul 04	Aug 28	153
116	512-21	1	6	16	Jun 30	Aug 21	66
117	Fram II	1	6	17	Jul 01	Aug 23	66
118	C80.1/3*QT4522//2*PASTOR	1	6	18	Jul 05	Sep 01	62
119	Tjalve	1	6	19	Jul 02	Aug 21	62
120	GN08647	1	6	20	Jul 03	Aug 29	63
121	GN08581	1	7	1	Jul 01	Aug 23	120
122	GN08597	1	7	2	Jul 02	Aug 25	62
123	Paros	1	7	3	Jul 02	Aug 27	142
124	GN03503	1	7	4	Jul 01	Aug 28	132
125	T9040/Paros	1	7	5	Jun 28	Aug 23	62
126	MAYOOR // TK SN1081/ AE.SQUARROSA (222)	1	7	6	Jul 01	Aug 28	85
127	TUI/RL4137	1	7	7	Jul 02	Aug 28	133
128	Runar	1	7	8	Jul 01	Aug 21	62
129	Bau/Milan -2	1	7	9	Jul 05	Aug 29	62
130	Filin	1	7	10	Jul 02	Aug 27	62
131	SW45126	1	7	11	Jun 28	Aug 25	81
132	Catbird -2	1	7	12	Jul 03	Aug 27	85
133	Tjalve	1	7	13	Jul 01	Aug 20	62
134	NK01565	1	7	14	Jul 03	Aug 29	62
135	Naxos (x3)	1	7	15	Jun 27	Aug 24	62
136	Granary	1	7	16	Jul 05	Sep 03	83
137	GN08531	1	7	17	Jul 01	Aug 23	99
138	NK00521	1	7	18	Jul 01	Aug 21	62
139	Altar84/Ae.squarrosa(219)// 2*Seri	1	7	19	Jul 02	Aug 29	62
140	T10014	1	7	20	Jul 02	Aug 23	136
141	GN04528	1	8	1	Jul 01	Aug 22	117
142	Croc_1/Ae.squarrosa (205)//Kauz	1	8	2	Jul 02	Aug 25	67
143	Avocet YrA	1	8	3	Jul 01	Aug 29	62
144	Bjarne	1	8	4	Jul 01	Aug 20	62
145	Rollo	1	8	5	Jun 30	Aug 20	62
146	SW46375	1	8	6	Jun 30	Aug 25	67
147	BAJASS-5	1	8	7	Jun 28	Aug 22	62
148	SW51127	1	8	8	Jul 01	Aug 29	98

	Name	Rep	Block	Plot	Heading	YM	Falling number
149	Reno	1	8	9	Jun 30	Aug 18	69
150	GN03531	1	8	10	Jul 01	Aug 25	62
151	Sumai #3-1 (12SRSN)	1	8	11	Jun 30	Aug 21	189
152	Tom	1	8	12	Jun 30	Aug 25	165
153	GN08530	1	8	13	Jun 28	Aug 18	62
154	GUAM92//PSN/BOW	1	8	14	Jul 03	Sep 01	109
155	SW71144	1	8	15	Jun 28	Aug 27	116
156	GN08541	1	8	16	Jul 03	Aug 25	73
157	GN10512	1	8	17	Jul 02	Aug 25	82
158	Gondo -1	1	8	18	Jul 04	Aug 27	62
159	GN07560	1	8	19	Jun 30	Aug 21	62
160	GN10521	1	8	20	Jul 01	Aug 25	63
161	Bjarne	2	1	1	Jun 28	Aug 22	62
162	GN05567	2	1	2	Jul 01	Aug 28	62
163	GN07581	2	1	3	Jun 28	Aug 25	62
164	SW71127	2	1	4	Jul 01	Aug 27	88
165	C80.1/3*QT4522//2*ATTILA	2	1	5	Jul 01	Aug 25	62
166	GN05551	2	1	6	Jun 28	Aug 25	62
167	Norrøna	2	1	7	Jul 01	Aug 22	62
168	GN08541	2	1	8	Jul 02	Aug 30	62
169	NK93604	2	1	9	Jun 28	Aug 22	62
170	NK01565	2	1	10	Jul 02	Sep 01	62
171	Zebra	2	1	11	Jun 30	Aug 25	103
172	Sport	2	1	12	Jul 01	Aug 18	62
173	Bombona	2	1	13	Jul 02	Aug 24	62
174	SW45126	2	1	14	Jul 01	Aug 25	62
175	GN05580	2	1	15	Jul 04	Aug 29	67
176	GN08530	2	1	16	Jun 28	Aug 20	62
177	Fram II	2	1	17	Jul 02	Aug 21	62
178	CBRD/KAUZ	2	1	18	Jul 02	Aug 24	62
179	Bjarne/LW91W86	2	1	19	Jul 04	Aug 29	62
180	Møystad	2	1	20	Jul 02	Aug 23	62
181	Saar	2	2	1	Jun 28	Aug 25	62
182	GN08597	2	2	2	Jul 02	Aug 25	62
183	GN09572	2	2	3	Jun 28	Aug 21	62
184	Polkka	2	2	4	Jul 01	Aug 21	62
185	AC Somerset	2	2	5	Jun 30	Aug 23	136
186	Paros/NK93602	2	2	6	Jul 01	Aug 25	67
187	GN08596	2	2	7	Jul 02	Aug 27	62
188	GN08595	2	2	8	Jul 02	Aug 28	62
189	Gondo -1	2	2	9	Jul 04	Sep 01	62
190	CJ9306	2	2	10	Jun 27	Aug 25	62

	Name	Rep	Block	Plot	Heading	YM	Falling number
191	GN03509	2	2	11	Jul 02	Aug 22	62
192	Pfau/Milan	2	2	12	Jul 02	Aug 24	62
193	Tom	2	2	13	Jul 02	Aug 21	179
194	Tjalve	2	2	14	Jul 02	Aug 21	62
195	MS 273-150	2	2	15	Jun 28	Aug 16	62
196	GN06578	2	2	16	Jul 03	Aug 28	124
197	Chara	2	2	17	Jul 02	Aug 27	62
198	SHA3/CBRD	2	2	18	Jul 02	Aug 23	62
199	Milan	2	2	19	Jun 30	Aug 27	62
200	T9040	2	2	20	Jul 01	Aug 24	62
201	Naxos (x3)	2	3	1	Jun 27	Aug 22	62
202	Saar	2	3	2	Jun 28	Aug 24	62
203	SW71237	2	3	3	Jun 30	Aug 27	62
204	HAHN/PRL//AUS1408	2	3	4	Jul 01	Aug 23	178
205	Sumai #3-1 (12SRSN)	2	3	5	Jul 02	Aug 25	198
206	Vinjett	2	3	6	Jun 30	Aug 23	62
207	Ning 8343 - Pl.4	2	3	7	Jul 02	Aug 24	94
208	Altar84/Ae.sq(219)//2*Seri/3/ Avle	2	3	8	Jun 28	Aug 18	78
209	GN06557	2	3	9	Jun 28	Aug 18	63
210	Brakar - Pl.1	2	3	10	Jul 01	Aug 18	62
211	GN07574	2	3	11	Jul 01	Aug 21	63
212	SW71144	2	3	12	Jun 30	Aug 25	72
213	Naxos/2*Saar	2	3	13	Jul 02	Aug 29	62
214	Granary	2	3	14	Jul 05	Sep 03	66
215	Avle	2	3	15	Jul 01	Aug 23	62
216	GN08581	2	3	16	Jul 01	Aug 21	108
217	GN08504	2	3	17	Jun 28	Aug 23	62
218	ALTAR84/AE.SQUARROSA (224)//ESDA	2	3	18	Jun 28	Aug 25	62
219	R37/GHL121//KAL/BB/3/ JUP/MUS/4/2*YMI #6/5/CBRD	2	3	19	Jun 28	Aug 25	62
220	Scirocco	2	3	20	Jun 28	Aug 23	62
221	512-87	2	4	1	Jun 28	Aug 20	62
222	SW44333	2	4	2	Jul 01	Aug 29	62
223	DH20070	2	4	3	Jun 28	Aug 22	76
224	GN10521	2	4	4	Jun 28	Aug 25	62
225	512-21	2	4	5	Jun 30	Aug 24	84
226	DH 49-18 Bastian/Adder	2	4	6	Jun 28	Aug 17	62
227	RB07	2	4	7	Jun 27	Aug 23	62
228	CJ9403	2	4	8	Jun 28	Aug 24	62
229	GN08557	2	4	9	Jul 03	Aug 23	73
230	Altar84/Ae.squarrosa(219)// 2*Seri	2	4	10	Jul 02	Aug 29	62

	Name	Rep	Block	Plot	Heading	YM	Falling number
231	ONPMSYDER-05	2	4	11	Jul 02	Aug 29	62
232	GN07548	2	4	12	Jun 28	Aug 23	62
233	Bjarne	2	4	13	Jun 28	Aug 23	62
234	GN09584	2	4	14	Jul 02	Aug 22	62
235	Croc_1/Ae.squarrosa (205)//Kauz	2	4	15	Jul 01	Aug 31	62
236	GN10510	2	4	16	Jul 01	Aug 18	62
237	SW44431	2	4	17	Jun 28	Aug 24	62
238	Catbird -2	2	4	18	Jul 04	Aug 28	69
239	GN03529	2	4	19	Jul 02	Aug 29	62
240	Runar	2	4	20	Jun 30	Aug 21	62
241	NK01568	2	5	1	Jul 01	Aug 25	62
242	Polkka	2	5	2	Jul 01	Aug 21	62
243	512-70	2	5	3	Jun 27	Aug 24	62
244	GN08588	2	5	4	Jun 28	Aug 27	62
245	512-50	2	5	5	Jun 28	Aug 25	62
246	SW71139	2	5	6	Jun 28	Aug 25	124
247	Paros/T9040	2	5	7	Jul 02	Aug 27	153
248	GN05589	2	5	8	Jul 02	Aug 27	62
249	GN07501	2	5	9	Jul 01	Aug 25	62
250	Sumai 3 (18.)	2	5	10	Jul 02	Aug 25	84
251	GN10512	2	5	11	Jul 01	Aug 23	67
252	GN10524	2	5	12	Jun 28	Aug 20	110
253	Bastian	2	5	13	Jun 28	Aug 17	62
254	GN04528	2	5	14	Jul 01	Aug 23	71
255	512-54	2	5	15	Jul 01	Aug 21	62
256	TUI/RL4137	2	5	16	Jul 01	Aug 29	106
257	GN08568	2	5	17	Jul 02	Aug 30	70
258	GN03597	2	5	18	Jul 02	Aug 30	73
259	T9040/Paros	2	5	19	Jun 27	Aug 20	62
260	Frontana (95)	2	5	20	Jun 30	Aug 29	120
261	GN08531	2	6	1	Jun 28	Aug 23	109
262	SW51127	2	6	2	Jul 01	Aug 31	97
263	SABUF/5/BCN/4/RABI//GS/CRA/3/ AE.SQUARROSA (190)	2	6	3	Jun 30	Aug 21	69
264	T2038	2	6	4	Jun 28	Aug 18	62
265	GN05507	2	6	5	Jun 28	Aug 21	62
266	GN07525	2	6	6	Jun 28	Aug 23	62
267	GN08533	2	6	7	Jul 02	Aug 25	62
268	Avans	2	6	8	Jul 01	Aug 23	62
269	GN08647	2	6	9	Jul 01	Aug 29	63
270	Bau/Milan -2	2	6	10	Jul 03	Aug 31	62
271	Rollo	2	6	11	Jun 28	Aug 21	62

	Name	Rep	Block	Plot	Heading	YM	Falling number
272	Zebra	2	6	12	Jun 28	Aug 22	111
273	GN07580	2	6	13	Jul 01	Aug 23	179
274	Tjalve	2	6	14	Jul 01	Aug 22	62
275	GN04537	2	6	15	Jun 30	Aug 22	62
276	GUAM92//PSN/BOW	2	6	16	Jul 02	Aug 29	62
277	MAYOOR//TKSN1081/ AE.SQUARROSA (222)	2	6	17	Jul 01	Aug 27	77
278	TJALVE/Purpur seed	2	6	18	Jul 01	Aug 25	62
279	T9040 (1995)	2	6	19	Jun 28	Aug 25	62
280	GN04526	2	6	20	Jun 28	Aug 25	64
281	Filin	2	7	1	Jun 30	Aug 29	62
282	Berserk -4	2	7	2	Jul 01	Aug 23	62
283	DH20097	2	7	3	Jun 28	Aug 23	118
284	MILAN/SHA7	2	7	4	Jul 02	Sep 02	62
285	Kariega	2	7	5	Jun 27	Aug 23	62
286	NK93602 (1995)	2	7	6	Jul 01	Aug 23	62
287	C80.1/3*QT4522//2*PASTOR	2	7	7	Jul 01	Sep 04	62
288	Reno	2	7	8	Jun 28	Aug 22	62
289	SW45204	2	7	9	Jun 28	Aug 27	62
290	BAJASS-5	2	7	10	Jun 28	Aug 25	63
291	CD87	2	7	11	Jun 28	Aug 29	62
292	GN08564	2	7	12	Jul 01	Aug 29	66
293	SW51114	2	7	13	Jun 30	Aug 31	76
294	Paros	2	7	14	Jul 01	Aug 30	126
295	GN06573	2	7	15	Jun 28	Aug 27	67
296	GN08534	2	7	16	Jul 01	Aug 28	62
297	Dulus	2	7	17	Jun 30	Aug 25	62
298	Avocet YrA	2	7	18	Jul 02	Sep 03	62
299	GN08554	2	7	19	Jul 02	Sep 03	67
300	NG8675/CBRD	2	7	20	Jul 01	Aug 27	66
301	BJY/COC//CLMS/GEN	2	8	1	Jun 27	Aug 29	102
302	SW46375	2	8	2	Jun 30	Aug 30	70
303	Nobeokabouzu (Mhazy)	2	8	3	Jun 28	Aug 30	75
304	NK00521	2	8	4	Jun 28	Aug 25	62
305	GN06600	2	8	5	Jun 30	Aug 27	112
306	Kukri	2	8	6	Jul 02	Sep 03	62
307	T10014	2	8	7	Jul 02	Aug 21	221
308	BCN*2//CROC_1/ AE.SQUARROSA (886)	2	8	8	Jul 02	Sep 04	103
309	SW91053	2	8	9	Jun 28	Aug 29	118
310	GN03531	2	8	10	Jun 30	Aug 31	81
311	Sabin	2	8	11	Jun 30	Aug 27	116

	Name	Rep	Block	Plot	Heading	YM	Falling number
312	QUARNA	2	8	12	Jun 30	Aug 27	66
313	GN03503	2	8	13	Jul 01	Aug 29	193
314	SW51069	2	8	14	Jul 01	Aug 27	122
315	NK01513	2	8	15	Jul 01	Aug 23	62
316	GONDO	2	8	16	Jul 04	Sep 03	62
317	CHD132/05	2	8	17	Jun 28	Sep 02	100
318	Dragon	2	8	18	Jul 02	Aug 31	62
319	J03	2	8	19	Jul 01	Aug 25	81
320	GN07560	2	8	20	Jun 28	Aug 23	62

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