COMPARISON OF DETERIORATION OF RYE SAMPLES STORED AT DIFFERENT STORAGE REGIMES

BY

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A Thesis
Submitted to the Faculty of Graduate Studies in
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ABSTRACT

The main objective of the study was to compare the deterioration of rye (*Secale cereale* L.) samples stored at different temperatures and moisture contents without decline in moisture throughout the study against the previously reported results of declining moisture content of samples stored at the same temperatures and initial moisture contents during 16 wk storage.

Germination, appearance of visible and invisible microflora, and grain free fatty acid values (FAV) were determined for samples at 10.0, 12.5, 15.0 and 17.5% moisture content (wet mass basis) stored at 10, 20, 30 and 40°C for 16 wk. The germination, moisture content and visible mould were determined every week while fatty acid values were measured every two weeks and invisible mould was measured every 4 weeks.

Germination rate was almost the same for all the moisture content samples stored at 10°C for this and a previous study, but a significant decrease was observed at other temperatures. Fatty acid values remained similar for both sets of storage conditions at 10 and 20°C, whereas at 30 and 40°C, fatty acid values of the rye samples which maintained constant moisture content were high. Visible mould appeared early in the samples whose moisture content was maintained and increased with an increase in temperature and moisture content during the experiment. *Penicillium spp.* and *Aspergillus glaucus* group were the predominant fungal species present under both storage regimes throughout the study.

Samples from the current study (case 1) which retained the initial moisture content throughout the study showed increased deterioration in quality when compared to

the samples from a previous (case 2) where there was a decline in moisture content during storage

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

1.1 Harvesting of Rye in Canada

Rye (*Secale cereale* L.) production in Canada is around 320 thousand tonnes, in which more than half of the production is exported every year (CWB 2005). Next to wheat, rye is the major crop used in the baking industry. A fluctuation in rye production could have a significant effect on the food industry throughout the world. Proper harvesting and threshing of rye is important because rye and other cereals have no true dormancy and improper decisions during harvest may lead to the risk of shattering and sprouting. To prevent this, rye is usually harvested and swathed at a very high moisture content (m.c.) of 45% and allowed to dry in the field before threshing at a moisture content of 22% (Hartman 1999). As the straight grade moisture content of rye is only 14%, it is not safe to store it at 22% m.c. Therefore, it must be dried to <14% m.c. for a long storage life (Anonymous 2006).

1.2 Post Harvest Treatments

Moisture content and temperature are the two most important factors in grain storage. Harvested crops can have very high moisture content and hence drying them to a safe moisture level is an important operation before storage. Drying and cooling not only prevent spoilage during storage but also ensure that the grain can be stored for a longer period of time without any quality losses.

The choice of drying and cooling method depend on the condition of the harvested grain. Drying can be done by either ambient air or heated air. Again the type of drying depends on the weather or ambient conditions. If the harvested grain was not very wet and the weather conditions are clear, then ambient air drying can be carried out. But

the major disadvantage in this method is the length of time that is taken. If the harvested grain has very high moisture which can spoil the grain in a few days and if the weather is damp, then heated air drying should be carried out to bring the moisture down to safer levels quickly. In both cases, dried grain has to be cooled to reduce moisture migration and to prevent insect infestation.

In Canada, around 80% of the harvested grains are stored on-farm (Muir 2001). This storage time varies from a few weeks to a few years depending upon the use and demand. During such storage periods, maintaining the quality and quantity of the grain is a major concern. Hence safe storage guidelines have to be developed.

During storage there are many factors that can affect the quality of grain, such as the temperature at which the grain is stored, moisture content of the grain, seed maturity and condition, storage time, inter granular gas composition, insects, microorganisms, mites, rodents, birds, dockage, granary structure and geographical location (Jayas 1995). Of all these factors, storage temperature and moisture content of the stored grain are the two main physical factors that have to be monitored continuously. This is because growth and multiplication of all the living organisms in stored grain depend on these two factors (Jayas 1995). When these two factors exceed safe levels, visible and invisible mold starts to grow and a deterioration of grain quality results (Bottomley et al. 1952).

During storage the quality of grain can be continuously monitored by following a few important parameters such as seed germination, fungal growth, free fatty acid values (FAV) of the grain, gluten quality and nutritive changes (Muir 2001). By closely observing the aforementioned parameters, the deterioration index of the grain can be determined.

Many studies have been conducted to determine the quality of stored grain by using these factors. Quality changes in rapeseed (Mills and Sinha 1980), wheat (Wallace et al. 1983), canola meal (White and Jayas 1989), flax seed (White and Jayas 1991), wild rice and rice (White and Jayas 1996), hull-less and hulled oats and barley (White et al. 1999a), solin (White et al. 1999b), maize (Zia-Ur-Rehman et al. 2002), rice, wheat and maize (Zia-Ur-Rehman 2006), rye and canola (Sathya 2006), durum wheat (Nithya 2008) have been studied during storage but in some cases there was a decline in moisture content when the samples were stored at 40°C for long periods.

Hence, a method to maintain the moisture content of the rye samples during storage was incorporated into this study and the difference in deterioration of quality of the rye while maintaining and losing initial moisture content was studied.

2. OBJECTIVES

The objectives of this study were:

(1) To measure the deterioration of rye samples stored at 10, 20, 30 and 40°C with initial moisture contents (wb) of 10.0. 12.5, 15.0 and 17.5% by maintaining these initial moisture contents throughout the 16 week study period.

(2) To compare the obtained results with the previously reported results (Sathya et al. 2008) of deterioration of rye samples that had declining moisture from 10.0. 12.5, 15.0 and 17.5% initial moisture contents during the course of a 16 week period study.

3. LITERATURE REVIEW

3.1 Quality and deterioration of rye during storage

3.1.1 Grain quality

Quality measurement of grain during storage is important because it is necessary to determine the marketability and possible quality losses during storage (Bailey 1992). The Canadian Grain Commission uses the measurement values of test weight, vitreousness, foreign material content, varietal purity, soundness and protein content to determine the grade. Though the grain can be graded using these parameters, the extent of deterioration can be determined by monitoring other factors such as seed germination, fatty acid value (FAV) and appearance of mold, as these factors are indicative of the exact condition of the grain. Many attempts have been made to derive correlation between the aforementioned parameters and the degradation of grain quality. Some factors were shown to be directly associated with deterioration while some other factors did not show any obvious trends but all of these parameters are inter-linked with grain deterioration.

3.1.1.A Quality assessment parameters

Grain respires even after harvesting but freshly harvested grain respires rapidly producing heat. This kind of heating due to respiration is called self heating. Respiration rate is an excellent indicator of the condition of grain and amount of spoilage in stored grain (Muir et al. 1985). If the amount of carbon dioxide in the grain bulk increases then it is a clear indication that the grain has started to spoil (Pronyk et al. 2004). During aerobic respiration the following changes take place in the grain, producing water, carbon dioxide and heat (Pomeranz 1992).

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + 2835\ kJ$$

In the case of interruption in oxygen supply to the grain, anaerobic metabolism can occur in wet grain. This process is called fermentation, and results in products like carbon dioxide and organic compounds like alcohols (Santin 2005).

$$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$$

When the temperature increases by every 10°C, respiration rate increases 2 to 3 folds. However, at higher temperatures the respiration decreases due to the enzymatic destruction of molds (White et al. 1982). Both the temperature and humidity of the grain determine the intensity of the respiration process. If the carbon dioxide (CO_2) level is above 2% in air of a grain mass, it is considered an important indicator of grain spoilage (Sinha et al. 1981).

Fatty acid value (FAV) is another indicator of quality deterioration of stored grain. They are formed as a result of enzymatic secretion from microorganisms in grain which break the lipids by hydrolysis. Due to this biochemical change the nutritive content of the grain gets lowered. Free fatty acids are expressed as mg of KOH required to neutralize the free fatty acid acids present in 100 g of moisture free grain sample. Increase in FAV is more pronounced in oilseeds because of the direct loss in oil quality in their oilseeds. Free fatty acid value is also associated with an increase in fungal growth and respiration (Mills and Sinha 1980, White et al. 1982, Dhingra et al. 1998). Christensen and Kaufmann (1969) reported that increase in the mold population had a positive correlation with FAV and CO_2. however, there is not an absolute value to correlate the FAV with the extent of deterioration of a sample and only relative changes are used to assess the deterioration.

Seed germination is the simplest and one of the primary factors used to determine the quality of the seeds (Pomeranz 1992). Once the germination decreases below 90% of the initial germination, the seed is considered to be spoiling and necessary measures have to be taken (Karunakaran et al. 2001; Schroth et al. 1998). The linkage between germination and quality relates to the fact that seeds without viability rapidly decompose (Golovina et al. 1997, Lindsay and Turner 1974). Germination has no correlation with moisture content of the grain but has negative correlation with storage fungi and temperature (Wallace and Sinha 1962). The other quality measurements carried out to test the condition of grain and the extent of deterioration during storage can include the measurement of mycotoxin, chitin and ergosterol content and the identification of microfloral species, which often requires expensive equipment and needs trained personnel. A simple test which can be performed at the farm level by the farmers, and which will give fast information is always necessary. Though inspection of grain for visible mold is fast and easy, it is not always reliable because even before the occurrence of visible mold, germination can be affected. Therefore, in order to determine storage conditions, seed germination is a good indicator of grain quality deterioration.

3.1.2 Deterioration of grain

3.1.2.A Pre-storage conditions causing deterioration

Quality loss of grain sometimes occurs due to pre-storage conditions such as grain condition during harvest, harvesting time and drying methods. Dodds and Warder (1966) determined the effect of harvest time on protein content of wheat, and the effect of drying methods on phosphorus and protein content of the samples.

Mills and Wallace (1979) studied the effect of harvest conditions on the crop. They found that wet harvesting not only naturally allowed the growth of fungal species but also led to the production of blackened seeds.

From these studies it was concluded that by preventing the harvesting of wet grain, following appropriate drying methods, and harvesting during appropriate time periods, reductions in the deterioration of grain can be realized before it enters into storage.

3.1.2.B Deterioration during storage

There are many factors that influence the safe storage of grain in bins and elevators (Jayas 1995). Those factors can be classified into biotic and abiotic factors (Table 1).

Table 1. Biotic and abiotic factors in stored grain ecosystem

Abiotic factors	Biotic factors
Moisture content	Grain
Temperature	Physical seed characteristics
Storage time	Microorganisms
Intergranular gas composition	Insects
Storage structure	Mites
Engineering properties of grain	Rodents and birds

Source: Mills (1996)

Between these biotic and abiotic factors there exists a strong correlation and if there are any adverse changes or improper balancing in any of these factors, grain will start deteriorating (Sinha 1973 and Wallace et al. 1983).

Temperature and moisture content are the two principle factors that play a major role in maintaining the quality of the stored grain. Sinha (1973) and Wallace et al. (1983) found that molds and mites thrived well when temperature and moisture content during storage exceeded the safe levels. As fungi, mites and insects start to multiply rapidly they produce heat, moisture and carbon dioxide during respiration which further intensifies the deterioration (White and Sinha 1980). Such deterioration can be prevented and the grain can be stored safely without any quality losses for many years once the moisture content and the temperature of the grain are kept low (Pixton et al. 1975).

Grain storage time also plays a vital role in deterioration of grain. High moisture grain (>18%) cannot be stored for a long duration (>20-30days) at 25°C without any spoilage. Hence the grain has to be dried before storage to prevent any spoilage. Sathya (2006) gave guidelines for estimated safe storage of rye. Figure 1 shows the safe storage period for rye at various temperatures and moisture contents.

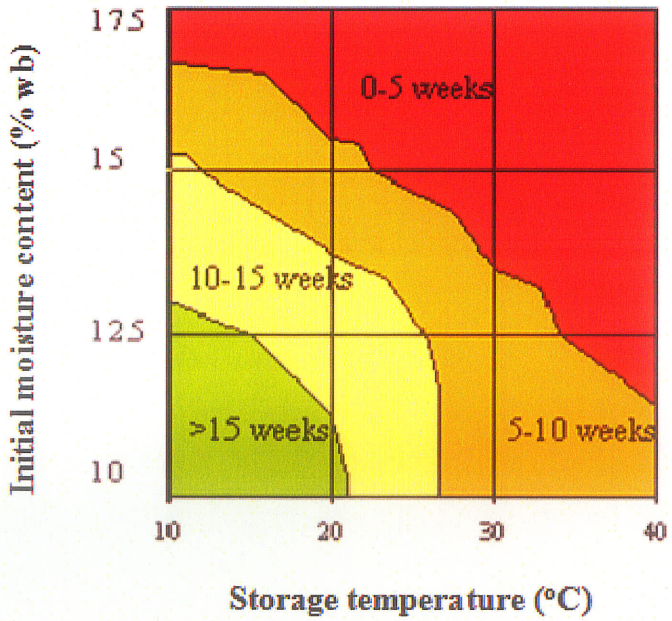


Fig.1. Estimated storage life of rye (Sathya et al. 2008).

Intergranular gas composition is another important factor to be considered during storage of grain. Many researches were carried out to study the relationship between gas composition and the deterioration of grain. White et al. (1982) studied the gas composition of stored canola under lab conditions at different temperatures and moisture conditions and Muir et al. (1985) studied the changes in gas composition in grain bulks. Pronyk et al. (2004) drew a conclusion that there is a strong relationship between CO_2 concentration and deterioration of canola which may similar for all grains.

Storing the grain without any microfloral infection is another important aspect to be considered during storage. Growth of fungi is usually governed by factors such as temperature, water activity, preservatives, and gas tension.

Storage temperature is an important factor favoring fungal growth in a grain sample. Storing the sample at lower temperature is not always possible. Fungal species in stored grain grow at both higher as well as lower temperatures. For example, *Aspergillus* species grows at higher temperature imposing severe challenges in tropical part of the world, while *Penicillium* thrives below 20°C causing a severe problem in temperate conditions. Like all other living organisms, fungi need water to grow which makes water activity (a_w) of the grain a vital part in supporting the growth of fungal species. The a_w is numerically equal to equilibrium relative humidity (ERH) when expressed as a decimal. Scott (1957) found a relationship between growth of microorganisms and water activity. Most of the fungi grow at minimum water activity of 0.85, while some xerophilic fungi can grow at even 0.75 a_w.

Gas tension is also responsible for fungal growth. If the oxygen concentration is high in the bulk grain sample, then fungal species start to grow. If the carbon dioxide

concentration increases then fungal growth will be decreased. Though all the factors individually cause fungal growth, they often work together. Hence to increase the storage life of grain all the factors should be managed simultaneously.

If we fail to maintain the above said factors all together time then the sample undergoes severe damage which makes it lose all its shiny and glossy appearance and becomes dull. As it progresses these stored grains eventually become unfit for further processing or use. Hence storage plays a key role in determining the quality of any grain based product.

Wallace et al. (1983) found that seeds with visible mold had musty smell, however all the seeds with musty smell did not show the presence of visible mold. Table 2 shows the effect of fungi on stored grain.

Table 2. Condition of grain due to fungal infection

Damage to seed	**Condition after damage**
Visible mold	Lower grade of grain
Musty smell	Lower grade of grain
Dull appearance	Lower grade of grain
Increased FAV	Rejected for seed purpose
Reduced germination	Lost viability and rejected
Mycotoxins	Potential carcinogen and feed refusal

Source: Mills (1986)

This degradation was directly related to FAV but not to germination rate of the sample. Lots of research has been carried out to quantify the fungal growth. Some of them are shown in Table 3.

Table 3. Experimental procedures followed by different researchers to enumerate fungal infection in grain bulk

Methods	Experimental procedure	Researchers
1	Counting propagules through dilution plating	Bottomley et al. (1952)
2	Measuring ergosterol and chitin content	Golubchuk et al. (1960) Pronyk et al. (2006)
3	Grading the mold by visual inspection and dilution plating	Friday et al. (1986)
4	Plate count method (placing sample on 7.5% NaCl saturated filter paper)	Wallace and Sinha (1962) Sinha (1983) Sathya et al. (2008) Nithya (2008)

However researchers found that enumeration and quantification of fungi is quite difficult and they alone cannot be used to determine or define the deterioration level.

Several researchers conducted experiments to establish safe storage guidelines with respect to temperature and moisture content for different grains over longer duration. Germination, moisture content, fatty acid value, microfloral inspection, ergosterol content, carbon dioxide production, and heat production were all the parameters that were used to determine the quality of stored grain. But in most of the experiments, there was a difficulty in maintaining the initial moisture content while carrying out the experiment for longer duration of time (Zia-Ur-Rehman 2006 and Sathya et al. 2008). Since there was a decline in moisture during the course of the experiment the results interpreted from the experiments reflect a condition which is not common and thus the developed guidelines will have limited use.

For example an experiment was conducted near Winnipeg using large bins (25 and 50 tonnes) to study the moisture movement and changes from September to June. At the end of the study there was only 1% decrease in moisture at the top of the cone in a grain bin and on average the moisture content of the entire bin increased by only 0.5% (Muir et al. 1980). Thus the decline in moisture content of the samples during the course of the experiment does not simulate the actual storage conditions.

Hence an experimental setup was designed in such a way that the initial moisture content of the samples were maintained throughout the experiment and to compare and study the quality changes in grain that retained the initial moisture content and that showed the decline in initial moisture content of the sample during the course of the experiment.

4. MATERIALS AND METHODS

4.1 Rye sample

Remington variety of fall rye (400 kg) was obtained from Cereal Research Centre, Agriculture and Agri-Food Canada, Winnipeg. Samples were obtained at 14% (wet mass basis) moisture content and were reconditioned to 10.0, 12.5, 15.0, 17.5% moisture content. Since it is not advisable to dry the harvested rye artificially, before it reaches 20% moisture content (Hartman 1999), all the rye samples will have moisture content below 20% before undergoing any post harvest treatment. Also the straight grade for rye is 14% moisture content. Hence a moisture range of 10.0-17.5% was selected for this study. The moisture contents (±0.2%) required for the study were achieved by adding a calculated quantity of distilled water. To lower the moisture content below 14% to the required level, the grain samples were spread and dried in the ambient air inside a closed room for several hours and the moisture content was monitored regularly until it reached the desired level. The conditioned samples were kept in plastic bags in a fridge at 5°C ± 2°C for 72 h. To ensure the uniform moisture distribution, the grain in the plastic bag was mixed thoroughly every 3 h during working hours for 3 days and the final moisture was determined by oven by drying 10 g of samples at 130°C for 16 h in a hot air (ASAE 2003). The samples were stored in a freezer (-5°C ± 2°C) until used for the experiments.

4.2 Environment Chamber

The entire experiment was carried out in environmental chambers (E15 and C1010, CONVIRON, Controlled Environments Limited, Winnipeg, MB and CRELAB, Climatic Research Equipment, WHL3-610M, Winnipeg, MB). All selected chambers were maintained at four different temperatures of 10, 20, 30 and 40°C (±2°C) with

relative humidity (RH) of 70±5%. The temperature range of 10-40°C was selected based on the range of temperatures the grain could undergo during and after harvest.

4.3 Equilibrium Relative Humidity (ERH)

ERH of 60, 75, 85 and 90% were maintained for 10.0, 12.5, 15.0, 17.5% moisture content using potassium hydroxide (KOH) solutions (Solomon 1951). Potassium hydroxide solutions of different specific gravities such as 1.285, 1.211, 1.147 and 1.108 were used to maintain relative humidity of 60, 75, 85 and 90% (60, 75, 85 and 90% are the ERH for 10, 12.5, 15 and 17.5% moisture content rye (Solomon 1951)). The ERH inside the environmental chambers were maintained in the range of 70±5% throughout the experiment.

4.4 Design of experimental setup

To maintain the moisture content of the stored grain sample, 2 L of KOH of known specific gravity was placed at the bottom of a plastic pail. Conditioned grain samples were taken in mesh bags holding 3 or 5 kg. Sampling for 16 weeks was from 5 kg mesh bag while the other two 3 kg bags were placed above and below the sample to act as a buffer. It was hypothesized that the buffer samples placed above and below the 5 kg sampling bag with same moisture content would prevent the moisture loss (Nithya 2008). A lid was loosely placed on the top of the pail (Figure 2). For each temperature and moisture content combination three replicates were done. Samples for quality analysis were taken mixing the rye samples. Subsamples were collected continuously for 16 weeks.

4.5 Moisture content

Measuring the moisture content was an extremely important factor, because this was a comparative study that dealt with results of deterioration at constant moisture content with previously reported results for deterioration under declining moisture content. So in this case, moisture was maintained throughout the experiment. Moisture content was expressed in wet mass basis. It was measured by taking 10 g of triplicate samples every week and allowing it to dry in a hot air oven at 130°C for 16 h (ASAE 2003).

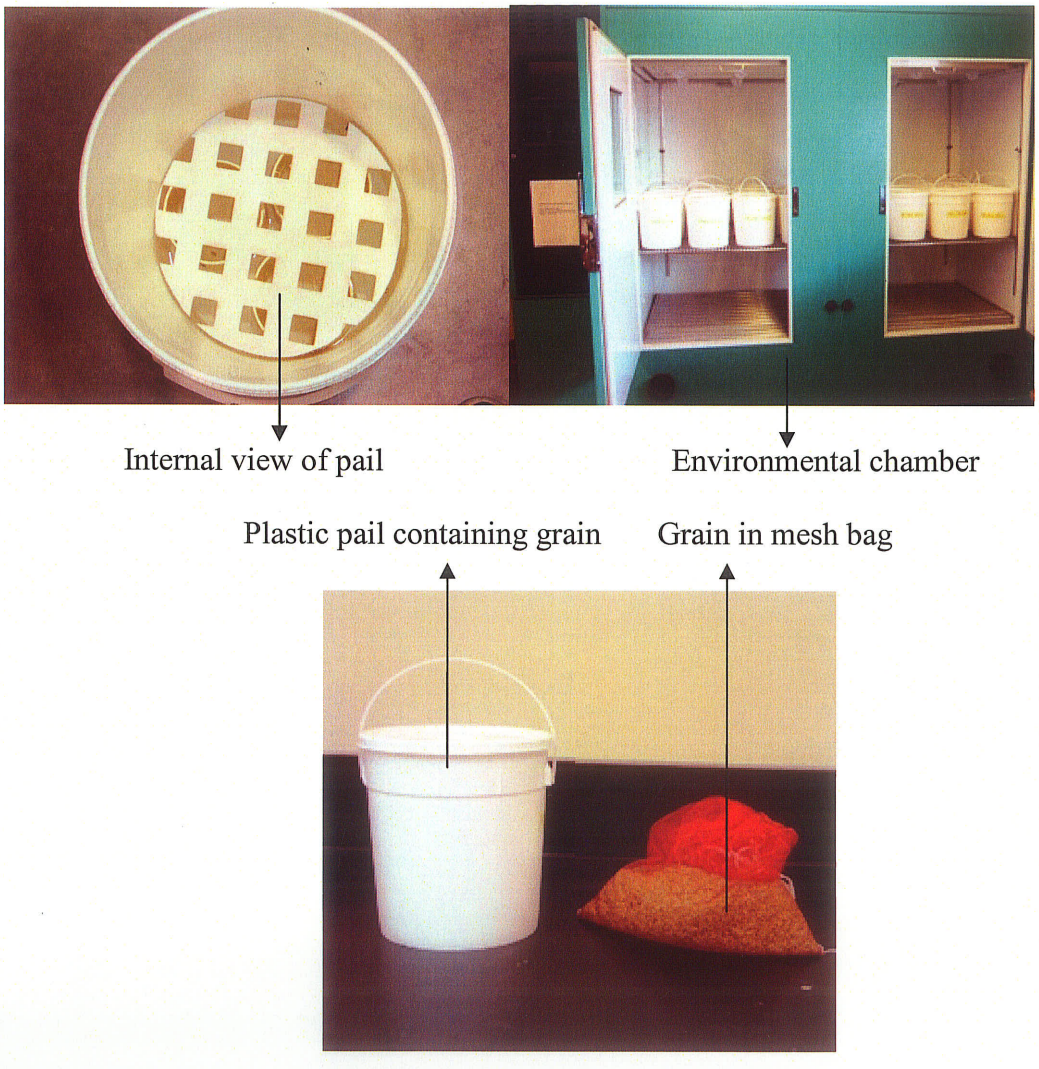


Figure 2. Experimental setup

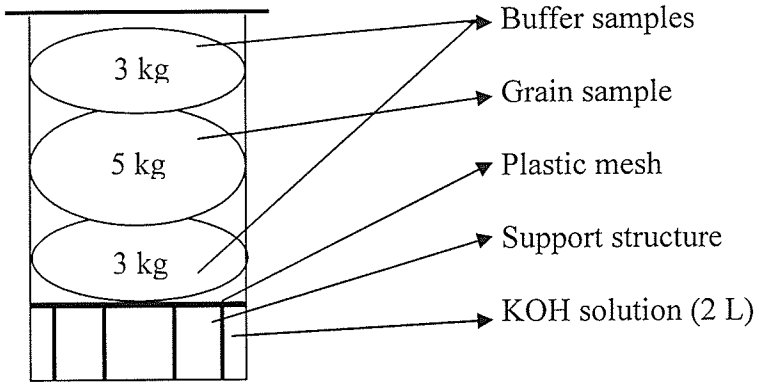


Fig.3. Model showing the experimental arrangement of samples in 20 L pail

4.6 Germination

Among the grain quality assessment parameters, seed germination was measured first, because it is the most sensitive indicator of grain quality. Germination was measured from the samples collected every week by placing 25 seeds on Whatman no.3 filter paper saturated with 5.5 ml of distilled water in a 90 mm diameter Petri dish. The dishes were stacked one above the other in a stand and were covered with polythene wrap for the first 4 days in room temperature (22±1°C). After 4 days, the wrap was removed by exposing the dishes to ambient air for 3 days and the number of seeds germinated was counted at the end of 7 days (Wallace and Sinha 1962).

4.7 Fatty Acid Value

Fatty acid value (FAV) was measured for the samples collected every two weeks using the American Association of Cereal Chemists Procedure (AACC 1962) with minor modifications. The samples used for FAV analysis were taken and weighed (approximately 10 g). Weighed samples were dried in a hot air oven at 130°C for 16 h and the dried grain samples were ground in a grinder (M-2, Fred Stein Laboratories, Inc, Atchison, KS). From the ground sample, 5 g was taken and folded in a Whatman no. 5

filter paper. The folded samples were placed in the thimbles and the thimbles in turn were attached to the fat extractor (Goldfisch Fat Extractor, Laboratory Construction Co, Kansas City, MO). Thirty milliliter of petroleum ether was taken in beakers and were attached to the extractor. The equipment was turned on and the solvent was allowed to evaporate and condense through the ground sample attached to the extractor continuously for 6 h. At the end of the tests, oil was separated by evaporating the solvent present. To the extract 25 ml of TAP solution (50% ethanol and 50% toluene with phenolphthalein as indicator) was added and titrated against KOH solution of known normality (1.273N) until the appearance of a pale pink color. The values obtained were expressed as mg KOH/ 100g of dried grain.

4.8 Visible and Invisible Mold

Invisible mold was also enumerated from the samples collected biweekly. Twenty five seeds from the sample were placed on a Whatman no. 3 filter paper saturated with 5.5 ml of 7.5% aqueous sodium chloride (NaCl) solution in a 90 mm diameter petri dish (Mills et al. 1978). The dishes were stacked one above the other in a stand and were covered with polythene wrap for first 4 days in room temperature (22±1°C). After 4 days the wrap was removed exposing the dishes to ambient air for 3 days and the number of seeds showing the growth of microfloral species were identified and enumerated using a dissection microscope at the end of 7 days (C-PS, SMZ 1000, Nikon, Melville, NY). Table 4 shows the characteristics of commonly occurring bacterial and fungal species in rye samples during storage.

Table 4. Commonly occurring bacterial and fungal species in rye during storage each with characteristic sexual and asexual morphologies (N.D.G. White, Research Scientist, Cereal Research Centre, Agricultural and Agri-Food Canada, Winnipeg, MB, Canada R3T 3X8).

Bacteria & Fungal spp.	**Appearance**
Penicillium	Bright blue to blue-gray color, branching, feathery nature
A. glaucus	Blue-gray in color, often found on seeds of fairly low moisture content, crystalline structure
A. candidus	Bright white in color
A. wentii	Brownish yellow
A. ochraceus	Pale yellow
Hormodendrum	Feather-like or tree-like nature, gray-green in color
Rhizopus	Relatively large, black in color, spread rapidly over plate, hyphae usually seen emerging from a crack in the seed coat and plenty of mycelia
Fusarium	White in color, granular (Sugar like), many branches, small spore; seed and mycelium often slightly pink or red.
Bacteria	Creamy yellow in color and sticky

Appearance of visible mold was verified by visually inspecting the stored sample in plastic pails during sample collection every week.

4.9 Statistical Analysis

In this study statistical analysis was done to observe the effect of moisture content, storage temperature and storage period on germination rate. A three factorial design model (16 weeks × 4 temperatures × 4 moisture contents) of analysis of variance (ANOVA) was used to analyze the effects of duration of experiment. A similar model was used to study the effect of moisture content, temperature and storage period on the

FAV. To make pair wise comparisons between quantitative variables coming from three or more independent groups, least significant difference (LSD) method was used. It was used to analyze the significant changes in the germination and fatty acid value. The differences within each level in both the germination and fatty acid value analysis under each variable were tested at a 95% confidence interval. General linear models (GLM) procedure in Statistical Analysis System software (SAS version 9.1, Statistical Analysis Systems Institute, Inc., Cary, NC) was used for all the analyses.

5. RESULTS AND DISCUSSION

The results obtained from the experimental setup which maintained the moisture content throughout the period of 16 weeks was taken as case 1 and the results of the previously reported samples where the moisture was allowed to decline were taken as case 2. Moisture content, germination, FAV, visible and invisible mold data for both the experiments were compared and are discussed below.

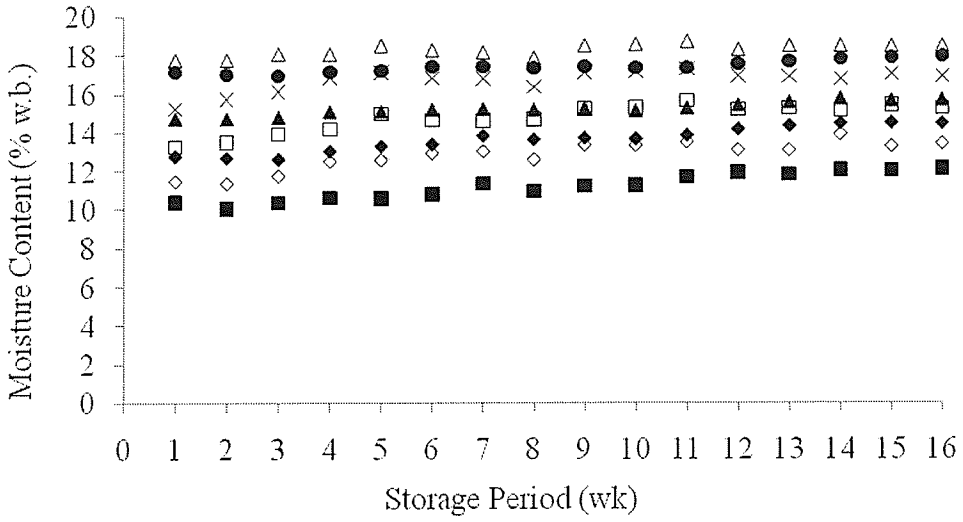
5.1 Moisture Content

Moisture content of the sample is an important parameter while storing the grain for long periods. Using buffer bags and constant ERH in the pails, the moisture was maintained for the entire study even at elevated temperatures (30 and 40°C) in the current study (case 1) which was not previously possible in many cases (Zia-Ur-Rehman 2006 and Sathya 2006). The experiment was designed in such a way that potassium hydroxide (KOH) solutions of different specific gravities were placed under the respective samples in pails to maintain the required relative humidity. This decline in moisture content was further prevented by having buffer samples above and below the reference sample.

Figure 4 shows the comparative changes in moisture content (% wb) with respect to storage period. Detailed data are given in appendix A at 10°C the samples showed a slight increase in moisture content while moisture content of samples stored at 20°C remained almost the same throughout the study in case 1. This is similar to what was observed for the samples of case 2 (Sathya et al. 2008). But at higher temperatures, there was a significant decline in moisture contents of the samples in case 2 (Sathya et al. 2008). The samples stored at 30°C without buffer and 0.5 L of KOH at 15.0 and 17.5% moisture content showed a steady decline in moisture and reached 12.5% moisture at the end of 16

weeks. But for the samples stored with buffer samples and 2 L of KOH, the moisture content remained almost constant. This is because the KOH solution maintained the required relative humidity inside the pails and also the buffer samples placed above and below the main sample prevented further loss of moisture from the interested sample.

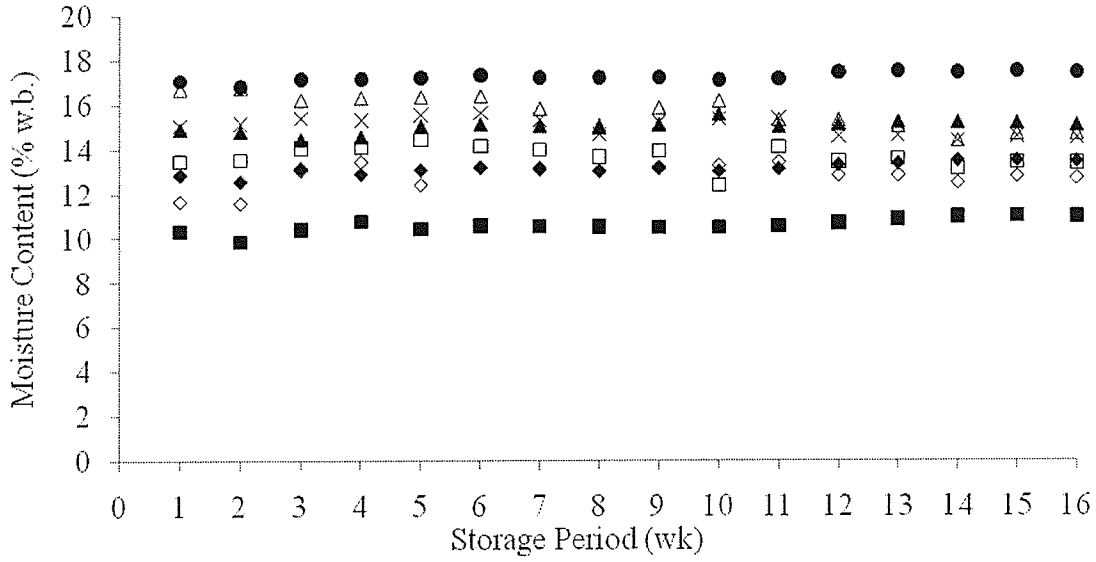
For the rye samples stored at 40°C, there was a drastic difference in moisture content between the samples stored with and without buffer samples. In case 2, high moisture content samples such as 15.0 and 17.5% reached around 8.0 and 10.0% moisture content as early as 5^{th} and 6^{th} week itself. But the samples stored with buffer samples maintained almost the same moisture throughout 16 weeks of study.



(a) 10°C

Current study (Case 1) Sathya et al. (2008) (Case 2)

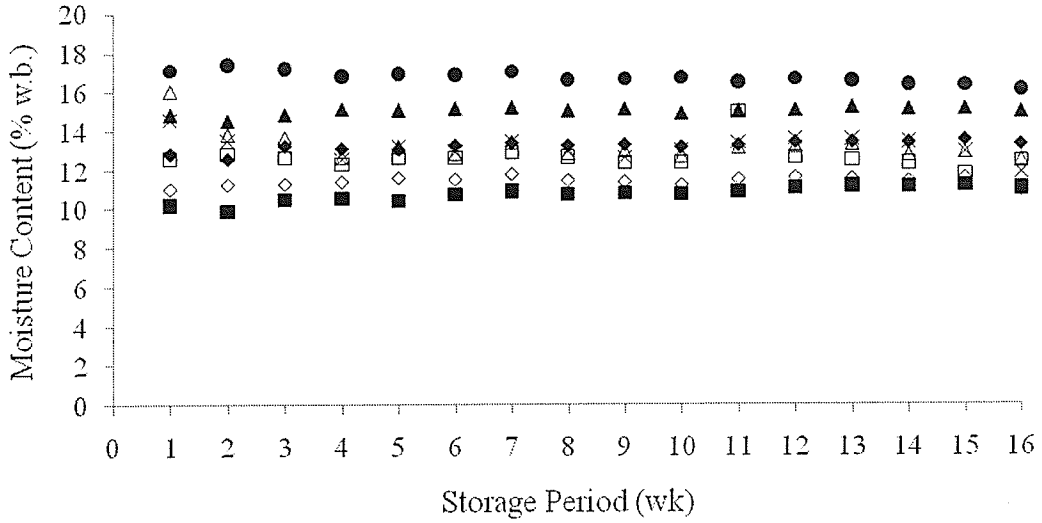
■10.0%, ◆12.5%, ▲15.0% and ● 17.5% ◇10.0%, □ 12.5%, ×15.0% and △17.5%.



(b) 20°C

Current study (Case 1) Sathya et al. (2008) (Case 2)

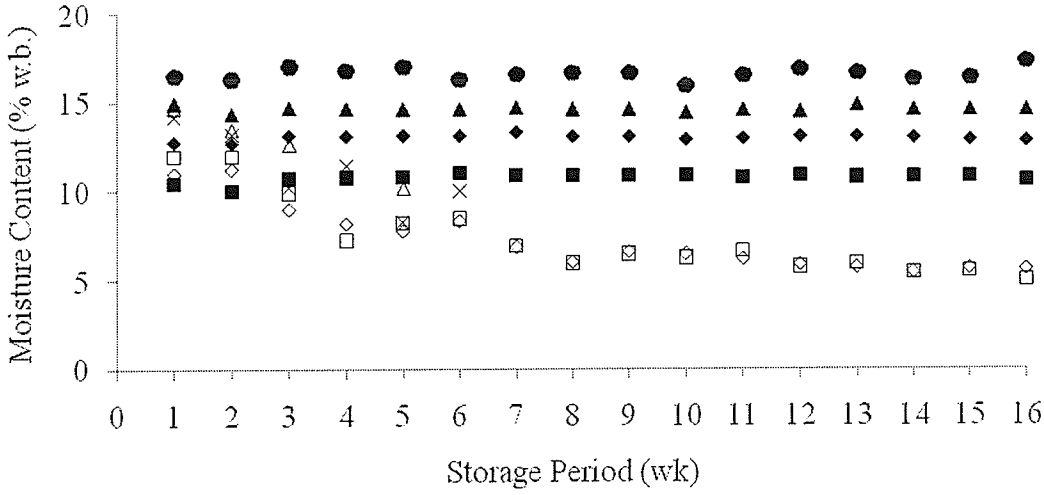
■10.0%, ◆12.5%, ▲15.0% and ● 17.5% ◇10.0%, □ 12.5%, ×15.0% and △17.5%.



(c) 30°C

Current study (Case 1) Sathya et al. (2008) (Case 2)

■10.0%, ♦12.5%, ▲15.0% and ● 17.5% ◇10.0%, □ 12.5%, ×15.0% and △17.5%.



(d) 40°C

Current study (Case 1) Sathya et al. (2008) (Case 2)

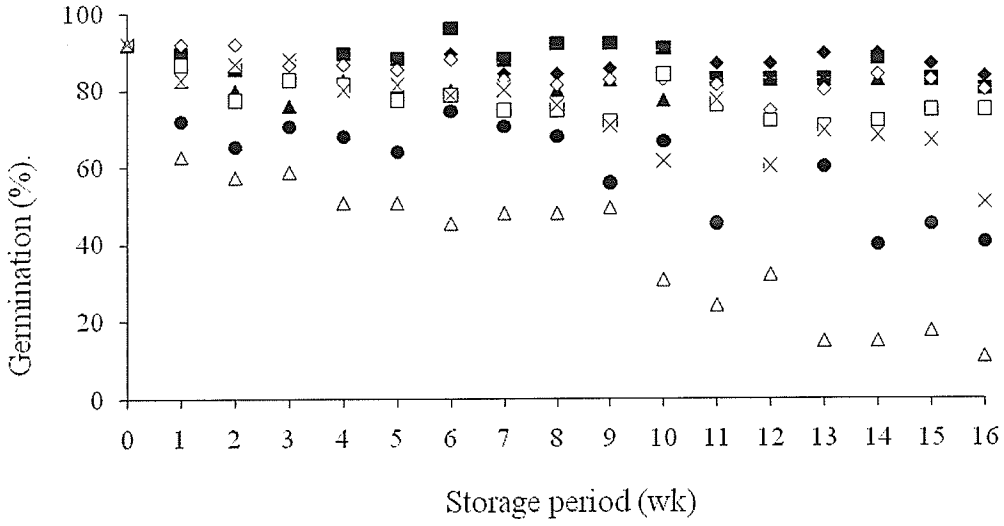
■10.0%, ♦12.5%, ▲15.0% and ● 17.5% ◇10.0%, □ 12.5%, ×15.0% and △17.5%

Figure 4. Comparative changes in moisture content (% wb) with respect to storage period at (a) 10°C (b) 20°C (c) 30°C (d) 40°C

5.2 Germination

Germination of the rye samples stored at 10, 20, 30 and 40°C for a period of 16 weeks is shown (Figure 5). Detailed data are given in appendix B. Seed germination for rye samples in case 1 at the start of the experiment was 92%. This remained above 80% for the samples stored at 10°C with 10.0, 12.5 and 15.0% moisture content throughout the experiment. In case 2, the germination of 80% was maintained only for the samples stored at 10°C with 10.0 and 12.5% moisture content. In both the cases germination decreased with an increase in storage temperature irrespective of moisture content.

Rye samples stored with 15.0 and 17.5 % moisture content at 40°C reached 0% germination as early as in 3rd and 4th weeks respectively for case 1, compared to 0% germination at 5th and 6th weeks for case 2 (Sathya et al. 2008). Overall, the germination of the samples in case 1 showed more decrease when compared to the samples stored at the same moisture contents and temperatures in case 2 (Sathya et al. 2008). This may be because in case 2 (Sathya et al. 2008), samples stored at higher temperatures showed decline in moisture from the second week, while in case 1 there was no such decline in moisture. Since the rate of deterioration of grain is higher when stored at higher moisture, the germination percentage of case 1 which maintained the initial moisture content even at higher temperatures, showed more decrease in germination than case 2 (Sathya et al. 2008). All the factors, moisture content, storage temperature and storage period had significant effect on the germination of rye samples (α=0.05).



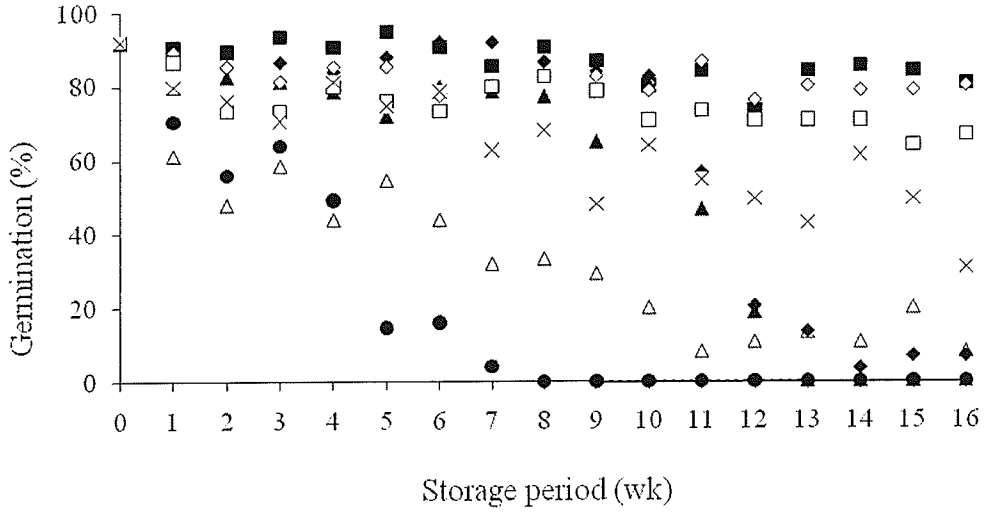
(a) 10°C

Current study (Case 1)

■10.0%, ◆12.5%, ▲ 15.0% and ● 17.5%

Sathya et al. (2008) (Case 2)

◇10.0%, □ 12.5%, ×15.0% and △17.5%.



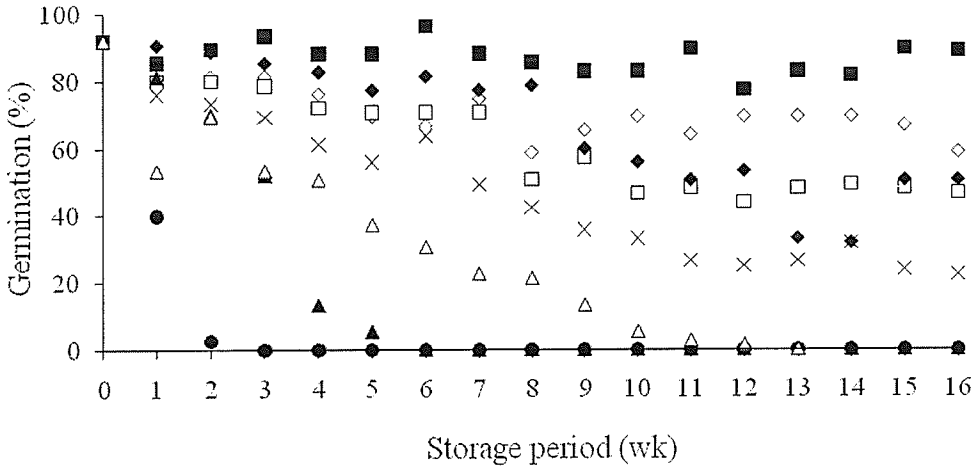
(b) 20°C

Current study (Case 1)

■10.0%, ◆12.5%, ▲ 15.0% and ● 17.5%

Sathya et al. (2008) (Case 2)

◇10.0%, □ 12.5%, ×15.0% and △17.5%.



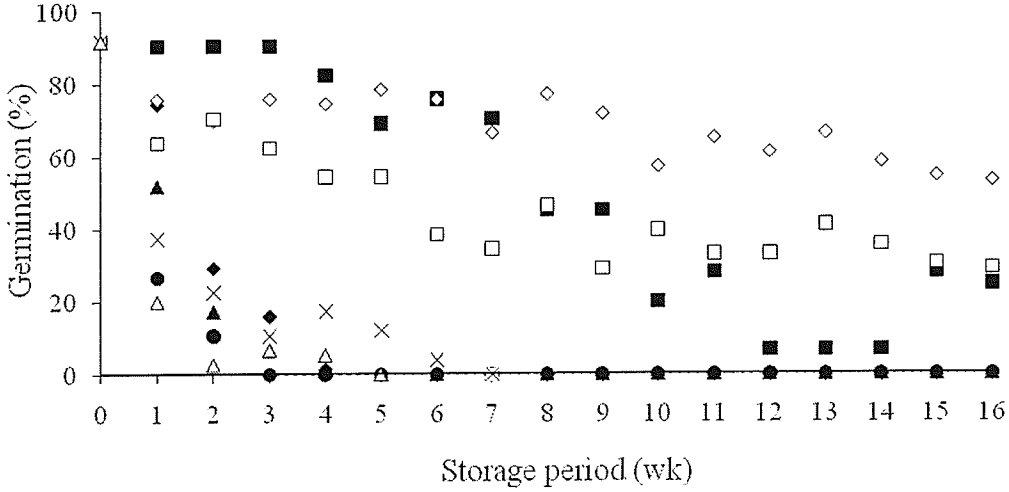
(c) 30°C

Current study (Case 1)

■10.0%, ◆12.5%, ▲ 15.0% and ● 17.5%

Sathya et al. (2008) (Case 2)

◇10.0%, □ 12.5%, ×15.0% and △17.5%.



(d) 40°C

Current study (Case 1)

■10.0%, ◆12.5%, ▲ 15.0% and ● 17.5%

Sathya et al. (2008) (Case 2)

◇10.0%, □ 12.5%, ×15.0% and △17.5%.

Figure 5. Comparative changes in germination with respect to storage period at (a) 10°C (b) 20°C (c) 30°C (d) 40°C

5.3 Free fatty acid value

Due to oxidative or hydrolytic biochemical changes occurring in the grain stored over a period of time, there will be nutritive loss in stored grain (Pomeranz 1992). The free fatty acids (FFA) are formed by the hydrolysis reaction caused by the enzymatic secretions of the associated micro-organisms in stored grain. Since high moisture grains favor mold growth, the changes in FAV occurring in the high moisture grain is also high. Therefore, fatty acid value (FAV) is an index to monitor the quality of stored grain (Christensen and Kaufmann 1969). As there is no absolute value to correlate FAV with deterioration of grain, relative change in FAV is used to associate the deterioration (Sinha 1983).

The relative changes FAV values for both the cases are given in Fig. 6. At 10 and 20°C the moisture content of all the samples were maintained throughout the study for both the cases. Therefore, there was not much difference in the trend of relative change in free fatty acid values produced in both the cases. But for the samples stored at 30 and 40°C, there were significant differences in relative changes in free fatty acid value in for both the cases.

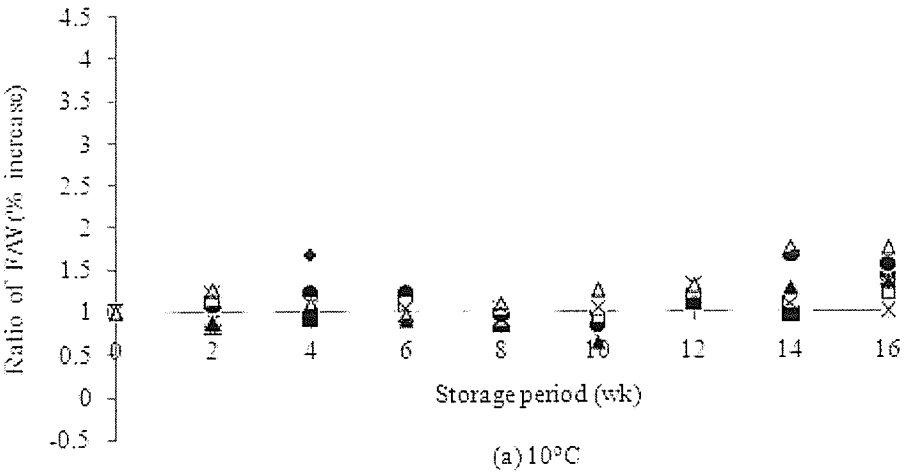
In case 1, for the samples stored at 30°C, the free fatty acid value increased as high as 4.5 times the initial FAV value during the 14^{th} week at 15.0% m.c. But for the samples stored at 30°C in case 2, there was only 2 fold increase in FAV value during the 14^{th} week at 15.0% m.c.

For the samples stored at 40°C in case 1, the FAV increased 4 times the initial value as early as in 4^{th} week itself and maintained the same level up to 8 weeks before gradually declining to 3 folds in 16^{th} week. In case 2, there was not much increase in FAV value as in case 1. At the end of 4^{th} week there was only 2.5 time increase in FAV value in case 2,

which is 1.5 times less than case 1. Further interpretation was not possible because in case 2, the FAV values were not determined once the germination reached 0%.

This increase in FAV values were observed in case 1, at higher temperatures (30 and 40°C) and high moisture content samples (15.0 and 17.5%) because mold thrives at high moisture grain. In case 2, the samples showed steady decline in moisture content which may not have supported mold growth eventually leading to lower fatty acid values.

Also, the FAV values were high during 4-8th week of the experiment because growth of bacteria at high moisture content samples might have influenced the FAV values (White et al. 1982). A decline in FAV values were observed during later part of the experiment which might have been due to the presence of molds which might have consumed some of free fatty acids present in the grain. Also there was a decline in FAV value below the initial FAV content this may be due to the sampling variability.



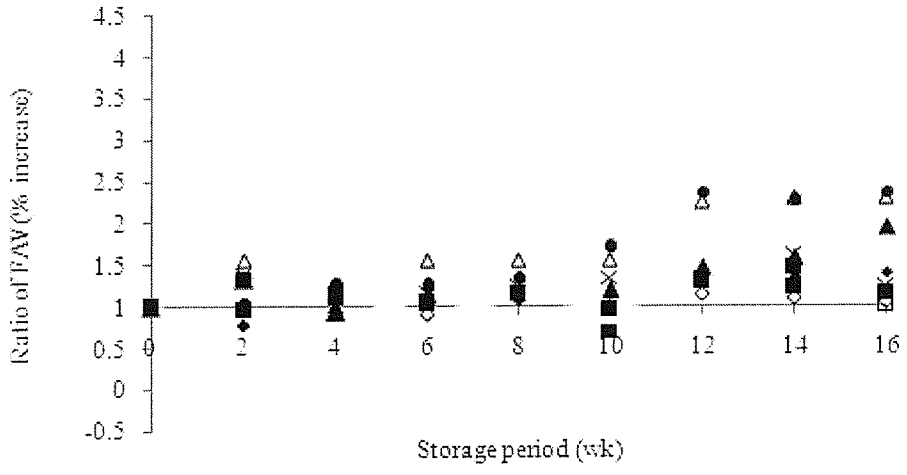
(a) 10°C

Current study (Case 1)

■10.0% ◆12.5% ▲15.0% and ● 17.5%

Sathya et al. (2008) (Case 2)

◇10.0% □12.5% ×15.0% and △17.5%.



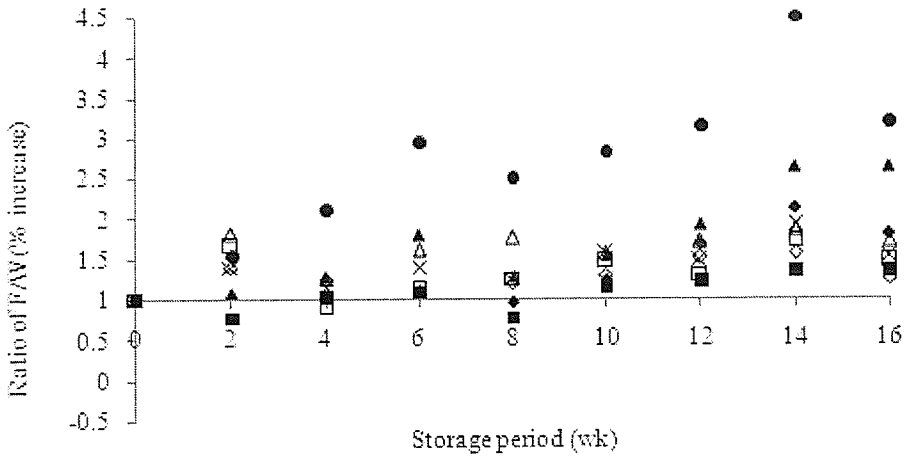
(b) 20°C

Current study (Case 1)

■10.0%, ◆12.5%, ▲15.0% and ● 17.5%

Sathya et al. (2008) (Case 2)

◇10.0%, □12.5%, ×15.0% and △17.5%.



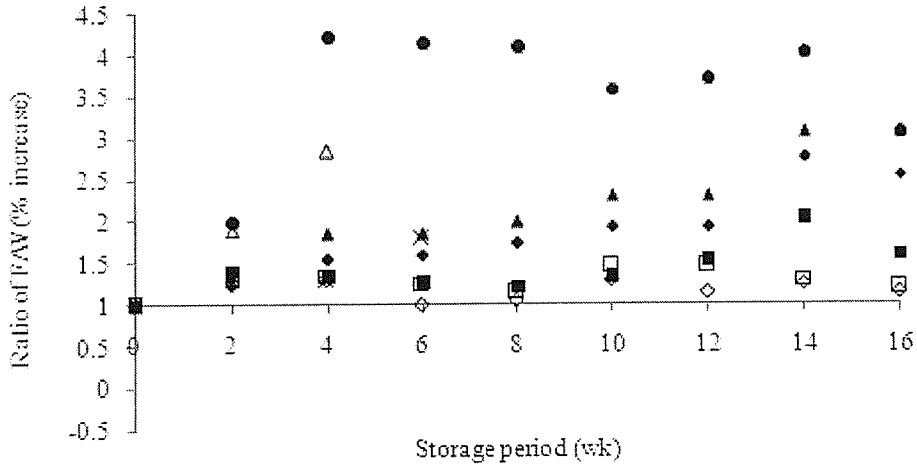
(c) 30°C

Current study (Case 1)

■10.0%, ◆12.5%, ▲ 15.0% and ● 17.5%

Sathya et al. (2008) (Case 2)

◇10.0%, □ 12.5%, ×15.0% and △17.5%.



(d) 40°C

Current study (Case 1)

■10.0%, ◆12.5%, ▲ 15.0% and ● 17.5%

Sathya et al. (2008) (Case 2)

◇10.0%, □ 12.5%, ×15.0% and △17.5%.

Figure 6. Relative changes in FAV from initial value of with respect to storage period at 10°C (b) 20°C (c) 30°C (d) 40°C

5.4 Microflora

Fungi developed in stored grain are responsible for the deterioration of grain, hence it is important to verify the microfloral growth to quantify the amount of deterioration. Irrespective of temperature and moisture content, visible mold appeared in all 17.5% moisture content samples for both cases.

For the samples with higher moisture content of 17.5%, visible mold appeared in the first week of storage at all temperatures except 10°C in both the cases (Table 5). Detailed data are given in appendix C. As the mold started to grow it produced a musty odor which was associated with increased fungal growth and decreased germination (Wallace et al. 1983). During the initial storage time *Penicillium spp.* were found predominantly in all samples in both the cases. At 10 and 20°C, *Penicillium spp.* was predominant while *A. glaucus* replaced them at higher storage temperatures (30 and 40°C). Bacteria appeared rarely at cooler temperatures for samples of case 1. *Alternaria* was abundant in samples stored at 10°C and infrequent at higher temperatures while there was no trace of *Alternaria* in the samples which had declining moisture content. However, the presence of *Alternaria* cannot be related with storage aspects as it is a field fungus which does not multiply in storage.

Hormodendrum was found less frequently in almost all samples but it was not detected in any of the samples of case 1. *Aspergillus ochraceus* increased with moisture content and storage period in both the cases. At 30°C, samples showed increased growth of *A. glaucus* in both the cases. But for the samples of case 1, stored at 40°C, lesser growth of microflora was found when compared to the samples of case 2. This result supports the conclusions of Nithya (2008) and Christensen and Kaufmann (1969). Other fungi such as

A. niger, Fusarium and *Rhizopus* were found rarely in some samples but they could not be compared and related.

Storage fungi pose a huge threat to stored grain because its growth and metabolic activity lead to decreased germination rate and contamination of the sample. Fungi also produce mycotoxins which are dangerous to animal and human health (Nithya 2008). To prevent these fungal growths the storage temperature should be below 20°C and the moisture content should be below 15.0%. Below this temperature and moisture fungi cannot grow (Abramson et al. 1990).

Table 5. Time of the first appearance of visible mold (wk) and respective germination rate in rye (%)

Initial moisture content (% wb)		10.0		12.5		15.0		17.5	
Temperature (°C)	Replicate	Case †		Case †		Case †		Case †	
		1	2	1	2	1	2	1	2
10	A	-	-	-	-	-	-	2, 18*	2, 60
	B	-	-	-	-	-	-	2, 14*	2, 52
	C	-	-	-	-	-	-	2, 17*	2, 60
20	A	-	-	-	-	-	-	1, 76	1, 60
	B	-	-	-	-	-	-	1, 64	1, 56
	C	-	-	-	-	-	-	1, 72	1, 68
30	A	-	-	9, 68	9, 56	4, 3*	5, 56	1, 32	1, 52
	B	-	-	9, 60	9, 64	4, 1*	5, 48	1, 44	1, 52
	C	-	-	9, 52	9, 52	4, 6*	5, 64	1, 44	1, 56
40	A	8,48	10, 64	3, 32*	5, 40	1, 40*	1, 36*	1, 68	1, 16*
	B	8,72	10, 48	3, 8*	5, 52	1, 62*	1, 40*	1, 76	1, 24*
	C	8,16	10, 60	3, 8*	5, 72	1, 54*	1, 36*	1, 72	1, 20*

† Case 1 - Current study; Case 2 - Study of Sathya et al. (2008)
*Visible mold might have occurred before this time in these cases because of the length of time interval between sampling dates

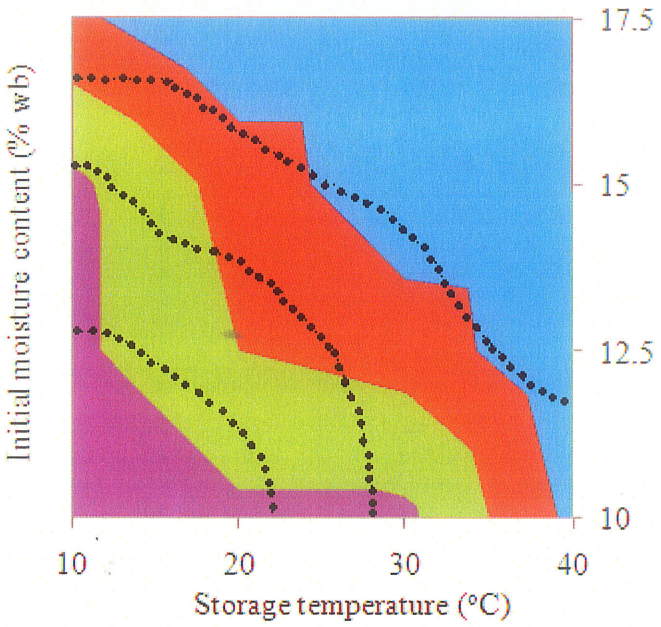


Figure 7. Modified safe storage guideline for rye. The dotted lines in this figure represent the boundries in figure 1 of Sathya et al. (2008)

6. CONCLUSIONS

Moisture content of the sample, storage temperature and the time of storage had significant (α=0.05) effect on the germination and free fatty acid values of rye.

By comparing the rye samples of case 1 and 2, when stored with 10.0, 12.5, 15.0 and 17.5% initial moisture content at 10, 20, 30 and 40°C for 16 wk the following conclusions were made.

At 10 and 20°C the samples in both the cases maintained the moisture content but at elevated temperatures of 30 and 40°C due to the absence of buffer samples there was decline in moisture in case 2 (Sathya et al. 2008).

Germination decreased quickly for the samples that maintained the initial moisture content because molds, which affect germination greatly, need a certain amount of water activity for growth and presence of moisture throughout the study helped them thrive in these conditions eventually leading to quicker deterioration of rye samples.

FAV was found high in the samples of case 1 at higher temperatures when compared to the samples of case 2. Also visible mold appeared earlier in the samples of case 1. At elevated temperature of 40°C, microfloral growth was much less in case 1 when compared to rye samples of case 2 in later part of the storage.

The above differences may be due to the presence of moisture content throughout the experiment in case 1 while it was not so in case 2 (Sathya et al. 2008). So it can be concluded that only the rye samples with $\leq$12.5% moisture content stored at $\leq$ 20°C would be safe for >15 weeks irrespective of maintaining or declining moisture content. By retaining the moisture in samples the seed lost viability and started to deteriorate earlier than the rye samples in case 2.

7. RECOMMENDATIONS FOR FUTURE STUDY

- Quality deterioration of other common grains can be studied under all possible conditions.
- This work can also be further extended by studying the milling, baking and nutritional changes of rye during the experimental period.
- Such a comparative study can be carried out for longer storage time to know the effects on rye samples.

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APPENDIX A: Moisture content

Table A.1. Moisture content of rye sample stored at 10°C

Storage period (wk)	Replication	Moisture content (% wb)			
		10.0	12.5	15.0	17.5
1	1	10.4	12.8	14.9	17.3
	2	10.3	12.9	14.6	16.0
	3	10.4	12.7	14.8	16.1
	Mean	10.4	12.8	14.8	17.2
	s.d.	0.1	0.1	0.2	0.2
2	1	9.9	12.6	14.8	17.2
	2	9.9	12.9	14.7	16.9
	3	10.4	12.6	14.7	16.8
	Mean	10.1	12.7	14.7	16.9
	s.d.	0.3	0.1	0.0	0.2
3	1	10.4	12.8	14.8	17.1
	2	10.3	12.9	14.9	16.9
	3	10.4	12.2	14.8	16.9
	Mean	10.3	12.6	14.8	16.9
	s.d.	0.1	0.3	0.0	0.2
4	1	10.6	12.9	15.3	17.2
	2	10.7	13.0	15.0	17.2
	3	10.6	13.2	15.0	17.1
	Mean	10.6	13.1	15.1	17.2
	s.d.	0.1	0.1	0.2	0.1

Storage period (wk)	Replication	Moisture content (% wb)			
		10.0	12.5	15.0	17.5
5	1	10.5	13.1	15.0	17.2
	2	10.5	13.3	15.1	17.3
	3	10.9	13.5	15.2	17.1
	Mean	10.6	13.1	15.1	17.2
	s.d.	0.2	0.2	0.1	0.1
6	1	10.6	13.3	15.1	17.5
	2	10.8	13.2	15.2	17.5
	3	10.9	13.8	15.3	17.3
	Mean	10.8	13.4	15.2	17.4
	s.d.	0.2	0.3	0.1	0.1
7	1	10.6	13.5	15.3	17.4
	2	12.5	13.5	15.2	17.5
	3	10.9	14.7	15.3	17.3
	Mean	11.3	13.9	15.3	17.4
	s.d.	1.0	0.7	0.1	0.1
8	1	10.7	13.4	15.2	17.5
	2	11.2	13.7	15.7	17.4
	3	10.9	13.9	15.2	17.2
	Mean	10.9	13.7	15.2	17.4
	s.d.	0.2	0.2	0.0	0.3

Storage period (wk)	Replication	Moisture content (% wb)			
		10.0	12.5	15.0	17.5
9	1	10.8	13.5	15.4	17.5
	2	11.8	13.4	15.2	17.5
	3	11.1	14.3	15.3	17.3
	Mean	11.2	13.7	15.3	17.4
	s.d.	0.5	0.5	0.1	0.1
10	1	10.7	13.4	15.2	17.4
	2	11.5	13.5	15.1	17.5
	3	11.6	14.2	15.1	17.2
	Mean	11.2	13.7	15.2	17.4
	s.d.	0.5	0.4	0.0	0.1
11	1	11.2	13.7	15.3	17.4
	2	12.3	13.9	15.2	17.6
	3	11.4	13.9	15.4	17.2
	Mean	11.7	13.9	15.3	17.4
	s.d.	0.6	0.1	0.1	0.2
12	1	11.5	13.9	15.5	17.6
	2	12.4	14.0	15.3	17.7
	3	11.8	14.6	15.5	17.4
	Mean	11.9	14.2	15.4	17.6
	s.d.	0.4	0.3	0.1	0.2

Storage period (wk)	Replication	Moisture content (% wb)			
		10.0	12.5	15.0	17.5
13	1	11.3	13.9	15.7	17.7
	2	12.3	14.4	15.5	17.8
	3	11.8	14.8	15.6	17.6
	Mean	11.8	14.4	15.6	17.7
	s.d.	0.5	0.4	0.1	0.1
14	1	11.8	14.2	15.9	17.8
	2	12.3	14.5	15.6	17.9
	3	12.0	14.7	15.8	17.7
	Mean	12.0	14.5	15.8	17.8
	s.d.	0.2	0.2	0.2	0.2
15	1	11.6	14.2	15.9	17.9
	2	12.3	14.5	15.6	18.2
	3	12.0	14.8	15.7	17.6
	Mean	11.9	14.5	15.7	17.9
	s.d.	0.3	0.3	0.1	0.3
16	1	11.8	14.2	15.8	17.9
	2	12.2	14.7	15.7	18.3
	3	12.2	14.5	15.7	17.7
	Mean	12.1	14.5	15.7	17.9
	s.d.	0.2	0.3	0.1	0.3

Table A.2. Moisture content of rye sample stored at 20°C

Storage period (wk)	Replication	Moisture content (% wb)			
		10.0	12.5	15.0	17.5
1	1	10.3	12.9	14.8	17.1
	2	10.4	12.9	14.9	16.9
	3	10.2	12.9	14.9	17.1
	Mean	10.3	12.9	14.9	17.1
	s.d.	0.1	0.0	0.1	0.1
2	1	9.9	12.7	15.2	16.9
	2	9.8	12.5	14.5	16.9
	3	9.9	12.6	14.7	16.7
	Mean	9.9	12.6	14.8	16.8
	s.d.	0.1	0.1	0.4	0.1
3	1	10.3	13.2	13.3	17.2
	2	10.5	13.1	15.0	16.9
	3	10.4	13.2	15.0	17.4
	Mean	10.4	13.2	14.4	17.2
	s.d.	0.1	0.1	1.0	0.3
4	1	10.9	12.9	14.4	17.2
	2	10.8	12.9	14.5	17.1
	3	10.6	12.9	14.8	17.1
	Mean	10.8	12.9	14.6	17.1
	s.d.	0.2	0.0	0.2	0.0

Storage period (wk)	Replication	Moisture content (% wb)			
		10.0	12.5	15.0	17.5
5	1	10.3	13.0	14.9	17.3
	2	10.3	13.1	15.1	17.1
	3	10.7	13.1	15.0	17.1
	Mean	10.6	13.3	15.1	17.2
	s.d.	0.2	0.1	0.1	0.1
6	1	10.5	13.3	15.1	17.4
	2	10.4	13.1	15.1	17.2
	3	10.8	13.2	15.1	17.4
	Mean	10.7	13.2	15.1	17.3
	s.d.	0.2	0.1	0.0	0.1
7	1	10.5	13.2	15.1	17.3
	2	10.4	13.1	15.0	17.1
	3	10.8	13.2	15.0	17.3
	Mean	10.5	13.2	15.0	17.2
	s.d.	0.2	0.0	0.0	0.1
8	1	10.4	13.0	14.9	17.3
	2	10.4	12.9	14.9	17.2
	3	10.7	13.1	14.9	17.1
	Mean	10.5	13.0	14.9	17.2
	s.d.	0.2	0.1	0.0	0.1

Storage period (wk)	Replication	Moisture content (% wb)			
		10.0	12.5	15.0	17.5
9	1	10.2	13.2	15.0	17.1
	2	10.4	13.1	15.0	17.3
	3	10.7	13.2	15.2	17.3
	Mean	10.5	13.1	15.1	17.2
	s.d.	0.2	0.0	0.1	0.1
10	1	10.3	12.9	14.8	17.2
	2	10.4	12.9	16.9	16.9
	3	10.8	13.4	14.9	17.2
	Mean	10.5	13.0	15.5	17.1
	s.d.	0.3	0.1	1.2	0.2
11	1	10.4	13.1	14.8	17.1
	2	10.5	13.1	15.1	17.1
	3	10.8	13.1	15.1	17.3
	Mean	10.6	13.1	14.9	17.2
	s.d.	0.2	0.0	0.2	0.1
12	1	10.6	13.2	15.1	17.4
	2	10.5	13.4	15.1	17.4
	3	10.9	13.3	15.1	17.5
	Mean	11.9	14.2	15.1	17.6
	s.d.	0.4	0.3	0.0	0.2

Storage period (wk)	Replication	Moisture content (% wb)			
		10.0	12.5	15.0	17.5
13	1	10.7	13.3	15.1	17.5
	2	10.7	13.4	15.3	17.4
	3	11.2	13.4	15.2	17.6
	Mean	10.9	13.4	15.2	17.5
	s.d.	0.3	0.0	0.1	0.1
14	1	10.7	13.4	15.2	17.5
	2	10.9	13.5	15.2	17.3
	3	11.3	13.5	15.2	17.4
	Mean	10.9	13.5	15.2	17.4
	s.d.	0.3	0.1	0.0	0.1
15	1	10.8	13.4	15.1	17.5
	2	10.9	13.5	15.1	17.3
	3	11.3	13.6	15.2	17.6
	Mean	10.9	13.5	15.2	17.5
	s.d.	0.3	0.1	0.0	0.1
16	1	10.8	13.4	15.1	17.5
	2	10.8	13.5	15.0	17.3
	3	11.4	13.5	15.1	17.5
	Mean	10.9	13.5	15.1	17.4
	s.d.	0.4	0.1	0.0	0.1

Table A.3. Moisture content of rye sample stored at 30°C

Storage period (wk)	Replication	Moisture content (% wb)			
		10.0	12.5	15.0	17.5
1	1	10.2	12.9	14.7	17.3
	2	10.2	12.9	14.9	17.1
	3	10.2	12.7	14.9	16.9
	Mean	10.2	12.8	14.9	17.1
	s.d.	0.0	0.2	0.2	0.2
2	1	10.1	12.4	14.4	16.9
	2	9.9	12.7	14.5	16.4
	3	9.8	12.7	14.7	19.0
	Mean	9.9	12.6	14.5	17.4
	s.d.	0.2	0.2	0.1	1.4
3	1	10.6	13.1	14.9	16.8
	2	10.5	13.2	14.8	17.4
	3	10.4	13.4	14.8	17.5
	Mean	10.5	13.2	14.8	17.2
	s.d.	0.1	0.1	0.1	0.4
4	1	10.6	13.1	15.1	16.8
	2	10.9	13.2	15.3	16.8
	3	10.2	13.1	14.9	16.9
	Mean	10.6	13.1	15.1	16.9
	s.d.	0.4	0.1	0.2	0.1

Storage period (wk)	Replication	Moisture content (% wb)			
		10.0	12.5	15.0	17.5
5	1	10.8	12.9	14.9	16.9
	2	10.2	13.2	15.4	16.7
	3	10.4	13.1	14.8	17.3
	Mean	10.4	13.1	15.1	16.9
	s.d.	0.3	0.1	0.3	0.3
6	1	11.1	13.1	15.0	16.7
	2	10.5	13.4	15.5	16.7
	3	10.8	13.3	14.9	17.3
	Mean	10.8	13.3	15.1	16.9
	s.d.	0.3	0.2	0.3	0.3
7	1	11.1	13.1	15.0	16.7
	2	10.5	13.6	15.6	16.9
	3	11.2	13.5	14.9	17.5
	Mean	10.9	13.4	15.2	17.1
	s.d.	0.4	0.3	0.3	0.4
8	1	10.9	12.9	14.8	16.5
	2	10.4	13.4	15.5	16.2
	3	11.1	13.4	14.8	17.2
	Mean	10.8	13.3	15.0	16.6
	s.d.	0.3	0.3	0.4	0.5

Storage period (wk)	Replication	Moisture content (% wb)			
		10.0	12.5	15.0	17.5
9	1	11.1	13.0	14.8	16.4
	2	10.5	13.5	15.6	16.4
	3	10.9	13.4	14.9	17.1
	Mean	10.9	13.3	15.1	16.7
	s.d.	0.3	0.3	0.4	0.4
10	1	11.0	12.8	14.6	16.6
	2	10.4	13.4	15.5	16.4
	3	10.9	13.3	14.6	17.3
	Mean	10.8	13.2	14.9	16.7
	s.d.	0.3	0.3	0.5	0.5
11	1	11.3	13.0	14.8	16.2
	2	10.6	13.3	15.5	16.0
	3	10.9	13.4	14.8	17.3
	Mean	10.9	13.3	15.0	16.5
	s.d.	0.4	0.2	0.4	0.7
12	1	11.7	13.1	14.8	16.4
	2	10.8	13.5	15.3	16.4
	3	10.8	13.6	14.9	17.2
	Mean	11.1	13.4	15.1	16.7
	s.d.	0.5	0.3	0.3	0.5

Storage period (wk)	Replication	Moisture content (% wb)			
		10.0	12.5	15.0	17.5
13	1	11.6	13.2	14.9	16.1
	2	10.9	13.4	15.8	16.3
	3	11.0	13.7	14.8	17.4
	Mean	11.2	13.4	15.2	16.6
	s.d.	0.4	0.2	0.6	0.8
14	1	11.8	13.2	14.9	16.2
	2	10.8	13.5	15.7	16.4
	3	10.9	13.6	14.8	16.5
	Mean	11.2	13.4	15.1	16.4
	s.d.	0.6	0.2	0.5	0.2
15	1	11.8	13.1	14.8	16.1
	2	10.9	13.7	15.7	16.1
	3	10.9	13.7	14.8	16.9
	Mean	11.2	13.5	15.1	16.4
	s.d.	0.5	0.4	0.5	0.4
16	1	11.6	13.0	14.6	16.1
	2	10.8	13.4	15.6	16.2
	3	10.8	13.5	14.8	16.1
	Mean	11.1	13.3	14.9	16.1
	s.d.	0.4	0.3	0.5	0.1

Table A.4. Moisture content of rye sample stored at 40°C

Storage period (wk)	Replication	Moisture content (% wb)			
		10.0	12.5	15.0	17.5
1	1	10.3	12.4	14.6	16.9
	2	10.1	12.8	14.9	16.2
	3	10.9	12.9	15.5	16.5
	Mean	10.5	12.7	14.9	16.5
	s.d.	0.4	0.2	0.5	0.3
2	1	9.8	12.4	14.5	16.6
	2	9.8	12.7	14.4	16.2
	3	10.5	12.9	14.4	16.3
	Mean	10.0	12.7	14.4	16.3
	s.d.	0.4	0.2	0.0	0.2
3	1	10.5	12.9	14.8	17.0
	2	10.5	13.4	14.8	16.9
	3	11.2	13.0	14.7	17.2
	Mean	10.8	13.1	14.7	17.1
	s.d.	0.4	0.3	0.0	0.1
4	1	10.5	12.9	14.6	16.8
	2	11.1	13.1	14.8	16.6
	3	10.9	13.4	14.6	16.9
	Mean	10.8	13.1	14.7	16.8
	s.d.	0.3	0.2	0.1	0.2

Storage period (wk)	Replication	Moisture content (% wb)			
		10.0	12.5	15.0	17.5
5	1	10.5	12.8	14.5	17.3
	2	10.7	13.2	14.8	16.5
	3	11.6	13.4	14.6	17.2
	Mean	10.8	13.1	14.7	16.9
	s.d.	0.5	0.3	0.1	0.4
6	1	10.6	12.9	14.6	16.2
	2	10.7	13.3	14.7	16.3
	3	11.9	13.1	14.7	16.5
	Mean	11.7	13.1	14.7	16.3
	s.d.	0.7	0.2	0.0	0.1
7	1	11.1	13.2	14.7	16.9
	2	10.5	13.4	14.8	16.1
	3	11.3	13.3	14.7	16.7
	Mean	10.9	13.3	14.7	16.6
	s.d.	0.4	0.1	0.0	0.4
8	1	10.9	12.8	14.7	16.8
	2	10.4	13.3	14.6	16.1
	3	11.4	13.2	14.7	16.9
	Mean	10.9	13.1	14.6	16.6
	s.d.	0.5	0.3	0.0	0.4

Storage period (wk)	Replication	Moisture content (% wb)			
		10.0	12.5	15.0	17.5
9	1	10.9	16.6	14.7	16.8
	2	10.4	13.3	14.6	16.1
	3	11.4	13.2	14.7	16.9
	Mean	10.9	14.4	14.6	16.6
	s.d.	0.5	1.9	0.0	0.4
10	1	10.8	12.7	14.5	15.8
	2	10.5	12.8	14.4	15.5
	3	11.4	13.1	14.4	16.5
	Mean	10.9	12.9	14.4	15.9
	s.d.	0.5	0.2	0.1	0.5
11	1	10.6	12.7	14.6	16.7
	2	10.5	13.2	14.6	16.2
	3	11.5	12.9	14.6	16.6
	Mean	10.8	12.9	14.6	16.5
	s.d.	0.4	0.3	0.0	0.3
12	1	10.7	12.8	14.5	16.7
	2	10.5	13.3	14.5	16.4
	3	11.5	13.1	14.7	17.6
	Mean	10.9	13.1	14.5	16.9
	s.d.	0.5	0.2	0.0	0.7

Storage period (wk)	Replication	Moisture content (% wb)			
		10.0	12.5	15.0	17.5
13	1	10.8	12.8	15.4	16.3
	2	10.5	13.3	14.5	16.7
	3	11.2	13.0	14.6	16.9
	Mean	10.8	13.1	14.9	16.7
	s.d.	0.4	0.4	0.5	0.3
14	1	10.6	12.8	14.6	16.3
	2	10.6	13.1	14.5	16.3
	3	11.3	13.0	14.6	16.3
	Mean	10.8	12.9	14.6	16.3
	s.d.	0.4	0.2	0.1	0.0
15	1	10.8	12.7	14.6	16.6
	2	10.6	13.1	14.6	16.0
	3	11.2	12.8	14.7	16.5
	Mean	10.9	12.9	14.6	16.4
	s.d.	0.3	0.2	0.0	0.3
16	1	10.6	12.6	14.8	17.2
	2	10.4	13.1	14.5	17.5
	3	10.9	12.8	14.5	17.2
	Mean	10.6	12.8	14.6	17.3
	s.d.	0.2	0.3	0.2	0.2

APPENDIX B: Germination data

Table B.1. Germination (%) of rye sample stored at 10°C

Storage period (wk)	Replication	Moisture content (% wb)			
		10.0	12.5	15.0	17.5
1	1	88	84	80	68
	2	96	84	84	76
	3	84	88	84	72
	Mean	89.3	85.3	82.7	72.0
	s.d.	6.1	2.3	2.3	4.0
2	1	80	84	84	72
	2	92	92	72	56
	3	84	80	84	68
	Mean	85.3	85.3	80.0	65.3
	s.d.	6.1	6.1	6.9	8.3
3	1	88	92	84	80
	2	84	84	72	68
	3	76	88	72	64
	Mean	82.7	88.0	76.0	70.7
	s.d.	6.1	4.0	6.9	8.3
4	1	84	84	88	64
	2	100	76	80	72
	3	84	84	80	68
	Mean	89.3	81.3	82.7	68.0
	s.d.	9.2	4.6	4.6	4.0

Storage period (wk)	Replication	Moisture content (% wb)			
		10.0	12.5	15.0	17.5
5	1	80	84	80	52
	2	92	92	72	68
	3	92	88	92	72
	Mean	88.0	88.0	81.3	64.0
	s.d.	6.9	4.0	10.0	10.5
6	1	92	88	76	76
	2	96	84	84	72
	3	100	96	80	76
	Mean	96.0	89.3	80.0	74.7
	s.d.	4.0	6.1	4.0	2.3
7	1	92	84	88	72
	2	92	84	84	76
	3	80	84	92	64
	Mean	88.0	84.0	88.0	70.7
	s.d.	6.9	0.0	4.0	6.1
8	1	92	80	84	76
	2	88	80	80	64
	3	96	92	76	64
	Mean	92.0	84.0	80.0	68.0
	s.d.	4.0	6.9	4.0	4.0

Storage period (wk)	Replication	Moisture content (% wb)			
		10.0	12.5	15.0	17.5
9	1	92	92	84	60
	2	92	80	80	56
	3	92	84	84	52
	Mean	92.0	85.3	82.7	56.0
	s.d.	0.0	6.1	2.3	4.0
10	1	92	84	80	72
	2	92	96	68	68
	3	88	92	84	60
	Mean	90.7	90.7	77.3	66.7
	s.d.	2.3	6.1	8.3	6.1
11	1	84	88	92	52
	2	80	96	80	44
	3	84	76	76	40
	Mean	82.7	86.7	82.7	45.3
	s.d.	2.3	10.0	8.3	6.1
12	1	84	88	92	52
	2	88	96	80	52
	3	76	76	76	76
	Mean	82.7	86.7	82.7	60.0
	s.d.	6.1	10.0	8.3	13.8

Storage period (wk)	Replication	Moisture content (% wb)			
		10.0	12.5	15.0	17.5
13	1	92	88	92	80
	2	72	92	80	52
	3	84	88	76	48
	Mean	82.7	89.3	82.7	60.0
	s.d.	10.0	2.3	8.3	17.4
14	1	92	88	92	40
	2	88	96	80	36
	3	84	84	76	44
	Mean	88.0	89.3	82.7	40.0
	s.d.	4.0	6.1	8.3	4.0
15	1	84	88	92	52
	2	80	96	80	44
	3	84	76	76	40
	Mean	82.7	86.7	82.7	45.3
	s.d.	2.3	10.0	8.3	6.1
16	1	80	84	85	44
	2	78	90	80	44
	3	82	76	76	40
	Mean	80.0	83.3	80.3	42.7
	s.d.	2.0	7.0	4.5	2.3

Table B.2. Germination (%) of rye sample stored at 20°C

Storage period (wk)	Replication	Moisture content (% wb)			
		10.0	12.5	15.0	17.5
1	1	92	92	84	76
	2	96	92	80	64
	3	84	80	76	72
	Mean	90.7	88.0	80.0	70.7
	s.d.	6.1	6.9	4.0	6.1
2	1	88	84	84	56
	2	92	88	84	44
	3	88	84	80	68
	Mean	89.3	85.3	82.7	56.0
	s.d.	2.3	2.3	2.3	12.0
3	1	100	92	80	52
	2	88	80	76	56
	3	92	88	88	84
	Mean	93.3	86.7	81.3	64.0
	s.d.	6.1	6.1	6.1	17.4
4	1	92	80	84	44
	2	88	88	68	48
	3	92	84	84	56
	Mean	90.7	84.0	78.7	49.3
	s.d.	2.3	4.0	9.2	6.1

Storage period (wk)	Replication	Moisture content (% wb)			
		10.0	12.5	15.0	17.5
5	1	92	84	84	24
	2	96	92	68	8
	3	96	88	64	12
	Mean	94.7	88.0	72.0	14.7
	s.d.	2.3	4.0	10.5	8.3
6	1	92	88	72	12
	2	88	92	76	16
	3	92	96	92	20
	Mean	90.7	92.0	80.0	16.0
	s.d.	2.3	4.0	10.5	4.0
7	1	84	84	80	8
	2	84	84	72	0
	3	88	84	84	4
	Mean	85.3	84.0	78.7	4.0
	s.d.	2.3	0.0	6.1	4.0
8	1	92	88	80	0
	2	96	84	84	0
	3	92	88	68	0
	Mean	90.7	86.7	77.3	0.0
	s.d.	6.1	2.3	8.3	0.0

Storage period (wk)	Replication	Moisture content (% wb)			
		10.0	12.5	15.0	17.5
9	1	92	84	72	0
	2	84	80	68	0
	3	84	88	56	0
	Mean	86.7	84.0	65.3	0.0
	s.d.	4.6	4.0	8.3	0.0
10	1	76	80	72	0
	2	80	80	64	0
	3	84	88	76	0
	Mean	80.0	82.7	70.7	0.0
	s.d.	4.0	4.6	6.1	0.0
11	1	92	76	56	0
	2	76	68	44	0
	3	84	80	40	0
	Mean	84.0	74.7	46.7	0.0
	s.d.	8.0	6.1	8.3	0.0
12	1	76	60	20	0
	2	76	68	8	0
	3	68	76	28	0
	Mean	73.3	68.0	18.7	0.0
	s.d.	4.6	8.0	10.0	0.0

Storage period (wk)	Replication	Moisture content (% wb)			
		10.0	12.5	15.0	17.5
13	1	92	40	0	0
	2	76	44	0	0
	3	84	36	0	0
	Mean	84.0	40.0	0.0	0.0
	s.d.	8.0	4.0	0.0	0.0
14	1	80	12	0	0
	2	84	4	0	0
	3	92	0	0	0
	Mean	85.3	5.3	0.0	0.0
	s.d.	6.1	6.1	0.0	0.0
15	1	92	8	0	0
	2	76	4	0	0
	3	84	8	0	0
	Mean	84.0	6.6	0.0	0.0
	s.d.	8.0	2.3	0.0	0.0
16	1	82	8	0	0
	2	76	4	0	0
	3	84	8	0	0
	Mean	80.7	6.7	0.0	0.0
	s.d.	4.1	2.3	0.0	0.0

Table B.3. Germination (%) of rye sample stored at 30°C

Storage period (wk)	Replication	Moisture content (% wb)			
		10.0	12.5	15.0	17.5
1	1	80	88	72	32
	2	88	92	84	44
	3	88	92	88	44
	Mean	85.3	90.7	81.3	40.0
	s.d.	4.6	2.3	8.3	6.9
2	1	92	80	68	24
	2	96	96	72	40
	3	80	88	72	20
	Mean	89.3	88.0	70.7	28.0
	s.d.	8.3	8.0	2.3	10.5
3	1	96	72	40	4
	2	96	96	60	8
	3	88	88	56	28
	Mean	93.3	85.3	52.0	13.3
	s.d.	4.6	12.2	10.5	12.8
4	1	88	96	12	0
	2	92	76	4	0
	3	84	76	24	0
	Mean	88.0	82.7	13.3	0.0
	s.d.	4.0	11.5	10.0	0.0

Storage period (wk)	Replication	Moisture content (% wb)			
		10.0	12.5	15.0	17.5
5	1	96	84	4	0
	2	88	76	0	0
	3	80	72	12	0
	Mean	88.0	77.3	5.3	0.0
	s.d.	8.0	6.1	6.1	0.0
6	1	100	80	0	0
	2	96	80	0	0
	3	92	84	0	0
	Mean	96.0	81.3	0.0	0.0
	s.d.	4.0	2.3	0.0	0.0
7	1	92	76	0	0
	2	92	76	0	0
	3	80	80	0	0
	Mean	88.0	77.3	0.0	0.0
	s.d.	6.9	2.3	0.0	0.0
8	1	88	88	0	0
	2	80	88	0	0
	3	88	60	0	0
	Mean	85.3	78.7	0.0	0.0
	s.d.	4.6	16.1	0.0	0.0

Storage period (wk)	Replication	Moisture content (% wb)			
		10.0	12.5	15.0	17.5
9	1	80	68	0	0
	2	88	60	0	0
	3	80	52	0	0
	Mean	82.7	60.0	0.0	0.0
	s.d.	4.6	8.0	0.0	0.0
10	1	84	76	0	0
	2	88	52	0	0
	3	76	40	0	0
	Mean	82.7	56.0	0.0	0.0
	s.d.	6.1	18.3	0.0	0.0
11	1	92	52	0	0
	2	92	48	0	0
	3	84	52	0	0
	Mean	89.3	50.7	0.0	0.0
	s.d.	4.6	2.3	0.0	0.0
12	1	76	52	0	0
	2	76	60	0	0
	3	80	48	0	0
	Mean	77.3	53.3	0.0	0.0
	s.d.	2.3	6.1	0.0	0.0

Storage period (wk)	Replication	Moisture content (% wb)			
		10.0	12.5	15.0	17.5
13	1	76	52	0	0
	2	84	24	0	0
	3	88	24	0	0
	Mean	82.7	33.3	0.0	0.0
	s.d.	6.1	16.1	0.0	0.0
14	1	84	44	0	0
	2	84	20	0	0
	3	76	32	0	0
	Mean	81.3	32.0	0.0	0.0
	s.d.	4.6	12.0	0.0	0.0
15	1	92	52	0	0
	2	92	48	0	0
	3	84	52	0	0
	Mean	89.3	50.7	0.0	0.0
	s.d.	4.6	2.3	0.0	0.0
16	1	92	52	0	0
	2	90	48	0	0
	3	84	52	0	0
	Mean	88.7	50.7	0.0	0.0
	s.d.	4.6	2.3	0.0	0.0

Table B.4. Germination (%) of rye sample stored at 40°C

Storage period (wk)	Replication	Moisture content (% wb)			
		10.0	12.5	15.0	17.5
1	1	84	72	40	20
	2	92	72	64	32
	3	96	80	52	28
	Mean	90.7	74.7	52.0	26.7
	s.d.	6.1	4.6	12.0	6.1
2	1	96	56	16	16
	2	96	16	28	12
	3	80	16	8	4
	Mean	90.7	29.3	17.3	10.7
	s.d.	9.2	23.0	10.0	6.1
3	1	88	32	16	0
	2	92	8	28	0
	3	92	8	8	0
	Mean	90.7	16.0	6.7	0.0
	s.d.	2.3	13.8	8.3	0.0
4	1	80	4	4	0
	2	96	0	0	0
	3	72	0	0	0
	Mean	52.7	1.3	1.3	0.0
	s.d.	12.2	2.3	2.3	0.0

Storage period (wk)	Replication	Moisture content (% wb)			
		10.0	12.5	15.0	17.5
5	1	76	0	0	0
	2	68	0	0	0
	3	64	0	0	0
	Mean	69.3	0.0	0.0	0.0
	s.d.	6.1	0.0	0.0	0.0
6	1	84	0	0	0
	2	76	0	0	0
	3	68	0	0	0
	Mean	76.0	0.0	0.0	0.0
	s.d.	8.0	0.0	0.0	0.0
7	1	80	0	0	0
	2	72	0	0	0
	3	60	0	0	0
	Mean	70.7	0.0	0.0	0.0
	s.d.	10.0	0.0	0.0	0.0
8	1	48	0	0	0
	2	72	0	0	0
	3	60	0	0	0
	Mean	45.3	0.0	0.0	0.0
	s.d.	28.0	0.0	0.0	0.0

Storage period (wk)	Replication	Moisture content (% wb)			
		10.0	12.5	15.0	17.5
9	1	48	0	0	0
	2	72	0	0	0
	3	60	0	0	0
	Mean	45.3	0.0	0.0	0.0
	s.d.	28.0	0.0	0.0	0.0
10	1	12	0	0	0
	2	48	0	0	0
	3	0	0	0	0
	Mean	20.0	0.0	0.0	0.0
	s.d.	24.9	0.0	0.0	0.0
11	1	24	0	0	0
	2	44	0	0	0
	3	16	0	0	0
	Mean	28.0	0.0	0.0	0.0
	s.d.	14.4	0.0	0.0	0.0
12	1	0	0	0	0
	2	16	0	0	0
	3	4	0	0	0
	Mean	6.7	0.0	0.0	0.0
	s.d.	8.3	0.0	0.0	0.0

Storage period (wk)	Replication	Moisture content (% wb)			
		10.0	12.5	15.0	17.5
13	1	0	0	0	0
	2	16	0	0	0
	3	4	0	0	0
	Mean	6.7	0.0	0.0	0.0
	s.d.	8.3	0.0	0.0	0.0
14	1	8	0	0	0
	2	12	0	0	0
	3	0	0	0	0
	Mean	6.7	0.0	0.0	0.0
	s.d.	6.1	0.0	0.0	0.0
15	1	24	0	0	0
	2	44	0	0	0
	3	16	0	0	0
	Mean	28.0	0.0	0.0	0.0
	s.d.	14.4	0.0	0.0	0.0
16	1	24	0	0	0
	2	36	0	0	0
	3	16	0	0	0
	Mean	25.3	0.0	0.0	0.0
	s.d.	10.0	0.0	0.0	0.0

Table B.5. Changes in germination stored at 10°C (n=3)

Storage period (wk)	Moisture content (% Wet basis)			
	10.0	12.5	15.0	17.5
0	92.0^{ab}±1.4*	92.0^{ab}±1.4*	92.0^{ab}±1.4*	92.0^{ab}±1.4*
1	89.3^{ac}±6.1*	85.3^{ab}±2.3*	82.6^{ac}±2.3*	72.0^{bc}±4.0†
2	85.3^{bc}±6.1†	85.3^{ab}±6.1†	80.0^{bc}±6.9†	65.3^{bd}±8.3*
3	82.6^{cd}±6.1*	88.0^{ab}±4.0†	76.0^{c}±6.9†	70.6^{bc}±8.3†
4	89.3^{ac}±9.2*	81.3^{b}±4.6*	82.6^{ac}±4.6*	68.0^{bd}±4.0†
5	88.0^{ad}±6.9*	88.0^{ab}±4.0†	81.3^{ac}±10.0*	64.0^{bd}±10.5†
6	96.0^{a}±4.0†	88.3^{ab}±6.1†	80.0^{bc}±4.0*	74.6^{b}±2.3†
7	88.0^{ad}±6.9*	84.0^{ab}±0.0†	88.0^{ab}±4.0†	70.6^{bc}±6.1†
8	92.0^{ab}±4.0†	84.0^{ab}±6.9†	80.0^{bc}±4.0*	68.0^{bd}±6.9†
9	92.0^{ab}±0.0†	85.3^{ab}±6.1*	82.6^{ac}±2.3*	56.0^{de}±4.0†
10	90.6^{ac}±2.3†	90.6^{ab}±6.1†	77.3^{bc}±8.3*	66.6^{bd}±6.1†
11	82.6^{cd}±2.3*	86.6^{ab}±10.0*	82.6^{ac}±8.3†	45.3^{ef}±6.1†
12	82.6^{cd}±6.1†	86.6^{ab}±10.0*	82.6^{ac}±8.3†	60.0^{cd}±13.8†
13	82.6^{cd}±10.0*	89.3^{ab}±2.3*	82.6^{ac}±8.3†	60.0^{cd}±17.4†
14	88.0^{ad}±4.0*	89.3^{ab}±6.1*	82.6^{ac}±8.3†	40.0^{f}±4.0†
15	82.6^{cd}±2.3*	86.6^{ab}±10.0*	82.6^{ac}±8.3†	45.3^{ef}±6.1†
16	80.0^{d}±2.0*	83.3^{ab}±7.0*	80.3^{bc}±4.5†	42.6^{f}±2.3†

† Values are significantly different from the values obtained in Sathya et al. (2008)
* Values are not significantly different from the values obtained in Sathya et al. (2008)
a,b,c,d,e and f are the variables used for comparison of means in least significant difference (LSD)

Table B.6. Changes in germination stored at 20°C (n=3)

Storage period (wk)	Moisture content (% Wet basis)			
	10.0	12.5	15.0	17.5
0	92.0^{ab}±1.4*	92.0^{ab}±1.4*	92.0^{ab}±1.4*	92.0^{ab}±1.4*
1	90.6^{ac}±6.1*	88.0^{ab}±6.9*	80.0^{bd}±4.0*	70.6^{b}±6.1†
2	89.3^{ac}±2.3*	85.3^{ab}±2.3†	82.6^{ab}±2.3*	56.0^{cd}±12.0*
3	93.3^{ab}±6.1†	86.6^{ab}±6.1†	81.3^{bc}±6.1*	64.0^{bc}±17.4*
4	90.6^{ac}±2.3*	84.0^{b}±4.0*	78.6^{bd}±9.2*	49.3^{d}±6.1*
5	94.6^{a}±2.3†	88.0^{ab}±4.0†	72.0^{ce}±10.5*	14.6^{e}±8.3†
6	90.6^{ac}±2.3†	92.0^{a}±4.0†	80.0^{bd}±10.5*	16.0^{e}±4.0†
7	85.3^{bd}±2.3*	92.0^{a}±4.0†	78.6^{bd}±6.1†	4.0^{f}±4.0†
8	90.6^{ac}±6.1†	86.6^{ab}±2.3*	77.3^{bd}±8.3*	0.0^{f}±0.0†
9	86.6^{ad}±4.6*	84.0^{b}±4.0*	65.3^{e}±8.3†	0.0^{f}±0.0†
10	80.0^{de}±4.0*	82.6^{b}±4.6†	70.6^{de}±6.1†	0.0^{f}±0.0†
11	84.0^{cd}±8.0*	74.6^{c}±6.1*	46.6^{ab}±8.3†	0.0^{f}±0.0†
12	73.3^{e}±4.6*	67.6^{d}±6.1*	18.6^{f}±10.0†	0.0^{f}±0.0†
13	84.0^{cd}±8.0*	40.0^{e}±4.0†	0.0^{f}±0.0†	0.0^{f}±0.0†
14	85.3^{bd}±6.1*	5.3^{f}±6.1†	0.0^{f}±0.0†	0.0^{f}±0.0†
15	84.0^{cd}±8.0*	6.6^{f}±2.3†	0.0^{f}±0.0†	0.0^{f}±0.0†
16	80.6^{de}±4.1*	6.6^{f} ±2.3†	0.0^{f}±0.0†	0.0^{f}±0.0†

† Values are significantly different from the values obtained in Sathya et al. (2008)
* Values are not significantly different from the values obtained in Sathya et al. (2008)
a,b,c,d,e and f are the variables used for comparison of means in least significant difference (LSD)

Table B.7. Changes in germination stored at 30°C (n=3)

Storage period (wk)	Moisture content (% Wet basis)			
	10.0	12.5	15.0	17.5
0	92.0^{ab}±1.4*	92.0^{ab}±1.4*	92.0^{ab}±1.4*	92.0^{ab}±1.4*
1	85.3^{bd}±4.6*	90.6^{a}±2.3†	81.3^{b}±8.3†	40.0^{b}±6.9†
2	89.3^{ac}±8.3†	88.0^{a}±8.0*	70.6^{c}±2.3*	28.0^{c}±10.5†
3	93.3^{ab}±4.6†	85.3^{a}±12.2*	52.0^{d}±10.5†	13.0^{d}±12.8†
4	88.0^{ac}±4.0†	82.6^{a}±11.5†	13.3^{e}±10.0†	0.0^{e}±0.0†
5	88.0^{ac}±8.0†	77.3^{a}±6.1†	5.3^{f}±6.1†	0.0^{e}±0.0†
6	96.0^{a}±4.0†	81.3^{a}±2.3†	0.0^{f}±0.0†	0.0^{e}±0.0†
7	88.0^{ac}±6.9†	73.3^{a}±2.3*	0.0^{f}±0.0†	0.0^{e}±0.0†
8	85.3^{bd}±4.6†	78.6^{a}±16.1†	0.0^{f}±0.0†	0.0^{e}±0.0†
9	82.6^{cd}±4.6†	60.0^{b}±8.0*	0.0^{f}±0.0†	0.0^{e}±0.0†
10	82.6^{cd}±6.1†	56.0^{b}±18.3*	0.0^{f}±0.0†	0.0^{e}±0.0†
11	89.3^{ac}±4.6†	50.6^{b}±2.3*	0.0^{f}±0.0†	0.0^{e}±0.0†
12	77.3^{d}±2.3†	59.3^{b}±6.1†	0.0^{f}±0.0†	0.0^{e}±0.0*
13	82.6^{cd}±6.1†	33.3^{c}±16.1†	0.0^{f}±0.0†	0.0^{e}±0.0*
14	81.3^{cd}±4.6†	32.0^{c}±12.0†	0.0^{f}±0.0†	0.0^{e}±0.0*
15	89.3^{ac}±4.6†	50.6^{b}±2.3*	0.0^{f}±0.0†	0.0^{e}±0.0*
16	88.6^{ac}±4.1†	50.6^{b}±2.3*	0.0^{f}±0.0†	0.0^{e}±0.0*

† Values are significantly different from the values obtained in Sathya et al. (2008)
* Values are not significantly different from the values obtained in Sathya et al. (2008)
a,b,c,d,e and f are the variables used for comparison of means in least significant difference (LSD)

Table B.8. Changes in germination stored at 40°C (n=3)

Storage period (wk)	Moisture content (% Wet basis)			
	10.0	12.5	15.0	17.5
0	92.0^{ab}±1.4*	92.0^{ab}±1.4*	92.0^{ab}±1.4*	92.0^{ab}±1.4*
1	90.6^{a}±6.1†	74.6^{b}±4.6†	52.0^{b}±12.0†	26.6^{b}±6.1†
2	90.6^{a}±9.2†	29.3^{c}±23.0†	17.3^{c}±10.0*	10.6^{c}±6.1†
3	90.6^{a}±2.3†	16.0^{d}±13.8†	6.6^{d}±8.3*	0.0^{d}±0.0*
4	82.6^{ab}±12.2*	1.3^{e}±2.3†	1.3^{d}±2.3†	0.0^{d}±0.0*
5	69.3^{bc}±6.1†	0.0^{e}±0.0†	0.0^{d}±0.0†	0.0^{d}±0.0*
6	76.0^{ac}±8.0*	0.0^{e}±0.0†	0.0^{d}±0.0*	0.0^{d}±0.0*
7	70.6^{bc}±10.0*	0.0^{e}±0.0†	0.0^{d}±0.0*	0.0^{d}±0.0*
8	60.0^{c}±28.0*	0.0^{e}±0.0†	0.0^{d}±0.0*	0.0^{d}±0.0*
9	60.0^{c}±28.0*	0.0^{e}±0.0†	0.0^{d}±0.0*	0.0^{d}±0.0*
10	20.0^{de}±24.9†	0.0^{e}±0.0†	0.0^{d}±0.0*	0.0^{d}±0.0*
11	28.0^{d}±14.4†	0.0^{e}±0.0†	0.0^{d}±0.0*	0.0^{d}±0.0*
12	28.0^{d}±8.3†	0.0^{e}±0.0†	0.0^{d}±0.0*	0.0^{d}±0.0*
13	24.6^{d}±8.3†	0.0^{e}±0.0†	0.0^{d}±0.0*	0.0^{d}±0.0*
14	6.6^{ef}±6.1†	0.0^{e}±0.0†	0.0^{d}±0.0*	0.0^{d}±0.0*
15	6.6^{ef}±14.4†	0.0^{e}±0.0†	0.0^{d}±0.0*	0.0^{d}±0.0*
16	0.0^{f}±0.0†	0.0^{e}±0.0†	0.0^{d}±0.0*	0.0^{d}±0.0*

† Values are significantly different from the values obtained in Sathya et al. (2008)
* Values are not significantly different from the values obtained in Sathya et al. (2008)
a,b,c,d,e and f are the variables used for comparison of means in least significant difference (LSD)

APPENDIX C: Fat acid value

Table C.1. FAV of rye sample stored at 10°C

Storage period (wk)	Replication	Moisture content (% wb)			
		10.0	12.5	15.0	17.5
2	1	10.6	12.9	11.5	14.1
	2	11.6	12.9	11.5	14.1
	3	10.4	12.9	11.5	14.1
	Mean	10.9	12.9	11.5	14.1
	s.d.	0.7	0.0	0.0	0.0
4	1	12.7	20.4	15.2	15.3
	2	10.2	22.9	15.2	17.8
	3	12.7	22.9	15.2	15.3
	Mean	11.9	22.1	15.2	16.1
	s.d.	1.5	1.5	0.0	1.5
6	1	12.7	12.7	12.7	15.3
	2	12.7	12.7	10.2	15.3
	3	12.7	12.7	12.7	17.8
	Mean	12.7	12.7	11.9	16.1
	s.d.	0.0	0.0	1.5	1.5
8	1	12.7	10.2	12.7	15.3
	2	10.2	10.2	12.7	12.7
	3	10.2	12.7	12.7	10.2
	Mean	11.0	11.0	12.7	12.7
	s.d.	1.4	1.5	0.0	0.0

Storage period (wk)	Replication	Moisture content (% wb)			
		10.0	12.5	15.0	17.5
10	1	10.1	10.1	10.1	12.7
	2	12.7	10.1	7.6	10.1
	3	12.7	10.1	7.6	10.1
	Mean	11.8	10.1	8.4	11.0
	s.d.	1.4	0.0	1.4	1.4
12	1	15.2	15.2	15.2	17.8
	2	12.7	12.7	17.8	17.8
	3	15.2	15.2	17.8	17.8
	Mean	14.4	14.4	16.9	17.8
	s.d.	1.4	1.4	1.4	0.0
14	1	12.7	15.2	15.2	20.3
	2	12.7	12.7	17.8	20.3
	3	12.7	15.2	17.8	25.4
	Mean	12.7	13.5	16.9	22.0
	s.d.	0.0	1.4	1.4	2.9
16	1	17.8	17.8	17.8	20.3
	2	17.8	17.8	17.8	20.3
	3	17.8	17.8	17.8	20.3
	Mean	17.8	17.8	17.8	20.3
	s.d.	0.0	0.0	0.0	0.0

Table C.2. FAV of rye sample stored at 20°C

Storage period (wk)	Replication	Moisture content (% wb)			
		10.0	12.5	15.0	17.5
2	1	12.7	11.0	20.2	15.2
	2	12.7	11.0	15.0	12.7
	3	12.7	8.8	17.6	12.7
	Mean	12.7	10.2	17.6	13.5
	s.d.	0.0	1.2	2.5	1.4
4	1	12.7	12.7	14.3	12.7
	2	17.8	12.7	12.7	20.3
	3	12.7	12.7	10.1	17.8
	Mean	14.4	12.7	12.4	16.9
	s.d.	2.9	0.0	2.1	3.8
6	1	12.7	15.2	17.2	15.2
	2	15.2	17.8	15.2	17.8
	3	12.7	15.2	12.7	17.8
	Mean	13.5	16.1	15.0	16.9
	s.d.	1.4	1.4	2.2	1.4
8	1	10.1	15.2	17.2	15.2
	2	17.8	15.2	12.7	17.8
	3	17.8	12.7	15.2	17.8
	Mean	15.2	14.4	15.0	17.8
	s.d.	4.4	1.4	2.2	0.0

Storage period (wk)	Replication	Moisture content (% wb)			
		10.0	12.5	15.0	17.5
10	1	10.1	15.2	17.2	22.9
	2	10.1	12.7	15.2	22.9
	3	7.6	10.1	15.2	22.9
	Mean	9.3	12.7	15.9	22.9
	s.d.	1.4	2.5	1.1	0.0
12	1	16.5	17.8	22.9	30.5
	2	16.5	17.8	17.8	33.1
	3	20.3	17.8	17.8	30.5
	Mean	17.8	17.8	19.5	31.4
	s.d.	2.2	0.0	2.9	1.4
14	1	17.8	17.8	22.9	30.2
	2	15.2	17.8	20.3	30.2
	3	15.2	17.8	20.3	30.2
	Mean	16.1	17.8	21.2	30.2
	s.d.	1.4	0.0	1.5	0.0
16	1	15.2	17.8	25.8	33.1
	2	15.2	17.8	25.9	30.5
	3	15.2	20.3	25.9	30.5
	Mean	15.2	18.6	23.9	31.4
	s.d.	0.0	1.4	1.6	1.4

Table C.3. FAV of rye sample stored at 30°C

Storage period (wk)	Replication	Moisture content (% wb)			
		10.0	12.5	15.0	17.5
2	1	10.1	12.7	15.2	20.3
	2	10.1	10.1	15.2	20.3
	3	10.1	7.6	12.7	20.3
	Mean	10.1	10.1	14.4	20.3
	s.d.	0.0	2.5	1.4	0.0
4	1	15.2	12.7	17.8	28.0
	2	12.7	15.2	15.2	30.5
	3	12.7	12.7	17.8	25.4
	Mean	13.5	13.5	16.9	28.0
	s.d.	1.4	1.4	1.4	2.5
6	1	15.2	15.2	20.3	38.2
	2	15.2	15.2	22.9	35.6
	3	12.7	12.7	28.0	43.2
	Mean	14.4	14.4	23.7	39.0
	s.d.	1.4	1.4	3.8	3.8
8	1	12.7	12.7	17.8	35.6
	2	7.6	12.7	17.8	33.1
	3	10.1	12.7	15.2	30.5
	Mean	10.1	12.7	16.9	33.1
	s.d.	2.5	0.0	1.4	2.5

Storage period (wk)	Replication	Moisture content (% wb)			
		10.0	12.5	15.0	17.5
10	1	15.2	17.8	20.3	38.2
	2	15.2	15.2	20.3	38.2
	3	15.2	15.2	20.3	35.6
	Mean	15.2	16.1	20.3	37.3
	s.d.	0.0	1.4	0.0	1.4
12	1	17.8	22.9	25.4	43.2
	2	15.2	22.9	25.4	40.7
	3	15.2	20.3	25.4	40.7
	Mean	16.1	22.0	25.4	41.6
	s.d.	1.4	1.4	0.0	1.4
14	1	17.8	28.0	33.1	43.2
	2	17.8	30.5	48.3	68.7
	3	17.8	25.4	22.9	66.2
	Mean	17.8	28.0	34.8	59.4
	s.d.	0.0	2.5	12.8	14.0
16	1	17.8	22.9	30.5	45.8
	2	17.8	35.6	35.6	40.7
	3	17.8	12.7	38.2	40.7
	Mean	17.8	23.7	34.8	42.4
	s.d.	0.0	11.4	3.8	2.9

Table C.4. FAV of rye sample stored at 40°C

Storage period (wk)	Replication	Moisture content (% wb)			
		10.0	12.5	15.0	17.5
2	1	15.2	18.8	17.8	28.0
	2	20.3	15.2	17.8	25.4
	3	20.3	15.2	17.8	25.4
	Mean	18.6	16.1	17.8	26.3
	s.d.	2.9	1.4	0.0	1.4
4	1	17.8	20.3	25.4	58.5
	2	17.8	20.3	25.4	53.4
	3	17.8	20.3	22.9	56.0
	Mean	17.8	20.3	24.6	56.0
	s.d.	0.0	0.0	1.4	2.5
6	1	17.8	20.3	25.4	50.9
	2	15.2	22.9	22.9	61.1
	3	17.8	20.3	25.4	53.4
	Mean	16.9	21.2	24.6	55.1
	s.d.	1.4	1.4	1.4	5.3
8	1	15.2	20.9	25.4	56.0
	2	15.2	22.9	28.0	53.4
	3	17.8	20.9	25.4	53.4
	Mean	16.1	22.9	26.3	54.3
	s.d.	1.4	0.0	1.4	1.4

Storage period (wk)	Replication	Moisture content (% wb)			
		10.0	12.5	15.0	17.5
10	1	17.8	25.4	30.5	45.8
	2	17.8	25.4	30.5	48.3
	3	17.8	25.4	30.5	48.3
	Mean	17.8	25.4	30.5	47.5
	s.d.	0.0	0.0	0.0	1.4
12	1	20.3	25.4	30.5	48.3
	2	20.3	25.4	30.5	50.9
	3	20.3	25.4	30.5	48.3
	Mean	20.3	25.4	30.5	49.2
	s.d.	0.0	0.0	0.0	1.4
14	1	28.0	33.1	40.7	53.4
	2	25.4	38.2	40.7	50.9
	3	28.0	38.2	40.7	56.0
	Mean	27.1	36.5	40.7	53.4
	s.d.	1.4	2.9	0.0	2.5
16	1	20.3	33.1	40.7	40.7
	2	15.2	33.1	38.2	40.7
	3	28.0	35.6	43.2	40.7
	Mean	21.2	33.9	40.7	40.7
	s.d.	6.4	1.4	2.5	0.0

Table C.5. Changes in FAV stored at 10°C (n=3)

Storage period (wk)	Moisture content (% Wet basis)			
	10.0	12.5	15.0	17.5
0	$13.2^{cb}\pm0.2$	$13.2^{cd}\pm0.2$	$13.2^{c}\pm0.2$	$13.2^{ef}\pm0.2$
2	$10.8^{e}\pm17.6$	$12.8^{cd}\pm6.4$	$11.5^{d}\pm2.9$	$14.1^{de}\pm2.9$
4	$11.8^{ce}\pm1.4$	$22.0^{a}\pm1.4$	$15.2^{b}\pm0.0$	$16.1^{cd}\pm1.4$
6	$12.7^{bc}\pm0.0$	$12.7^{d}\pm0.0$	$11.8^{dc}\pm1.4$	$16.1^{cd}\pm1.4$
8	$11.0^{de}\pm1.4$	$11.0^{e}\pm1.4$	$12.7^{cd}\pm0.0$	$12.7^{ef}\pm2.5$
10	$11.8^{ce}\pm1.4$	$10.1^{e}\pm0.0$	$8.4^{e}\pm1.4$	$11.0^{f}\pm1.4$
12	$14.4^{b}\pm1.4$	$14.4^{c}\pm1.4$	$16.9^{a}\pm1.4$	$17.8^{bc}\pm0.0$
14	$12.7^{bc}\pm0.0$	$13.5^{cd}\pm1.4$	$16.9^{a}\pm1.4$	$22.0^{a}\pm2.9$
16	$17.8^{a}\pm0.0$	$17.8^{b}\pm0.0$	$17.8^{a}\pm0.0$	$20.3^{ab}\pm0.0$

a,b,c,d,e and f are the variables used for comparison of means in least significant difference (LSD)

Table C.6. Changes in FAV stored at 20°C (n=3)

Storage period (wk)	Moisture content (% Wet basis)			
	10.0	12.5	15.0	17.5
0	$13.2^{b}\pm0.2$	$13.2^{d}\pm0.2$	$13.2^{ef}\pm0.2$	$13.2^{d}\pm0.2$
2	$12.7^{bc}\pm1.4$	$10.2^{e}\pm1.2$	$17.6^{cd}\pm19.5$	$13.5^{d}\pm1.4$
4	$14.4^{ab}\pm2.9$	$12.7^{d}\pm0.0$	$12.4^{f}\pm2.1$	$16.9^{c}\pm3.8$
6	$13.5^{b}\pm1.4$	$16.1^{bc}\pm1.4$	$15.0^{df}\pm2.2$	$16.9^{c}\pm1.4$
8	$15.2^{ab}\pm4.4$	$14.4^{cd}\pm1.4$	$15.0^{df}\pm2.2$	$17.8^{c}\pm0.0$
10	$9.3^{c}\pm1.4$	$12.7^{d}\pm1.5$	$15.9^{de}\pm1.1$	$22.9^{b}\pm0.0$
12	$17.8^{a}\pm14.1$	$17.8^{ab}\pm0.0$	$19.5^{bc}\pm2.9$	$31.5^{a}\pm1.4$
14	$16.1^{ab}\pm1.4$	$17.8^{ab}\pm0.0$	$21.2^{b}\pm1.5$	$30.2^{a}\pm0.0$
16	$15.2^{ab}\pm0.0$	$18.6^{a}\pm1.4$	$25.9^{a}\pm1.6$	$31.4^{a}\pm1.4$

a,b,c,d,e and f are the variables used for comparison of means in least significant difference (LSD)

Table C.7. Changes in FAV stored at 30°C (n=3)

Storage period (wk)	Moisture content (% Wet basis)			
	10.0	12.5	15.0	17.5
0	$13.2^{c}\pm0.2$	$13.2^{c}\pm0.2$	$13.2^{d}\pm0.2$	$13.2^{f}\pm0.2$
2	$10.1^{d}\pm0.0$	$10.1^{c}\pm2.5$	$14.4^{d}\pm1.4$	$20.3^{ef}\pm0.0$
4	$13.5^{c}\pm1.4$	$13.5^{c}\pm1.4$	$16.9^{cd}\pm1.4$	$28.0^{de}\pm2.5$
6	$14.4^{bc}\pm1.4$	$14.4^{c}\pm1.4$	$23.7^{bc}\pm3.8$	$39.0^{bc}\pm3.8$
8	$10.1^{d}\pm2.5$	$12.7^{c}\pm0.0$	$16.9^{cd}\pm1.4$	$33.1^{cd}\pm2.5$
10	$15.2^{bc}\pm0.0$	$16.1^{bc}\pm1.4$	$20.3^{bd}\pm0.0$	$37.3^{bc}\pm1.4$
12	$16.1^{ab}\pm1.4$	$22.0^{ab}\pm1.4$	$25.4^{b}\pm0.0$	$41.6^{bc}\pm1.4$
14	$17.8^{a}\pm0.0$	$28.0^{a}\pm2.5$	$34.8^{a}\pm12.8$	$59.4^{a}\pm14.8$
16	$17.8^{a}\pm0.0$	$23.7^{a}\pm11.4$	$34.8^{a}\pm3.8$	$42.4^{b}\pm2.9$

a,b,c,d,e and f are the variables used for comparison of means in least significant difference (LSD)

Table C.8. Changes in FAV stored at 40°C (n=3)

Storage period (wk)	Moisture content (% Wet basis)			
	10.0	12.5	15.0	17.5
0	$13.2^{d}\pm0.2$	$13.2^{g}\pm0.2$	$13.2^{e}\pm0.2$	$13.2^{e}\pm0.2$
2	$18.6^{bc}\pm2.9$	$16.4^{f}\pm1.4$	$17.8^{d}\pm0.0$	$26.3^{d}\pm1.4$
4	$17.8^{bc}\pm0.0$	$20.3^{e}\pm0.0$	$24.6^{c}\pm1.4$	$56.0^{a}\pm2.5$
6	$16.9^{bd}\pm1.4$	$21.2^{de}\pm1.4$	$24.6^{c}\pm1.4$	$55.1^{a}\pm5.3$
8	$16.1^{cd}\pm1.4$	$22.9^{d}\pm0.0$	$26.3^{c}\pm1.4$	$54.3^{a}\pm1.4$
10	$17.8^{bc}\pm0.0$	$25.4^{c}\pm0.0$	$30.5^{b}\pm0.0$	$47.5^{b}\pm1.4$
12	$20.3^{bc}\pm0.0$	$25.4^{c}\pm0.0$	$30.5^{b}\pm0.0$	$49.2^{b}\pm1.4$
14	$27.1^{a}\pm1.4$	$36.5^{a}\pm2.9$	$40.7^{a}\pm0.0$	$53.4^{a}\pm2.5$
16	$21.2^{b}\pm6.4$	$33.9^{b}\pm1.4$	$40.7^{a}\pm2.5$	$40.7^{c}\pm0.0$

a,b,c,d,e and f are the variables used for comparison of means in least significant difference (LSD)

APPENDIX C: Invisible mold data

Table D.1. Invisible mold of rye sample stored at 10°C

Storage period (wk)	Moisture content	Replicate	Percent of seeds infected by										
			A.candidus	*A.glaucus*	*A.ochraceous*	*A.wentii*	*Actinomycetes*	*Penicillium*	*Alternaria*	Bacteria	*Fusarium*	*Versicolor*	*A.niger*
4	10.0	a	10	20	6			36	48	3			
		b	4	6	10			48	30				
		c	6	18	14			40	48	2			
	12.5	a	10	10	10			40	24	4			
		b	12	16	4			38	12				
		c	6	10	4			22	10				
	15.0	a	4	14	10			32	18				
		b	6	10	14			36	12	2			
		c	4	8	8			46	4				
	17.5	a	8	4	10			28	4				
		b	2	2	6			12		2			
		c	0	6	6			14	4	1			

Storage period (wk)	Moisture content	Replicate	Percent of seeds infected by										
			A.candidus	*A.glaucus*	*A.ochraceous*	*A.wentii*	*Actinomycetes*	*Penicillium*	*Alternaria*	Bacteria	*Fusarium*	*Versicolor*	*A.niger*
8	10.0	a		16				10	20	4			
		b	4	16	4			36	12				4
		c	8	12				22	8	2			
	12.5	a	2	12				20	24	2	4		
		b		20				32	12				
		c	6	24	4			20	20	6			
	15.0	a	12	30	4			40	12				
		b	20	20				36	8		2		
		c	30	35	4			40	16				
	17.5	a	48	4	2			80	8				
		b	50		4			66		2			8
		c	52	2				80	4				

Storage period (wk)	Moisture content	Replicate	Percent of seeds infected by										
			A.candidus	*A.glaucus*	*A.ochraceous*	*A.wentii*	*Actinomycetes*	*Penicillium*	*Alternaria*	Bacteria	*Fusarium*	*Versicolor*	*A.niger*
12	10.0	a	16	16				40	24		4		
		b	12	20				16	20		4	2	
		c	8	12				12	24	2			
	12.5	a	8	16	8			16	20	4			
		b	4	16			2	36	2	4			2
		c	10	8				12	28				
	15.0	a	6	2	8		2	36	8				
		b	12	12				20	24				
		c	4	16	4			16	4	2		4	
	17.5	a	8	28			8	4	4				
		b	2	42	4			8	24				
		c	8	36				4	12	4	4		

Storage period (wk)	Moisture content	Replicate	Percent of seeds infected by										
			A.candidus	*A.glaucus*	*A.ochraceous*	*A.wentii*	*Actinomycetes*	*Penicillium*	*Alternaria*	Bacteria	*Fusarium*	*Versicolor*	*A.niger*
16	10.0	a	22	8			4	36					
		b	16	16	4			32	14	2			
		c	30	16			2	40	8	8			1
	12.5	a	42	8			4	48	4				
		b	32	16				36	4	8			
		c	36	18	8			60	8	4			
	15.0	a	26	32				28	12	4			
		b	12	36				32	8	2	1		1
		c	20	24				28	8		2		
	17.5	a	16	14	8			48	8				
		b	32	18				40	8				
		c	20	28				16	4	4			1

Table D.2. Invisible mould of rye sample stored at 20°C

Storage period (wk)	Moisture content	Replicate	Percent of seeds infected by										
			A.candidus	*A.glaucus*	*A.ochraceous*	*A.wentii*	*Actinomycetes*	*Penicillium*	*Alternaria*	Bacteria	*Fusarium*	*Versicolor*	*A.niger*
4	10.0	a	40	16	8		4	34	12				4
		b	44	24				40	4		4		
		c	38	14			2	28					
	12.5	a	30	12				36	4				
		b	40	24	4		2	44	4	8			4
		c	24	16				48	16		12		
	15.0	a	24	30				36	22		16		
		b	20	40			2	22	8	2	4	2	
		c	16	36				46	12		8		
	17.5	a	24	18				6	4		4		
		b	40	28				20	8		8		
		c	4	32	2			8	12				

Storage period (wk)	Moisture content	Replicate	Percent of seeds infected by										
			A.candidus	*A.glaucus*	*A.ochraceous*	*A.wentii*	*Actinomycetes*	*Penicillium*	*Alternaria*	Bacteria	*Fusarium*	*Versicolor*	*A.niger*
8	10.0	a	16	32				20	4				
		b		16				52	8	4	12	4	4
		c		32				40	12			8	
	12.5	a	16	32				36	4			8	
		b	16	28				16	16	4	8		
		c	12	32				12	8		8		
	15.0	a	24	84				8	8				
		b	12	60	8			16	8		12		
		c	16	64	4			28	16		12		
	17.5	a	16	40				40			4		
		b	20	52				28					
		c	16	40				12		8			

Storage period (wk)	Moisture content	Replicate	Percent of seeds infected by										
			A.candidus	*A.glaucus*	*A.ochraceous*	*A.wentii*	*Actinomycetes*	*Penicillium*	*Alternaria*	Bacteria	*Fusarium*	*A.versicolor*	*A.niger*
12	10.0	a	4	20				12					
		b		20	4			8	4				
		c	24	16				12	4				
	12.5	a	4	8				16					
		b	4	12	8			12	12				
		c	16	8	4			16	8		4		
	15.0	a	12	22	8			16					
		b		16			8	24	4				
		c		24	4			36	4	4			
	17.5	a	8	44				40					
		b	8	28				28	8	4			
		c	4	36	12			32	2		8		

Storage period (wk)	Moisture content	Replicate	Percent of seeds infected by										
			A.candidus	*A.glaucus*	*A.ochraceous*	*A.wentii*	*Actinomycetes*	*Penicillium*	*Alternaria*	Bacteria	*Fusarium*	*A.versicolor*	*A.niger*
16	10.0	a	12	12				12					
		b	16	20				8					
		c	12	12	8			12					
	12.5	a	4	12	4			8		8			
		b	8	24	8			16		4			
		c	12	10	12			4					
	15.0	a	12	32	4			16					
		b	20	36				20					
		c	20	24				28		8			
	17.5	a	18	40	4			36					
		b	14	36	8			28		4			
		c	8	50	8			20		8			

Table D.3. Invisible mould of rye stored at 30°C

Storage period (wk)	Moisture content	Replicate	Percent of seeds infected by										
			A.candidus	*A.glaucus*	*A.ochraceous*	*A.wentii*	*Actinomycetes*	*Penicillium*	*Alternaria*	Bacteria	*Fusarium*	*A.versicolor*	*A.niger*
4	10.0	a	12	28	4			12		2	4		
		b	8	20	4			24	2				
		c	12	16				12	2	2			
	12.5	a	12	36	4			8					2
		b		8						4			
		c		4			4						
	15.0	a	26	40			4	24	8				8
		b	20	36			4	32		2			
		c	34	36	20			42	8				8
	17.5	a	24	28	20			36					
		b	10	16	4		8	42					
		c	12	12	16			38					

Storage period (wk)	Moisture content	Replicate	Percent of seeds infected by										
			A.candidus	*A.glaucus*	*A.ochraceous*	*A.wentii*	*Actinomycetes*	*Penicillium*	*Alternaria*	Bacteria	*Fusarium*	*A.versicolor*	*A.niger*
8	10.0	a	4	22	4			12		8			
		b	8	16				8		4			
		c		18	8			10		8		2	
	12.5	a	12	16				20	4				
		b	8	36			8	18					4
		c	12	30	8		4	24		4			
	15.0	a	8	24			4	22		8			
		b	12	20	4			24			2		
		c	10	28				26	4				
	17.5	a	32	16			4	36				2	
		b	26	12				36		8			
		c	18	16				22	8				

Storage period (wk)	Moisture content	Replicate	Percent of seeds infected by										
			A.candidus	*A.glaucus*	*A.ochraceous*	*A.wentii*	*Actinomycetes*	*Penicillium*	*Alternaria*	Bacteria	*Fusarium*	*A.versicolor*	*A.niger*
12	10.0	a	12	12				40					8
		b	16	16			4	36	8		2		
		c	16	4			4	36					
	12.5	a	20	8	4			40		4			
		b	28	4				66					8
		c	4					54		12			
	15.0	a	32					50					
		b	48	12				46	4				
		c	44	8	4			20					
	17.5	a	34	8				32					
		b	24	4	4			20					
		c	22				4	32			2		

Storage period (wk)	Moisture content	Replicate	Percent of seeds infected by										
			A.candidus	*A.glaucus*	*A.ochraceous*	*A.wentii*	*Actinomycetes*	*Penicillium*	*Alternaria*	Bacteria	*Fusarium*	*A.versicolor*	*A.niger*
16	10.0	a	8	16	4			12					
		b	4	12	8		8	20		8			
		c	12	20				12	4				
	12.5	a	4	16				8		4	4		
		b	8	12	8			12	8				
		c		8				16		4			
	15.0	a	12	20	8		8	16					
		b	4	36			4	32			2		
		c		24	4			36					
	17.5	a		48				36					
		b	8	58				28		4			
		c	8	66			4	32	4				

Table D.4. Invisible mould of rye sample stored at 40°C

Storage period (wk)	Moisture content	Replicate	Percent of seeds infected by										
			A.candidus	*A.glaucus*	*A.ochraceous*	*A.wentii*	*Actinomycetes*	*Penicillium*	*Alternaria*	Bacteria	*Fusarium*	*A.versicolor*	*A.niger*
4	10.0	a	16	16	4		4	6					
		b	10	12			4	14		8			
		c	6	20					4				
	12.5	a	12	16				16		4	4		
		b	20	22	8			10	8		8		
		c	14	8	4			8					
	15.0	a	18	18	8			12					
		b	20	16				8			4		
		c	8	10	4			10		4			
	17.5	a	12	24				10					
		b	16	18			8	8		4			
		c	10	26			12	16	4				

Storage period (wk)	Moisture content	Replicate	Percent of seeds infected by										
			A.candidus	*A.glaucus*	*A.ochraceous*	*A.wentii*	*Actinomycetes*	*Penicillium*	*Alternaria*	Bacteria	*Fusarium*	*A.versicolor*	*A.niger*
8	10.0	a	28	24	8			32	12	2			
		b	24	20				22		4			
		c	26	44				20	4		8		
	12.5	a	16	40	8			12	4	4			
		b	20	36	4			14		4			
		c	20	24	4			10					
	15.0	a	22	36				28		4			
		b	14	36				24					
		c	14	32	8			32		8			
	17.5	a	32	36				22		8	4		
		b	28	28				12		2			
		c	24	20	8			30					

Storage period (wk)	Moisture content	Replicate	Percent of seeds infected by										
			A.candidus	*A.glaucus*	*A.ochraceous*	*A.wentii*	*Actinomycetes*	*Penicillium*	*Alternaria*	Bacteria	*Fusarium*	*A.versicolor*	*A.niger*
12	10.0	a	36	24				4					
		b	28	28				10		4			
		c	24	32				8					
	12.5	a	28	24				16		8			
		b	20	32				2					
		c	8	44				6					
	15.0	a	40	30				8					
		b	36	26	12			4					
		c	20	42				16					
	17.5	a	28	30	4			12					
		b	32	42				6					
		c	36	38	4			8					

Storage period (wk)	Moisture content	Replicate	Percent of seeds infected by										
			A.candidus	*A.glaucus*	*A.ochraceous*	*A.wentii*	*Actinomycetes*	*Penicillium*	*Alternaria*	Bacteria	*Fusarium*	*A.versicolor*	*A.niger*
16	10.0	a	44	24				14					
		b	28	28				10		4			
		c	32	32				8					
	12.5	a	20	24				6		8			
		b	20	32				12					
		c	8	44				6					
	15.0	a	44	8				8					
		b	40	16	12			4					
		c	20	12				6					
	17.5	a	32	40	4			2					
		b	32	32				6					
		c	44	20	4			18					