# VIGOUR LOSS OF WHEAT SEED CAUSED BY THRESHING

BY

LUC BOURGEOIS

A Thesis
Submitted to the Faculty of Graduate Studies
in partial Fulfilment of the Requirements
for the Degree of

Master of Science

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# VIGOUR LOSS OF WHEAT SEED CAUSED BY THRESHING

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A Thesis submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements of the degree of

MASTER OF SCIENCE

## ABSTRACT

Bourgeois, Luc, M.Sc. University of Manitoba, January 1993.

VIGOUR LOSS OF WHEAT SEED CAUSED BY THRESHING.

Supervisor: Dr. E.H. Stobbe, Department of Plant Science.

Improper handling of seed during harvesting may result in severe seed vigour loss. The objective of this study was to determine the effect of threshing on wheat seed vigour. A conventional combine and an axial flow rotary combine (single rotor) were used at three cylinder speeds. In 1991, some samples were threshed with a belt thresher to provide damage-free samples. Additional studies were conducted to determine the effect of kernel water content (KWC) at harvest and kernel characteristics on threshing damage. The proportion of visually damaged seeds was assessed for all samples and subsequent tests were conducted using visually sound seed. Seed vigour was reduced when wheat was threshed at a high cylinder speed. Wheat kernels threshed with the rotary combine was less damaged than wheat kernels threshed with the conventional combine. Both field emergence and yield were reduced in plots planted with kernels threshed at a high cylinder speed compared to kernels threshed at a low cylinder speed. Vigour of sound wheat kernels was negatively correlated with the number of broken kernels in samples threshed at a low KWC (12-16%). However, seed harvested at a high KWC (over 17%) had few visually broken seeds but lower vigour compared to seed threshed at a low KWC. Threshing at high kernel water content resulted in more internal damage in seeds than threshing between 13 and 16% KWC. There was a negative correlation between seed vigour and seed length and a positive correlation between seed vigour and circularity factor of the seed. The seed vigour of durum wheat was severely reduced by conventional combine threshing. Durum wheat seed lots threshed with the conventional combine produced fewer normal seedlings, fewer seedlings in the field and 300 kg $ha^{-1}$ less yield than seed lots threshed with the belt thresher. To maintain high vigour in wheat seed, it is essential to thresh at low cylinder speed and low kernel water content, particularly for long seeded wheat such as durum wheat.

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# 1. General Introduction

Low vigour wheat seed lots are responsible for significant yield loss in the Canadian Prairies by the establishment of uneven crops. Seed vigour is lost from the time of maturity on the seed parental plants to the time of planting the seed. Single or multiple factors can be responsible for seed vigour loss. Vigour can be assessed by several laboratory vigour tests such as the cold germination test or the conductivity test.

Seeds are subjected to great impact forces during threshing with commercial combines. Individual seeds have variable resistance to impact forces. Germplasm, kernel water content (KWC) and seed size contribute to the variation of resistance of seed to impact forces.

The greatest impact forces during threshing occur in the drum (concave and cylinder) of combines. Different drum design may vary in grain separation efficiency and in damaged caused to kernels.

The objectives of this research were: to determine the effect of increasing cylinder speed on seed vigour with rotary and conventional combines; to compare threshing efficiency and seed quality obtained with the two combines; to determine the effect of KWC at harvest on seed vigour loss; to compare the response of different wheat cultivars between belt threshed samples and conventional combined samples; and to compare laboratory vigour tests with field performances of all seed lots produced in this study.

Besides contributing to an understanding of seed vigour loss caused by threshing, this research will also contribute to our ability to make intelligent recommendations regarding the harvest of high vigour seed.

# 2. Review of literature

## 2.1. Viability and vigour of seed

Viable seed refers to "seed that contain structures and substances including enzyme systems that give it the capacity to germinate under favourable conditions in the absence of dormancy" (Copeland and McDonald, 1985). Differences in field emergence and yield among several seed lots of high viability have underlined weaknesses in using seed viability as a sole seed quality factor (Ayre, 1980; Sonntag, 1989; Empey, 1992).

As early as 1876, Nobbe identified variation of strength and health of germinated seeds within seed lots of a similar cultivar, and introduced the concept of "shooting strength" (Copeland and McDonald, 1985). However, it is only in the last few decades that Nobbe's concept gained interest. In 1977, a joint committee of the Association of Official Seed Analysts (AOSA) and the International Seed Testing Association agreed on a common definition of seed vigour: "seed vigour is the sum total of those properties of the seed which determines the potential level of activity and performance of the seed or seed lot during germination and seedling emergence" (*In* McDonald, 1980). This definition of seed vigour was refined in 1979 as follows: "seed vigour comprise those seed properties which determine the potential for rapid uniform emergence and development of normal seedlings under a wide range of environment conditions" (*In* McDonald, 1980). This definition of seed vigour integrates the "environment factor." Field- and weather-conditions are seldom ideal. High vigour seed does better than low vigour seed in cool soils (Tekrony et al., 1989; Ayre, 1980) or dry seedbed (Naylor and Gurmu, 1990). High vigour seed ensures adequate plant populations across a wide range of field conditions encountered during emergence (Tekrony and Egli, 1991).

### 2.1.1. Relationship between seed vigour and viability

A nonviable seed is the ultimate consequence of seed degradation, whereas, the loss of vigour is an intermediate stage of seed degradation (Delouche and Caldwell, 1960). Seed degradation is an inexorable and irreversible process, all living things must eventually deteriorate and die.

Delouche and Caldwell (1960) graphed the percentage of germinated seed versus the increasing deterioration to show the loss of viability and vigour in a seed lot (Figure 2.1). They not only demonstrated that seed vigour precedes a loss in viability but they also provided an explanation for vigour differences between two seed lots of identical viability; seed lots of high viability (X and Y) may have high vigour (X) or low vigour (Y).

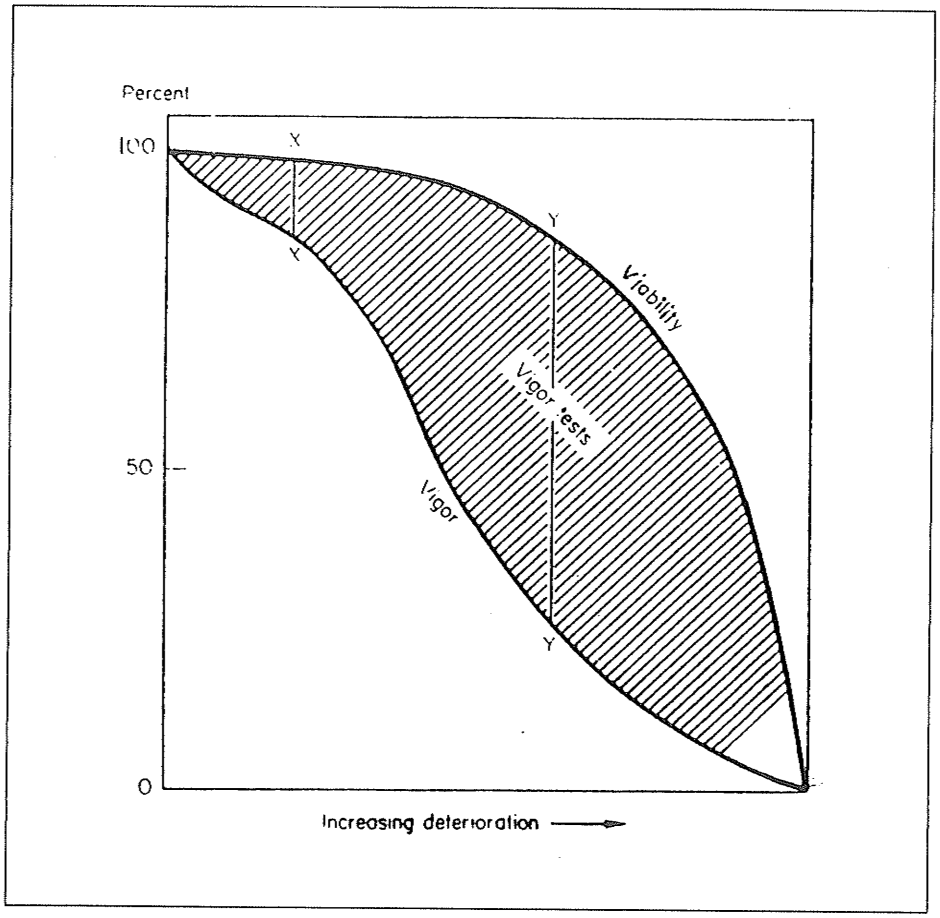


**Figure 2.1.** Relationship of seed viability and vigour during seed deterioration (Delouche and Caldwell, 1960)

Seeds at physiological maturity produced from an unstressed mother plant have maximum vigour (Seshu et al., 1988; Roberts and Osei-Bonsu, 1990). The maintenance of high vigour seed depends on the level of degradation of the seed entering storage and the storage environment (Copeland and McDonald, 1985). Livesley and Bray (1991) concluded that lesions arising in the aleurone layer of aged seeds may have a significant role to play in loss of seed viability during storage. Seed vigour, and thereby storage time, is reduced when seed is subjected to stresses prior to storage. Pre storage stresses may be due to field weathering and threshing damage. Severe field weathering on wheat and barley was shown to decrease seed germination in a cold germination test (Wytinck, 1991). Grosh and Milner (1959) demonstrated that weathering was responsible for stress-cracking in wheat seeds; a moisture gradient in the seed during wetting and drying cycles creates enough pressure to rupture the aleurone layer and the testa of the seed. Such cracks are barely visible, though they make the endosperm and embryo vulnerable to fungi's infection (Caldwell and Davies, 1957). Physical damages, through threshing and handling, result in seed coat cracking and also embryo bruising. Bruised embryos develop into abnormal seedlings (Spreafico, 1965) or become vulnerable to fungi's infections (Caldwell and Davies, 1957) or insect pests (Tuff and Telford, 1964; Fleming, 1988).

Poor environmental conditions -- drought, nutrient deficiencies and low temperatures -- during the growth of the seed mother plants, can result in poor seed vigour production (Seshu et al., 1988). Other stress caused by diseases or insects also lead to the production of low vigour seed.

Seed degradation can be hastened by poor storage environment; a cool and dry environment is recommended for long storage of high vigour seed (Copeland and McDonald 1985).

## 2.1.2. Changes in seed during deterioration

Physiological disfunction in seed is responsible for a reduction of seed vigour. An understanding of the relation among physiological disfunctions and seed vigour may provide tools to determine seed vigour loss.

Cell membrane loses integrity in aging seed (Abdul-Baki, 1980). Such a disfunction leads to a loss of nutrients for the embryo and provides a pathway for harmful microorganisms (Matthews, 1981).

Van de Venter and Grabe (1989) found that low vigour seed had low oxygen uptake. A reduction in the number of living cells is thought to be associated with a reduction in oxygen uptake. However, oxygen uptake measurement may be impaired by external factors such as micro-organism activity, temperature and water availability (Abdul-Baki, 1980).

Alpha-amylase is the enzyme required for the break down of storage food reserves (starch) into sugar readily usable by the embryo. Water uptake activates this enzyme. Severe field weathering prior to harvest is responsible for high alpha-amylase content in seeds although Livesley and Bray (1991) found that alpha-amylase content was not related to seed vigour. Hampton and Coolbear (1990) suggest that the measurement of enzyme production capacity would be a better vigour indicator than the measurement of enzyme content in the seeds.

Several physiological functions in plants depend on the presence of hormones. Germination was negatively related to abscisic acid (ABA) levels (Abdul-Baki, 1980). It is not yet determined if ABA has a direct role in embryo growth or if ABA is blocking essential biochemical pathways for germination.

Low seed vigour was often related to the presence of seedling abnormalities (Spreafico, 1965; Roberts and Osei-Bonsu, 1990). Abnormal seedlings may have missing parts such as seminal roots or coleoptile. Abnormal seedlings may also have a slow growth and development (Ayre, 1980; Tekrony et al., 1989). Seedling abnormalities may result from hormonal and physiological disfunctions (Livesley and Bray, 1991) but may also be related to internal mechanical damage (Spreafico, 1965).

Physiological disfunctions and seedling abnormalities occur gradually leading to a gradual decrease in seed vigour (Hampton and Coolbear, 1990). However, physiological disfunctions may be independent from each other. For example, although seed threshed at high kernel water content (KWC) had low nutrient leachate, it performed poorly in the cold germination test (Entz et al., 1991). Therefore, seed vigour assessment based on a single physiological function measurement may be misleading. Several authors recommend the use of at least two seed vigour tests for assessing the vigour of a seed lot (Johnson and Wax, 1978; Hampton and Coolbear, 1990; Steiner et al., 1989)

### 2.1.3. Measurement of seed vigour using laboratory tests

An ideal vigour test should be: 1. inexpensive, 2. rapid, 3. uncomplicated, 4. objective, 5. reproducible, and 6. correlated with field performance (McDonald, 1980).

The standard germination test, as described in the AOSA seed vigour handbook, is the internationally accepted seed viability test (AOSA, 1983). Report of the percentage of abnormal seedling in the standard germination test may provide some indication on seed vigour (Hampton and Coolbear, 1990). However, it is generally accepted that the standard germination test overestimates seed vigour (Oliveira et al., 1984; Tekrony and Egli, 1991).

Seedling growth tests indirectly measure synthesis efficiency of growing plants (Hall and Wiesner, 1990; Steiner, 1990). Unfortunately slight variation in environmental factors, such as moisture or light, can lead to major variation in growth rates (McDonald, 1980).

Germination potential of seed under a stressful environment is assessed with stress tests (AOSA, 1983). The most common stress test is the cold germination test, where low temperature during germination is used to stress seeds. Fungal pathogen or acid can also be used. These stress tests are time- and labor-consuming (AOSA, 1983).

Artificially aging seed may hasten deterioration processes that occur in seeds (AOSA, 1983). Seeds aged by using high hygrometry and high temperatures, are germinated in a standard- or cold-germination test. The artificial aging test is also time- and labour-consuming (AOSA, 1983).

Biochemical tests measure activity in seed that ensure growth and development of the embryo upon hydration (Abdul-Baki, 1980). The most reliable biochemical tests are the tetrazolium (TZ) and the conductivity tests (Hampton and Coolbear, 1990). The TZ test provides an assessment of the reducing capacity of the tissue by dehydrogenase enzymes (McDonald, 1980); the hydrogen ions released by the reaction reduce the tetrazolium salt to a red pigment. The TZ test can be used to assess viability (presence of pigment or not) or vigour (intensity of pigment) (AOSA, 1983). The electrical conductivity test measures the nutrient leakage from the seed (AOSA, 1983). This test gives an indirect measurement of membrane integrity of the seed.

Other biochemical tests measure seed respiration (Van de Venter and Grabe, 1989), ATP content (Hampton and Coolbear, 1990) and alpha-amylase activity (Livesley and Bray, 1991). Such tests require expensive laboratory equipment. Results of these tests may be misleading since microorganisms, pre harvest stresses and storage conditions may affect biochemical activity of a seed lot (Abdul-Baki, 1980).

Pre harvest stresses may induce dormancy in seed. A common characteristic between a dormant and a low vigour seed is germination failure. Studies have shown similar biochemical responses in dormant and low vigour seed (Woodstock, 1973). However, it is generally accepted that dormancy is reversible, whereas, seed vigour is not. Therefore, it is recommended that vigour tests are conducted several times after harvest, to monitor any relief in dormancy.

### 2.1.4. Field performance of low vigour seed

Vigourous seeds have high emergence compared to low vigour seeds especially under stressful field conditions (Matthews, 1981). Tekrony et al. (1989) found that high vigour corn seed had a consistently higher emergence rate than medium- and low-vigour seed, across a range of different tillage systems. In two years out of three, low vigour seed did not achieve acceptable emergence under zero-tillage, whereas, high vigour seed always produced an acceptable stand.

Ayre (1980) studied the effect of seed vigour on winter wheat establishment. Plots sown with low vigour seed had uneven emergence and averaged 146 plants $m^{-2}$, whereas, high vigour seed gave a uniform stand with 257 plants $m^{-2}$. A poor wheat stand or a non uniform stand does not utilize the field resources as well as an optimum stand and may provide space for weed development (Tekrony and Egli, 1991).

Yield compensation by tillering or by increased kernel number per spike can reduce yield difference among seed lots. Ayre (1980) showed a difference of only 10% in ear number and grain yield following a 44% difference in stand between high- and low-vigour winter wheat. Some studies demonstrated the negative effect of seed vigour on field emergence but failed to demonstrate similar effect on yield (Ngoma, 1992; Tekrony and Egli, 1991)

Ayre (1980) also noticed a slow development of winter wheat grown from low vigour seed. Development of the spikelet from the growing point was faster for seedling grown from high vigour seed compared to low vigour seed and this lag was noticed until anthesis.

In conclusion, while high seed vigour may not always increase yield (Tekrony and Egli, 1991), it will increase the probability of high yields when compared to low vigour seed (Graven and Carter, 1991).

## 2.2. Vigour losses caused during harvest

### 2.2.1. Impact damages in combine harvesters

Pierce and Hanna (1985) measured corn kernel damage during different phases of on-farm handling procedures (Table 2.1.). Damage occurred primarily during threshing operation, followed by conveying damage, pre harvest damage and drying damage.

**Table 2.1.** Amount of corn damage resulting from the various harvest and post harvest operations (modified from Pierce and Hanna, 1985)

| Damage indicator | Moisture content | Total damage associated with: Pre harvest | Harvesting | Drying | Conveying |
|---|---|---|---|---|---|
| | | ........................ % ...................... | | | |
| Severe† | 19 | 15 | 63 | 2 | 20 |
| | 24 | 7 | 79 | 3 | 11 |
| Minor‡ | 19 | 9 | 56 | 2 | 33 |
| | 24 | 7 | 42 | 0 | 51 |

† Severe damage: kernels obviously broken, missing pieces of endosperm, or with deep pericarp splits.
‡ Minor damage: sound kernels except for pericarp chips or cracks.

Tuff and Telford (1964) observed that almost 50% of wheat kernels threshed by combine were fractured compared to 1% in hand threshed samples. Such damage in combine threshed wheat was sufficient to increase the grain vulnerability to storage insects. Caldwell and Davies (1957) observed that cracks in wheat seeds also increased occurrence of fungal infection that impeded seedling development.

Mechanical damage to grain during threshing was widely studied for large seeded pulse crops (Evans et al., 1990; King and Riddolls, 1960; King and Riddolls, 1962). Soybean, field beans and peas lose commercial quality as well as seed vigour when seeds split during threshing.

"Hard to thresh" crops, such as corn or flax, require high velocity impacts to separate grain from the stalk causing severe kernel damage (Machacek and Brown, 1945; Hall and Johnson, 1970).

Straw acts as a cushion to protect kernels from direct impacts and to reduce seed damage (Vas and Harrison, 1969; Bilanski, 1966).

Damage severity of seed under impact forces varies with kernel mechanical resistance (Mitchell and Roundthwaite, 1964). Fissures in a kernel caused by KWC gradient (stress cracking) reduce the kernel resistance to impact forces (Mohsenin, 1986). Hard kernels have a high protein content and small starch granules that confer a glassy characteristic to seeds (Bennett, 1950). Hard kernels can resist deformation but are more brittle than soft kernels and are more subject to visual damage (Mohsenin, 1986). Kolowca and Slipek (1978) have found a strong relationship between kernel breakage and glassiness among several cultivars of durum wheat.

### 2.2.2. Kernel water content at harvest

Kernel water content affects three mechanical properties of kernels: brittleness, plasticity and elasticity (Zoerb and Hall, 1960). Brittleness is highest at low KWC, whereas, plasticity increases with KWC (Bilanski, 1966). An Impact force applied on a brittle seed results in cracking and splitting, whereas, a similar force applied on a plastic seed results in squashing and shearing (Zoerb and Hall, 1960; Mitchell and Roundthwaite, 1964; Harrison, 1975). Elasticity is intermediate between brittleness and plasticity, improving the resistance of kernels to visual damage (Jindal et al., 1979). A material that is perfectly elastic is characterized by a small hysteresis loss (Zoerb and Hall, 1960). Hysteresis is energy dissipated as heat and defined as the difference between the work of compression and the work of retraction (Mohsenin, 1986).

The elasticity behaviour of seeds can only provide a limited degree of protection from physical damage. Moisture is rarely uniform throughout the kernel (Mohsenin, 1986). In this case, part of a kernel may be brittle, whereas, another part may be elastic. Under this condition, internal or non-visual damage may occur.

Kernel water content can vary greatly from kernel to kernel. Therefore, a seed lot may contain individual seed with variable resistance to impact forces (Mohsenin, 1986).

Elastic behaviour of a seed may hide physiological damage occurring inside the kernel. The location of the impact on the seed can result in severe physiological disturbance. Evans et al. (1990) showed that an impact velocity of 30 m $s^{-1}$ to soybean hypocotyl resulted in at least 60% less germinated seed compared with a similar impact anywhere else on the seed. Damage in the vicinity of the wheat embryo significantly reduced germination compared with seed damaged on the opposite side of the embryo (Table 2.2.) (Kolganov, 1958; Mlodzianowska et al., 1982; Moes et al., 1991 unpublished data).

**Table 2.2.** Loss of germination under favourable conditions due to the nature of damage to the wheat kernel (modified from Kolganov, 1958)

| Nature of Damage | Germination (%) |
|---|---|
| Whole grains (control) | 98 |
| Skin cracks in vicinity of embryo | 69 |
| Skin over embryo torn off | 57 |
| Embryo damaged | 44 |

Kernel water content influences seed separation from the material other than grain. Crop with a high KWC requires more energy to separate grain from the material other than grain. The rotor power of an axial flow rotary combine required to thresh barley was 33.6 and 55.5 kW at 10 and 18% KWC, respectively (Harrison, 1991). Threshing at high KWC (over 20%) enhances the chance of plugging the combine, increases grain loss and reduces germination of the harvested seed (Johnson, 1959).

### 2.2.3. Interaction between cylinder speed, KWC and seed vigour

It is generally accepted that most of the seed damage occurs in the combine drum (concave and cylinder system). Chowdhury and Buchele (1978) found that the degree of visual damage and seed vigour were improved if seed would escape quickly out of the drum. It is the unnecessary beating of shelled kernels that causes damage (Chowdhury and Buchele, 1978). Vas and Harrison (1969) found that high cylinder speed and small concave clearance resulted in increased threshing efficiency and increased mechanical damage. They concluded that combine operators should consider kernel damage as well as threshing efficiency in adjusting their combines. Results from studies by King and Riddolls (1960 and 1962) indicate that wheat harvested at a high cylinder speed had lower seed germination. Small concave clearance in these studies improved threshing efficiency without affecting seed germination.

Entz et al. (1991) showed that seed harvested at high cylinder speed had lower vigour when threshed at 22.5 compared to 10% KWC. The low vigour was observed by a decrease of germination using the cold germination test. By comparison, leachate conductivity increased as the KWC at harvest decreased (at a similar cylinder speed). The conductivity test overestimated the vigour of the seed lot threshed at high KWC. Therefore, pericarp damage was not responsible for the loss of vigour. Entz et al. (1991) concluded that "seed threshed at high KWC were deformed but not broken resulting in a loss of cold germinated vigour, while seeds of low KWC tended to break on impact and were therefore not included in the vigour test".

King and Riddolls (1962) found less visual damage in wheat threshed at high KWC compared to low KWC. They also observed that seed lots harvested at high cylinder speed had a reduction in germination. Wastage, which includes seeds with visual damage and seed with germination failure, was the greatest for samples threshed at high KWC and high cylinder speed.

Mitchell (1955) also found that seed germination was negatively affected by a combination of high cylinder speed and high KWC. Under the conditions of studies by Mitchell (1955), a strong relationship between broken seed number and seed vigour was established for samples threshed at a common KWC. However, no such relationship was found among samples threshed at different KWC.

A survey conducted by Arnold and Jones (1963) showed that there was considerable variation in the cylinder speed used in combine harvesters by English farmers. Several operators used an unnecessarily high cylinder speed, which resulted in severe visual damage and a low germination percentage.

## 2.2.4. Combine types versus seed quality

Separation systems have been developed to improve combine capacity, quality of grain, and performance of combines in various crops and under various crop conditions (Garbers, 1986). Combines with the tangential threshing drum are most widely used and are referred to as conventional combines (Wrubleski and Smith, 1980). Crop is fed tangentially into a cross mounted cylinder concave assembly (Renaud, 1984). Separation occurs mostly by impact of the cylinder on the crop, while grain escapes through the open grate concave. A shaking straw walker separates the remaining grain from the straw. Drum width and diameter, as well as the size of the straw walker, vary among conventional combine makes and models (Garbers, 1986). Differences in drum design among conventional combines can lead to difference in kernel breakage during threshing (Renaud, 1984).

Conventional type combines have been modified by replacing the straw walker by several drums, for example, the Claas CS system has eight drums (Garbers, 1986). In the Claas CS combine, separation was improved for corn threshed at KWC above 20%, but there was increased kernel damage at KWC below 20% compared to a single cylinder conventional combine (Racop et al., 1984). The Claas CS system requires more energy and its construction is complex compared with conventional type combines (Garbers, 1986).

A two drum combine was also reported by Kolganow (1958). The cylinder speed increases while the concave clearance decreases from the first to the second drum. Therefore, easily threshed seeds are separated in the first drum and increasing friction forces in the second drum threshed out the remaining seeds. Kolganow showed that seeds recovered from the first drum germinated better than seeds recovered from the second drum. Unfortunately, seeds threshed from both drums were mixed in a single hopper that reduced the overall quality of the seed lot.

The axial flow rotary combine has one or two longitudinally mounted rotor(s) (Renaud, 1984). Threshing and grain separation takes place along the full rotor(s) length. Concave sieves around the rotor(s) allow threshed seeds to escape from the beating rotor(s).

Neither users nor manufacturers are convinced of the benefit of switching from a conventional combine to a rotary combine (Garbers, 1986). They argue that rotary combines require more energy, have complex construction, shred straw (rendering it unusable) and have difficulties threshing in tough conditions (plugging). Wrubleski and Smith (1980) found that wheat threshing efficiency was improved at high feed rate with the rotor system compared to the conventional system. They suggested that this improvement is the result of a fast grain separation due to a larger concave area compared to the conventional combine.

In corn, Paulsen and Nave (1980) found no difference in threshing efficiency between a single rotor axial flow, a double rotor axial flow and a conventional combine among several KWC and cylinder speeds. They did, however, notice breakage differences among the three combines; the single rotor axial flow had the lowest proportion of broken kernel followed in order by the conventional combine and the double rotor axial flow combine.

A recent study by Harrison (1992) determined the kernel damage for barley in a single rotor axial flow combine, as affected by the feed rate and KWC of the crop, the rotor speed and concave clearance of the combine. This study concluded that kernel damage was a negatively correlated to feed rate and KWC of the crop, but positively correlated to rotor speed. Concave clearance had no effect on kernel damage.

# 3. Vigour loss of wheat seed caused by threshing: I. Seed damage and vigour studies

## 3.1. Introduction

There is compelling evidence that mechanical threshing damage induces loss of seed vigour. Threshing wheat using high combine cylinder speed was the chief factor in inducing loss of vigour, as shown by a reduction of normal seedlings in germination tests (Mitchell, 1955; Mitchell and Roundthwaite, 1964). Visually damaged wheat seeds were associated with the use of high cylinder speeds and to a lesser extent with small concave clearance (King and Riddolls, 1960). However, several authors have underlined that threshing efficiency (proportion of grain recovered from spikes) was greatly improved by increasing the cylinder speed (Harrison, 1992; Vas and Harrison, 1969; Wrubleski and Smith, 1980)

The type of combine used is another factor that might influence seed damage during threshing. Two major types of combines are available, the conventional type with a transverse cylinder, in which material flow is tangential to the cylinder, and the axial flow rotary type, in which material flow is parallel to the axis of the cylinder. The axial flow rotary combine is hereafter referred to as rotary combine. Harrison (1992) suggested that rotary combines were more gentle with cereal grains than conventional combines.

Seed vigour has been assessed by numerous vigour tests

(AOSA, 1983). Previous studies have indicated significant correlation between cold germination tests (Sonntag, 1989), conductivity tests (Entz et al., 1991) and field performance of seed lots.

The objectives of this study were: (1) to determine the effect of cylinder speed on seed threshing efficiency (the proportion of sound seed recovered from the spikes); (2) to determine the vigour of seed threshed at various cylinder speeds; (3) to compare the vigour of seed threshed by two combine types (conventional and rotary).

## 3.2. Materials and methods

### 3.2.1. Threshing procedures

#### 3.2.1.1. Crop characteristics

Harvesting studies were conducted on Katepwa wheat on farmer's fields using commercial combines. The fields were located near Rosser, Manitoba, and Portage la Prairie, Manitoba, in 1990 and 1991, respectively.

The cultivar Katepwa was used because of its popularity in the prairies. In 1989, 44% of the wheat grown on the Canadian prairies were Katepwa wheat (Anon. 1990). The average Katepwa yield in Manitoba was 2.7 t $ha^{-1}$ and 2.2 t $ha^{-1}$ for 1990 and 1991 crop, respectively (Anon. 1991).

The crop was swathed August 21, 1990 and August 12, 1991. The swather width was 8.4 m and 9.6 m in 1990 and 1991, respectively. Kernel water content at swathing was in the 20 to 30% range. The crop was allowed to dry down for three days before threshing took place at which time the KWC was less than 14%. The swath length averaged 290 m and 374 m in 1990 and 1991, respectively. Each swath represented an experimental unit.

Both years, the weather was hot and dry between swathing and threshing. No precipitation occurred while the crop was swathed.

### 3.2.1.2. The experimental design

The experiment was established as a factorial randomized complete block design. Samples were collected from four replicates, although six replicates were used to determine grain yield among experimental treatments in 1991.

The two factors were combine type and cylinder speed. The combine type was an axial flow rotary (single rotor)[1] and a conventional combine[2]. Manufacturer representatives adjusted and operated the combines. They determined the optimum cylinder speed, concave clearance and grain cleaning settings for the crop conditions in each year (Table 3.1.). A speed higher and lower than the optimal speed was then used for each combine.

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1 Case-IH 1680, Regina, SK
2 John Deere 9000 series, Regina, SK

**Table 3.1.** Combine adjustments, 1990 and 1991.

| Combine type | Conventional | | Rotary | |
|---|---|---|---|---|
| Year | 1990 | 1991 | 1990 | 1991 |
| Cylinder speed | .................... RPM | | .................. | |
| - Optimum | 800 | 800 | 850 | 800 |
| - Low | 500 | 600 | 630 | 700 |
| - High | 1040 | 1000 | 950 | 900 |
| Peripheral Speed† | .................... m/s | | .................... | |
| - Optimum | 27.6 | 27.6 | 33.9 | 31.9 |
| - Low | 17.3 | 20.7 | 25.1 | 27.9 |
| - High | 35.9 | 34.6 | 37.9 | 35.9 |
| Concave clearance | .................... mm | | .................. | |
| - front | 6.3 | 0.3 | 15.6 | 19.0 |
| - rear | 3.1 | 0.1 | 15.6 | 19.0 |

† Peripheral speed = RPM * $\pi$ * D * F
where, D is the diameter of the cylinder, 0.762m and 0.66m
for the rotary and the conventional combine, respectively;
F is the conversion factor from minutes to seconds (1/60)

3.2.1.3. Sampling procedures

Twenty to thirty subsamples were taken from the combine hopper loading auger from each experimental unit, hereafter referred to as the swath. In 1990, subsamples within a swath were bulked (average mass 10 kg). The KWC was determined[3] for the bulk sample. In 1991, KWC was determined for each subsample.

3 Model 919, Labtronics, Winnipeg, MB

Total harvested seed was determined for each swath using a weighing wagon.

At harvest in 1991, a sample of unthreshed wheat was collected and threshed with a belt thresher[4]. The belt threshed samples were used as a damage free standard.

## 3.2.2. Sample procedure

### 3.2.2.1. Assessment of visual damage

In 1990, bulk samples were reduced to 500 g, using a conical sample divider. In 1991, there was little difference in KWC among subsamples. Therefore, one subsample per swath was randomly chosen for further study. The following procedure was used in both years: (1) samples were sieved[5] with a 2.2 by 19 mm lower and a 3.2 by 19 mm upper sieve; (2) each fraction was hand sorted into sound, broken and unthreshed seed (whitecaps); (3) vigour tests were conducted using only visually sound seed from the sieved fraction between 2.2 and 3.2 mm. The proportions of broken seeds and whitecaps were expressed in percentage by mass of the total sample.

Kernel mass and protein content were measured to indicate the uniformity of the seed physical characteristics. Kernel weight was

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4 Agriculex, model SPT-1, Guelph, ONT.
5 Carter Day dockage tester, Winnipeg, MB

determined by weighing four subsamples of 100 seeds. Protein content of seed with 14% KWC was determined with a near-infrared product analyzer[6] on ground grains.

3.2.2.2. Vigour studies

- Conductivity test

The procedure to determine leachate conductivity followed that described by Entz et al. (1990). Three subsamples of 100 seeds were soaked in 75 ml of distilled water. The flasks were held at 20°C for one day. The conductivity was then measured with a reversed ohmmeter, and expressed in mhos ($ohm^{-1}$). The solution was agitated before the reading. The electrode was held in the solution until the reading stabilized. Between each sample the electrode was cleaned with distilled water.

- Cold germination test

Four subsamples of 50 seeds were placed on two layers of filter paper (Whatman #1) in 9 cm petri dishes and soaked with 6 ml of distilled chilled water (0°C). The seeds were held at 5°C in the dark for 14 days, after which germination was evaluated. Seeds were

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6 Model Instalab 800, Dickey-John Canada Inc, Devon, AB

classified as non germinated or producing a normal or an abnormal seedling. Seedlings that had one visible shoot and three distinct, symmetrical roots were considered normal. The other seedlings were considered abnormal.

- Standard germination test

This test was the same as the cold germination test, except that the petri dishes were held at 20$^{o}$C. Seedling evaluation was made four days after the test was initiated.

3.2.3. Data analyses

Data were analyzed using SAS system procedures (SAS, 1985). Differences with $p<0.05$ were considered meaningful. Analyses of variance were conducted for data within each experimental year. Polynomial contrasts were used to determine trends across the three cylinder speeds for each combine with the exception of yield data, where mean comparisons were used to show differences between treatments. The results from the belt threshed samples were not included in the analyses of variance.

A combined analysis of variance over the two years was also conducted to determine the consistency of the results over the years. Cylinder speeds were not equal between the two years. The sums of squares of interactions including cylinder speed were, therefore, not meaningful and pooled with the error sum of squares. The combine by year interactions, describe the response of the combines to seed damage between years. When significant, the sum of square of the interaction was partitioned into the year effect within each combine, following the method described by Steel and Torrie (section 15.4)(1980).

Correlation and regression analyses were used to determine strength of relationship among the different tests conducted on the seed samples.

# 3.3. Results and discussion

## 3.3.1. Threshing efficiency, cylinder speed and combine type

Threshing efficiency refers to the ratio between grain harvested and grain lost. Seed growers should also consider the amount of sound seed recovered at harvest to optimize threshing efficiency. In this study, the sound seeds represent the mass of visually undamaged seed greater than 2.2 mm.

Significant differences in seed yield at harvest were observed between the combines and among the cylinder speeds (Table 3.2). In both years, yield increased with increasing cylinder speed. In 1991 the difference in yield between low- and high-cylinder speeds was 11% for the conventional combine and 6% for the rotary combine. Cylinder speed has frequently been cited by others as the primary factor affecting threshing efficiency (Harrison, 1992; Wrubleski and Smith, 1980).

The amount of broken seeds was positively related to cylinder speed (Table 3.2). In contrast, the presence of whitecaps was negatively related to increasing cylinder speed. For both combines, samples threshed at the low cylinder speed had a higher amount of whitecaps and a lower amount of broken seeds than samples threshed at the high cylinder speed (Table 3.2). The quantity of kernels recovered from a spike is therefore the best at high cylinder speed.

**Table 3.2.** Grain yield harvested, dockage (small seeds and non wheat seeds), broken seeds, whitecaps and sound seed yield in 1990 and 1991 threshing experiments.

| | Conventional | | | Rotary | | |
|---|---|---|---|---|---|---|
| Cylinder Speed | High | Optimum | Low | High | Optimum | Low |
| | kg ha$^{-1}$ | | | | | |
| | | | | 1990 | | |
| Grain yield | 3490 c† | 3370 b | 3260 a | 3550 c | - | 3420 bc |
| Dockage | 100 c | 82 ab | 92 bc | 85 b | - | 74 a |
| Broken | 152 d | 63 c | 15 b | 21 b | - | 6 a |
| Whitecaps | 17 a | 18 a | 55 c | 13 a | - | 36 b |
| Seed yield | 3221 b | 3207 b | 3098 a | 3431 d | - | 3304 c |
| | | | | 1991 | | |
| Grain yield | 3140 cd | 3090 c | 2800 a | 3170 d | - | 3000 b |
| Dockage | 173 c | 156 b | 143 a | 171 c | - | 139 a |
| Broken | 61 d | 32 c | 18 b | 16 b | - | 6 a |
| Whitecaps | 36 a | 51 b | 89 c | 59 b | - | 119 d |
| Seed yield | 2870 cd | 2851 c | 2550 a | 2924 d | - | 2736 b |

† Means within a row followed by different letters are different at $p<0.05$.
- Missing data.

Dockage, which is mostly composed of seeds smaller than 2.2 mm in diameter, was the greatest for high cylinder speed threshing. High proportion of small seeds or dockage confirms the improvement in threshing efficiency at high cylinder speeds (Table 3.2). However, high cylinder speed increased the impact forces on kernels resulting in more broken seeds than at low cylinder speed (Figure 3.1a).

The conventional combine had the least wastage (dockage, broken seeds and whitecaps) at the optimum cylinder speed (Table 3.2). At all cylinder speeds in 1990, and at high cylinder speed in 1991, little wastage for the rotary combine resulted in higher yields of sound seeds than with the conventional combine at any cylinder speed (Table 3.2).

Results of this experiment suggest that grain farmers with conventional combines should use a high cylinder speed to maximize threshing efficiency (yield). The yield of visually sound seed was seriously reduced at high cylinder speeds, due to a large number of broken seeds (Figure 3.1a) suggesting that seed growers should not use high cylinder speed (Table 3.2). A narrow range of cylinder speed around the optimum cylinder speed is the best compromise between threshing efficiency and low seed breakage for the conventional combine.

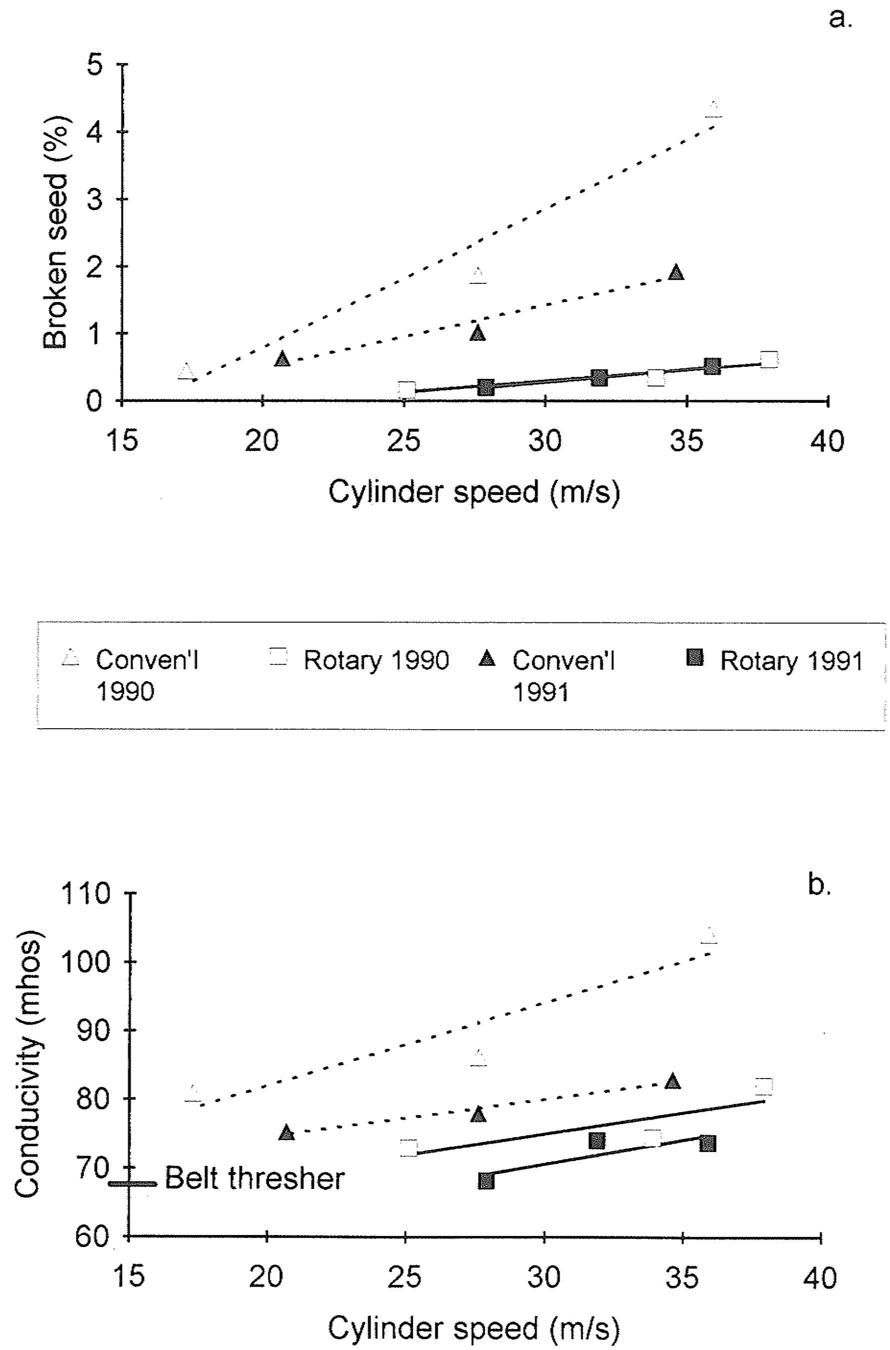


**Figure 3.1.** Percent broken seed (a.) and conductivity test (b.) versus peripheral cylinder speed.

Vas and Harrison (1969) concluded that "in practical situations operators should consider kernel damage as well as threshability in adjusting their combines". Such considerations did not appear to be common practice as noted in a survey of English farmers (Arnold and Jones,1963). The survey showed that cylinder speed varied greatly and was not adjusted to the KWC at harvest. Farmers use high cylinder speeds because they increase threshability, reduce the chances of plugging and increase daily threshing acreage (Renaud, 1984).

For the rotary combine, increasing cylinder speed did not affect yield nor the sample composition as dramatically as for the conventional combine. Centrifugal forces play a greater role in rotary combine threshing mechanisms than in those of conventional combines (Renaud, 1984). Friction forces are secondary in threshing efficiency as shown by no relationship between threshing efficiency and concave clearance in Harrison study (1992). The wider concave clearance in 1991 (19 mm) did not affect threshing efficiency of the rotary combine in comparison to 1990 where the rotary combine had a concave clearance of 15.6 mm (Table 3.1).

### 3.3.2. Seed vigour, cylinder speed and combine type

- Conductivity test

In both years, combine by cylinder speed interactions were significant (Table 3.3 and 3.4). The cylinder speed increase with the conventional combine had a greater effect on leachate conductivity than with the rotary combine (Figure 3.1b). A slight increase of cylinder speed with the conventional combine results in noticeable increase of leachate conductivity of the threshed seed samples.

The leachate conductivity was the highest for seed samples threshed with a high cylinder speed (Figure 3.1b). The increase was linear, although quadratic functions were significant in both years (Table 3.3 and 3.4). A greater increase in conductivity was generally observed between optimum and high cylinder speeds (with the exception of the rotary combine in 1991). Seed sustained low and optimum cylinder speed without severe damage.

Seeds threshed with the rotary combine had lower leachate conductivity than seeds threshed with the conventional combine. In 1991, the belt threshed seeds had similar leachate conductivity than seeds threshed with the rotary combine at a low cylinder speed.

**Table 3.3**. Mean squares from 1990 analyses of variance.

| Source of variation | df | Percent broken seeds | Conduc-tivity | Cold germination Seedling types | | | Standard germination Seedling types | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Normal | Non germ. | Abnormal | Normal | Non germ. | Abnormal |
| Replicates | 3 | 0.2 † | 23.3 * | 8.3 | 1.9 | 7.2 | 1.4 | 0.3 | 1.1 |
| Combine (C) | 1 | 20.5 ** | 1169.0 ** | 943.8 ** | 17.5 ** | 704.2 ** | 150.0 ** | 10.7 ** | 80.7 ** |
| Cylinder Speed (S) | 2 | 9.7 ** | 577.7 ** | 500.8 ** | 31.9 ** | 288.7 ** | 121.9 ** | 9.0 ** | 66.2 ** |
| C x S | 2 | 6.1 ** | 108.0 ** | 44.0 ** | 2.8 | 24.5 * | 26.8 ** | 1.2 | 18.1 ** |
| Contrasts (S+CxS) | | | | | | | | | |
| Conventional C | | | | | | | | | |
| - linear | 1 | 29.8 ** | 1038.2 ** | 835.9 ** | 48.6 ** | 481.5 ** | 247.3 ** | 14.7 ** | 141.3 ** |
| - quadratic | 1 | 1.4 * | 146.0 ** | 5.0 | 4.1 * | - | 14.0 ** | 1.1 | 7.3 |
| Rotary C | | | | | | | | | |
| - linear | 1 | 0.4 | 130.3 ** | 228.9 ** | 10.6 ** | 141.0 ** | 22.5 ** | 2.1 | 19.8 * |
| - quadratic | 1 | - | 56.9 ** | 20.0 | 6.2 * | 3.9 | 0.7 | 2.5 | 0.2 |
| Error | 15 | 0.2 | 5.5 | 5.7 | 0.8 | 5.4 | 1.6 | 0.6 | 2.5 |

† mean squares followed by * and **, are significant at p=0.05 and p=0.01, respectively

**Table 3.4.** Mean squares from 1991 analyses of variance

| Source of variation | df | Percent broken seeds | Conductivity | Cold germination Seedling types | | | Standard germination Seedling types | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Normal | Non germ. | Abnormal | Normal | Non germ. | Abnormal |
| Replicates | 3 | - † | 9.0 * | 1.3 | 0.7 | 1.6 | 0.2 | 0.5 | 0.6 |
| Combine (C) | 1 | 4.3 ** | 276.8 ** | 350.1 ** | 17.8 ** | 217.9 ** | 145.0 ** | 1.7 | 137.8 ** |
| Cylinder Speed (S) | 2 | 1.3 ** | 89.9 ** | 126.0 ** | 4.5 * | 82.7 ** | 42.0 ** | 0.8 | 59.5 ** |
| C x S | 2 | 0.5 ** | 13.6 * | 13.0 | 0.3 | 9.0 | 12.8 ** | 0.1 | 13.0 ** |
| Contrasts (S+CxS) | | | | | | | | | |
| Conventional C | | | | | | | | | |
| - linear | 1 | 3.4 ** | 114.9 ** | 206.6 ** | 6.1 * | 141.6 ** | 53.3 ** | 0.1 | 98.0 ** |
| - quadratic | 1 | 0.2 * | 3.1 | 13.5 | 1.0 | 4.5 | 2.3 | 0.2 | 6.0 * |
| Rotary C | | | | | | | | | |
| - linear | 1 | 0.2 * | 63.3 ** | 55.1 ** | 2.0 | 36.1 ** | 6.8 * | 0.5 | 17.0 ** |
| - quadratic | 1 | - | 25.7 ** | 2.9 | 0.5 | 1.0 | 1.7 | 0.9 | 0.6 |
| Error | 15 | 0.03 | 2.5 | 4.6 | 0.8 | 2.7 | 1.7 | 0.8 | 0.8 |

† mean squares followed by * and **, are significant at p=0.05 and p=0.01, respectively

- Cold germination test

The cold germination test showed a decrease in the germination of normal seedlings from sound seeds as the cylinder speed was increased (Figure 3.2a). For both years and combines, the lowest number of normal seedlings occurred in samples harvested at high cylinder speeds. Fewer normal seedlings were found in samples threshed with the conventional combine than with the rotary combine (Table 3.3 and 3.4). There was a similar germination pattern for seed threshed with the belt thresher and with the rotary combine at a low cylinder speed (Figure 3.2a, 3.2c and 3.2.d)

The reduction of the proportion of normal seedling with increased cylinder speed, was the result of an increase of non germinated seeds and abnormal seedlings (Figure 3.2c and 3.2d).

Non germinated seeds were fewer in samples threshed with the rotary combine than with the conventional combine. Non germinated seed increased greatly between optimum and high cylinder speed for both years and both combines. The quadratic relationship was significant between cylinder speed and non germinated seed (Table 3.3 and 3.4). Seed required high impact forces to fail germination.

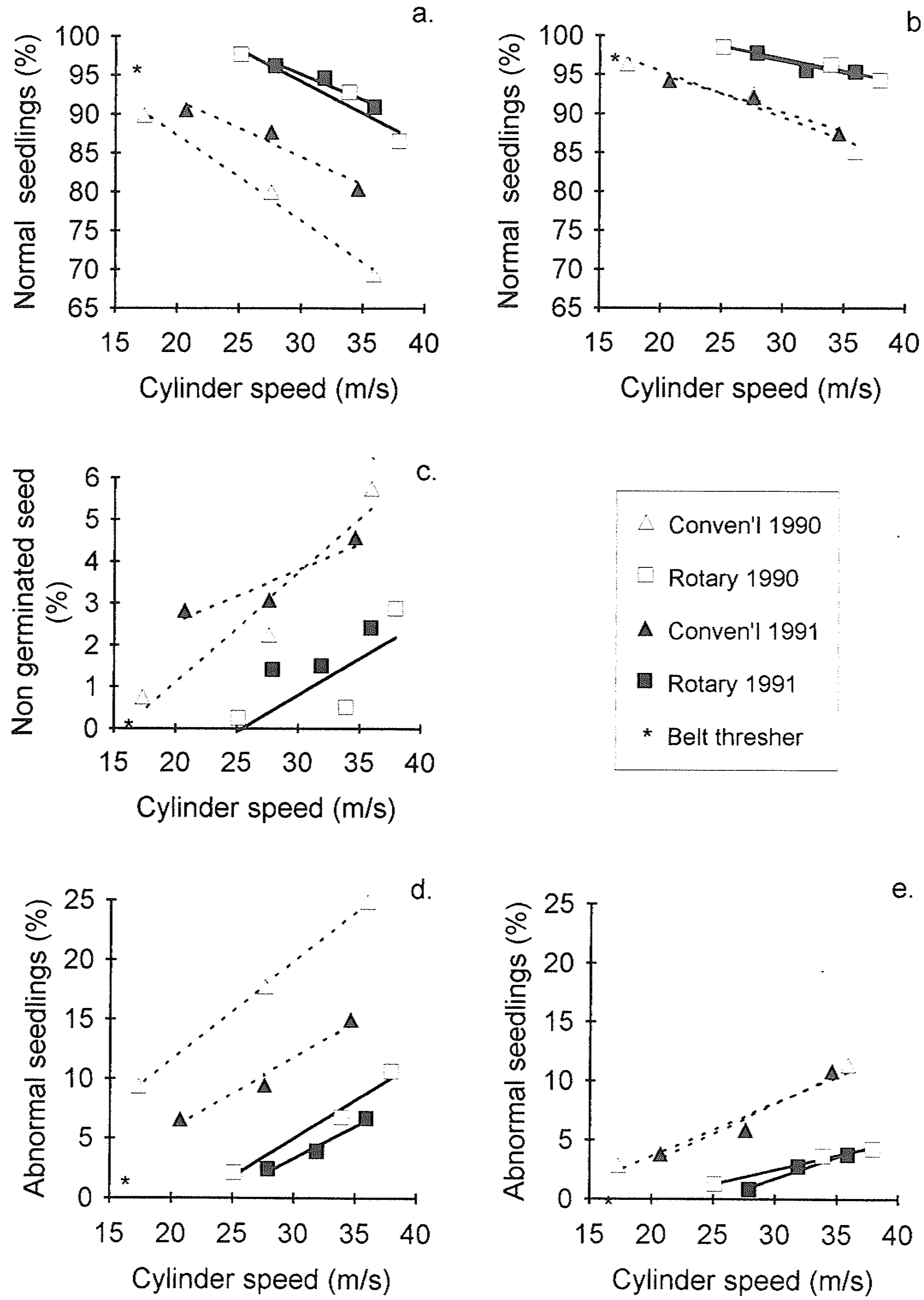


**Figure 3.2.** Results of the vigour tests performed on sound seed; a) & b) normal seedlings in cold and standard germination tests, respectively; c) non germinated seed in the cold germinated test; and d) & e) abnormal seedlings in the cold and standard germination tests, respectively.

The relationship between cylinder speed and abnormal seedling number was linear and negative (Table 3.3 and 3.4). Abnormal seedling represented 25% and 15% of samples threshed with a conventional combine with high cylinder speed, in 1990 and 1991 respectively (Figure 3.2d). These results indicated that high cylinder speed induced severe embryo damage resulting in germination failure but also induced minor damage resulting in abnormal seedlings.

- Standard germination test

The standard germination test showed similar trends as the cold germination test (Figure 3.2b and 3.2e; Table 3.3 and 3.4). However, the extent of seed damage, revealed by the proportion of non germinated seed and abnormal seedlings, were less than with the cold germination test. Some of the seed that were classified as damaged under cold stress, appeared undamaged under the ideal conditions of the standard germination test. Similar observations were made by Spreafico (1965).

The proportion of non germinated seeds was not significant among treatments in 1991. No sample had more than 5% non germinated seed in the standard germination test. Seed certification requires 90% germinated seeds in a standard germination test, regardless of the number of abnormal seedling. It implies that all the samples collected in this experiment were eligible for certification. The proportion of non germinated seed in a standard germination test does not indicate vigour status of a seed lot.

### 3.3.3. Year by combine interaction

Year by combine interaction was significant for the percentage of broken seed, the leachate conductivity test and the proportion of normal and abnormal seedlings in the cold germination test (Table 3.5). Results of the standard germination test were similar to seed harvested in both years.

By further partitioning the sum of square into the difference between years within each combine, only the conductivity test had a significant year by rotary combine interaction (Table 3.5). Percentage broken seed, normal- and abnormal-seedlings (cold germination test) followed a similar pattern between the two years in seed lots threshed with the rotary combine.

Seeds threshed in 1990 with the conventional combine had significantly more broken seed, higher conductivity, fewer normal seedlings and more abnormal seedlings than seed threshed in 1991 (Table 3.5). These differences were greater at high cylinder speeds than at low cylinder speeds (Figure 3.1, 3.2a, and 3.2d). Therefore, kernels absorbed greater impact forces without exhibiting visual damage or vigour loss in 1991 than in 1990. Vas and Harrison (1969) suggested that high straw to grain ratio in drums reduce seed breakage. Greater amount of straw in 1991, may have cushioned the impact force on the seed.

**Table 3.5.** Mean squares from combined (1990 and 1991) analyses of variance

| Source of variation | df | Percent broken seeds | Conduc-tivity | Cold germination Seedling types | | | Standard germination Seedling types | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Normal | Non germ. | Abnormal | Normal | Non germ. | Abnormal |
| Replicates | 3 | 0.1 † | 12.8 | 4.1 | 2.1 | 4.9 | 0.7 | 0.1 | 0.5 |
| Year (Y) | 1 | 3.3 * | 779.9 ** | 196.6 ** | 4.0 | 250.5 ** | 0.1 | 1.3 | 0.7 |
| Error A | 3 | 0.2 | 19.5 | 5.5 | 0.4 | 3.9 | 0.9 | 0.7 | 1.1 |
| Combine (C) | 1 | 21.9 ** | 1291.7 ** | 1221.7 ** | 35.3 ** | 852.8 ** | 295.0 ** | 10.4 ** | 194.6 ** |
| Cylinder Speed (S) | 2 | 9.2 ** | 534.2 ** | 559.5 ** | 30.1 ** | 336.4 ** | 153.1 ** | 2.7 | 115.3 ** |
| Y x C | 1 | 3.0 * | 154.1 ** | 72.1 * | - | 69.3 ** | - | 2.0 | 1.6 |
| * Y within Conventional C | 1 | 6.3 ** | 808.5 ** | 253.5 ** | | 291.7 ** | | | |
| * Y within Rotary C | 1 | - | 120.2 * | 15.36 | | 28.1 | | | |
| Error B | 36 | 0.6 | 17.5 | 11.2 | 1.2 | 7.2 | 4.2 | 1.0 | 3.0 |

† mean squares followed by * and **, are significant at p=0.05 and p=0.01, respectively

Seed samples contained more small seeds and had a higher protein content in 1991 than in 1990 (Table 3.6). Small seed size and high protein content in 1991 resulted from adverse climatic conditions (extreme heat and drought) during ripening. Adverse conditions during ripening increase the protein percentage in seed because fewer carbohydrates are formed (Tsai et al., 1970). Differences in such seed characteristics, as seed size and protein content, may have reduced the resistance of 1990 wheat seeds to impact damage.

Hot and dry conditions in 1991 during ripening resulted in a rapid drying. The crop received no precipitation while drying. Stress cracking resulting from cycles of drying and wetting of the grain (Grosh and Milner, 1959), may have been fewer in 1991 than in 1990. Cracks in seed coat and endosperm of seeds, make them less resistant to impact forces (Mohsenin, 1986). The higher conductivity in 1990 confirms more cracks in seed coats in 1990 than in 1991. Cracks in seed coats may be the result of impact damage but also from stress cracking (Grosh and Milner, 1959).

Kernel water content at harvest modifies the mechanical resistance of seed to impact forces (Bilanski, 1966). Variance of KWC was greater in 1990 than in 1991 (Table 3.6). The average KWC were similar between 1990 and 1991, although some samples were tougher in 1990 than in 1991. The toughest samples threshed in 1990 had a greater proportion of non germinated seeds than the driest samples (Table 3.7). Leachate conductivity was the least for the toughest samples threshed in 1990. Tough seeds are less susceptible to external or pericarp damage. Seeds have greater elasticity but are more susceptible to internal damage at high KWC than at low KWC (King and Ridolls, 1962).

Seeds threshed at different KWC exhibit different types of damage. Variable KWC at harvest results in greater seed to seed variation of vigour.

**Table 3.6.** Mean comparison of protein content, seed size and KWC between years.

| Year | Protein | Seed smaller than 2.2mm | KWC. Mean | KWC. Variance |
|---|---|---|---|---|
| | ........ % | ........ | | |
| 1990 | 12.8 a | 1.7 a | 13.6 | 2.92 |
| 1991 | 14.7 b | 5.1 b | 13.2 | 0.04 |

Means within a column followed by a different letterare different at p>0.05.

**Table 3.7.** Mean comparison of KWC, broken seed proportion, leachate conductivity, and cold germination test results, among 1990 replicates.

| Rep | KWC | Brk | Cdc | NCG | DCG | ACG |
|---|---|---|---|---|---|---|
| 1 | 16.7 a | 1.9 a | 89.6 b | 78.7 a | 3.8 a | 17.5 a |
| 2 | 13.9 b | 2.1 a | 88.0 b | 80.7 a | 3.5 ab | 15.8 a |
| 3 | 12.2 c | 2.2 a | 90.3 ab | 80.7 a | 2.5 ab | 16.8 a |
| 4 | 11.9 c | 2.7 a | 93.6 a | 79.0 a | 1.8 b | 15.8 a |

Means within a column followed by a different letter are different at p>0.05.

Rep: replicate number; KWC: kernel water content; Brk: Broken seed; Cdc: leachate conductivity; NCG, DCG and ACG: normal seedlings, non germinated seed and abnormal seedlings in the cold germination test.

### 3.3.4. Relationship between seed vigour and seed physical characteristics

A correlation analysis was conducted using all data from 1990 and 1991. The proportion of broken seeds in a sample was significantly correlated with the results of the leachate conductivity test, cold germination test and standard germination test (Table 3.8). Pierson's coefficients were significant among all tests. Results obtained from different tests provided a similar conclusion on the vigour status of seeds.

Sound seeds from a seed lot that had a high number of broken seed, had a high leachate conductivity and a high number of abnormal seedlings. Regression analyses confirm the relation between broken seed and vigour test regardless of threshing treatments applied to the seed and of year (Figure 3.3). The number of normal seedlings (cold germinated test) and leachate conductivity can be predicted with the following equations:

- Y = % Normal Seedling and X = % Broken Seed

  $Y = 1.18 \times X^2 - 11.5 \times X + 97.04$ ............ $R^2 = 0.89$

- Y = Conductivity (Mhos) and X = % Broken Seed

  $Y = 7.00 \times X + 72.11$ ............................... $R^2 = 0.82$

**Table 3.8.** Correlation analyses among seed vigour tests and broken seed proportion in seed samples.

| | CDC | NCG | DCG | ACG | NSG | DSG | ASG |
|---|---|---|---|---|---|---|---|
| BRK | -0.91**† | -0.90** | 0.68** | 0.90** | -0.85** | 0.65** | 0.79** |
| CDC | | -0.92** | 0.64** | 0.93** | -0.80** | 0.57** | 0.76** |
| NCG | | | -0.79** | -0.99** | 0.90** | -0.62** | -0.85** |
| DCG | | | | 0.67** | -0.86** | 0.61** | 0.82** |
| ACG | | | | | -0.84** | 0.58** | 0.80** |
| NSG | | | | | | -0.65** | -0.97** |
| DSG | | | | | | | 0.43** |

† Correlation coefficients followed by * and **, are significant at p=0.05 and p=0.01, respectively.

BRK: per cent broken seed; WCP: per cent white caps; CDC: conductivity test; NCG, DCG and ACG; normal seedlings, non germinated seeds and abnormal seedlings in the cold germination test; and NSG, DSG and ASG; normal seedlings, non germinated seeds and abnormal seedlings in the cold germination test.

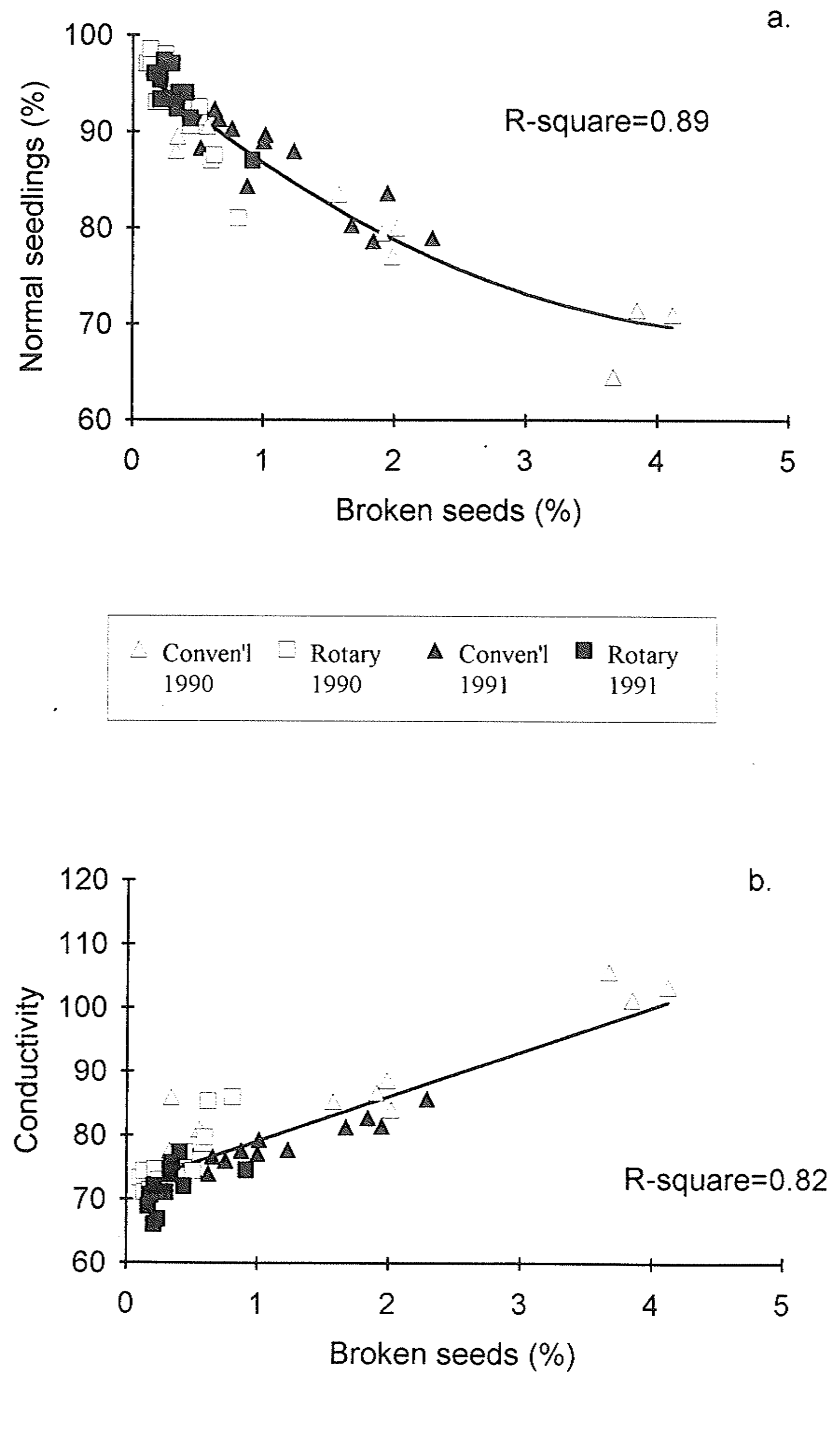


**Figure 3.3.** Percent normal seedlings in the cold germination test (a.) and leachate conductivity (b.) of sound seeds compared to the proportion of broken seeds in a threshed seed sample.

Proportion of broken seed can be used to predict vigour loss of a seed lot at the time of threshing. In case of high proportion of broken seed, the combine should be adjusted to minimize the impact force applied to seeds. Monitoring broken seed proportion in a seed cleaning unit may indicate specific operations that damage seed. A reduction in the proportion of broken seed should prevent seed vigour loss due to impact.

The predictive equation should be used for Katepwa wheat and KWC at harvest ranging 12-15%. Mitchell (1955) suggested that relations between broken seed and seed vigour can only be established within small KWC ranges.

## 3.4. Conclusion

Threshing efficiency is improved with high cylinder speeds. Loss of seeds in unthreshed spikes was unacceptable with low cylinder speed for the conventional combine. Sound seed yield between optimum and high cylinder speed (conventional combine) was similar due to high wastage in samples threshed at high cylinder speed.

Seed vigour is affected by cylinder speed. As cylinder speed increased, seeds produced fewer normal seedlings in cold germination tests and were more subject to seed content leachate. Increase in abnormal seedling proportion was directly related to an increase of cylinder speed.

At any cylinder speed, the axial flow (single rotor) rotary combine is gentler with seeds than the conventional combine. The effect of increased cylinder speed was smaller on seed damage and seed vigour for the rotary than for the conventional combine. The rotary combine was gentler than the conventional combine. However, even with the rotary combine, the cylinder speed should be adjusted as low as possible (less than 800 RPM for the conditions of the experiments) because higher cylinder speeds reduced seed vigour. The seed threshed with the rotary combine at low cylinder speed displayed a similar level of vigour as seed threshed with the belt thresher.

Results were consistent over the years for the samples threshed with the rotary combine. The samples threshed with the conventional combine responded similarly at low cylinder speeds but not at high cylinder speeds. The difference may be attributed to seed characteristics that made the seed more resistant to impact damage in 1991 than in 1990.

The percentage of normal seedlings and leachate conductivity of sound seeds can be predicted from the proportion of broken seed. The equations are limited to katepwa wheat threshed around 12-15% KWC.

# 4. Vigour loss of wheat seed caused by threshing: II. Field performances.

## 4.1. Introduction

Registered Katepwa seed lots varied in yield as much as 13% in Sonntag (1989) and Empey (1992) experiments. The yield differences were attributed to variation in seed vigour because low yielding seed lots had few normal seedlings in cold germination tests.

Planting low vigour wheat seed results in poor plant establishment, slow seedling development and a lack of plant to plant uniformity (Ayre, 1980). Yield differences were observed between plots planted with high- and low-vigour wheat seed (Ayre, 1980; Entz et al., 1991; Sontag, 1989; Empey, 1992). However, this observation was not made by Tekrony and Egli (1991). Low plant density, in plots planted with low vigour seed, was compensated by tillers and seed per spike. Low seed vigour may have an effect on yield in those situations where plant density is low and tiller production is impeded, such as deep seeding, late planting or weed competition (Tekrony and Egli, 1991).

Threshing wheat at high cylinder speed increases the proportion of broken seed in a sample and reduces the vigour of the sound seed (Johnson, 1959; Mitchell, 1955; King and Riddolls, 1960; Vas and Harrison, 1969; Arnold and Jones, 1963). High cylinder speed threshing with a Vogel-type stationary thresher reduced seed vigour ratings in laboratory vigour tests, field emergence and yield (Entz et al., 1991). No such results are available for commercial combines.

In a previous study, seed vigour was affected by combine type and cylinder speed in laboratory vigour tests (Figure 3.1 and 3.2, page 34 and 40). Seed vigour was reduced when seeds were threshed at high cylinder speed. The conventional combine induced more vigour loss to seed than the axial flow (single rotor) rotary combine ("rotary combine").

The objectives of this study were: (1) to determine field performance among seed lots threshed with two combine types at three cylinder speeds; (2) to determine the relationship between laboratory seed vigour tests and field performance; and (3), to compare field emergence and yield among seed lots threshed with a belt thresher, a conventional and a rotary combine.

# 4.2. Materials and Methods

## 4.2.1. Characteristics of the seed lots

Katepwa seed lots were obtained from threshing studies in 1990 at Rosser, Manitoba and in 1991 at Portage la Prairie, Manitoba. A conventional[1] and a rotary[2] combine were adjusted at three cylinder speeds to thresh the seed lots on commercial Katepwa wheat fields (Table 3.1, page 26). Wheat threshed with a belt thresher[3] was included into the 1991 threshing study only.

The six seed lots harvested in 1990 were evaluated in the field in 1991 and 1992, namely 1991 and 1992a, respectively. The seven seed lots harvested in 1991 were evaluated in the field in 1992, namely 1992b.

A cold germination test was conducted on the 1990 harvested seed lots two months prior to the 1992 growing season to determine if there was any loss of vigour during the 18 month storage period. The cold germination was conducted at 5°C following the procedure described in section 3.2.2.2.

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1 John Deere, 9000 series, Regina, SK.
2 Case IH 1680, Regina, SK.
3 Agriculex, model SPT-1, Guelph, ONT.

### 4.2.2. Cultural practices

The seed lots were planted at the field research site at Portage la Prairie, Manitoba on May 13, 1991 and May 7, 1992. The soil type was a Neuhorst clay loam, and the previous crop each year was canola. Plots were planted directly (zero-tillage) into the canola stubble.

A 2 m Noble hoe-type seed drill[4] with a row spacing of 0.2 m was used. The drill was adapted for plot work with the addition of a belt cone and spreader. The plot area was 2 m wide by 7 m in length.

Fertilizer was applied to supplement soil fertility levels according to soil tests (see Appendix table 2).

The seeding rate was 200 seeds $m^{-2}$, and the planting depth was 7.5 cm deep to provide an extra stress to the emerging seedlings. Both rate and depth are within the optimum range proposed by the "Field Crop Production Guide For Manitoba" (1988-90).

Pesticides were applied as required and are summarized in Appendix table 3.

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4 Noble Equipment Co., Nobleford, AB

## 4.2.3. Yield and yield components

### 4.2.3.1. Experimental design

The experiment was conducted as a factorial in randomized complete block design with six replicates. The factors were combine type used for harvesting the seed (conventional or rotary), and the cylinder speed used for harvesting the seed (high, optimum and low). Tests 1992a and 1992b were conducted in adjacent plot areas.

### 4.2.3.2. Assessments

The plant stand was determined when seedlings were in the 2- to 3-leaf stage, on June 7, 1991 and June 4, 1992. Plant stands were determined by counting seedlings in 1 $m^2$ taken from the four center rows in each plot.

The wheat spikes were counted when the kernels were in the milk to soft dough stage, on August 6, both years. Spike number was determined by counting all spikes in 1 $m^2$ taken from the centre four rows in each plot. Spikes per plant were calculated from the spike counts and the plant stand counts.

The plots were combine harvested August 21, 1991 and September 12, 1992 with a Wintersteiger[5] plot combine. Samples were allowed to air dry for one day in 1991 and five days in 1992. A 0.52 mm and a 0.20 mm round sieves were used to clean the samples before weighing. Kernel water content was determined[6] to correct yield to a 14% KWC basis.

Yield per plant was calculated from yield and plant stand counts. Yield per spike was calculated from yield and spike counts.

Thousand kernel mass was only determined in 1992 by weighing four lots of one-hundred seeds. Thousand kernel mass, yield per plant and yield per spike were used to calculate the number of seeds per plant and per spike.

4.2.3.3. Environmental conditions

Growing season rainfall, daily minimum- and maximum-temperatures, and soil temperature (10 cm below a grass covered surface), were collected within 0.5 km of the experiment site (see Appendix table 4).

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5 Wintersteiger, nurserymaster elite, Salt Lake City, UT
6 Labtronic model 919, Winnipeg, MB (1991);
Dickey John, model 919 automatic, Cornwall, ONT (1992)

#### 4.2.3.4. Statistical analyses

Treatment variances were homogeneous between years (*F* test procedures described in Gomez and Gomez, 1984, page 268). A combined analysis of variance over 1991, 1992a and 1992b, was performed using the model described by Gomez and Gomez (1984) (chapter 8.1.2). Contrasts were used between 1991 and 1992a to compare the 1990 harvested seed lots planted in 1991 and 1992. Contrasts were used between 1992a and 1992b to compare seed lots harvested in 1990 and 1991, planted in 1992. Differences with $P<0.05$ were considered meaningful, and least significant difference ($P=0.05$) were used as the basis of comparison among treatments.

Simple correlation analyses were performed to determine the strength of relationships between yield components and yield, and also between laboratory vigour studies, percentage broken seed, and field performances.

Least significant difference was used to compare the seed lot threshed in 1991 with the belt thresher and with the commercial combines.

## 4.3. Results

There were no significant interactions between treatments and years (Table 4.1 and 4.2). However, year means were different for yield and yield per spike. There were significant differences for most variables with 1990 harvested seed lots when planted in 1991 or 1992 (contrasts 1991 vs 1992a). Treatment means were similar between 1990 harvested seed lots and 1991 harvested seed lots when they were planted in 1992 (contrast 1992a vs 1992b). Therefore, differences between growing seasons (1991 versus 1992) accounted for the significant year effect rather than differences between 1990 and 1991 harvested seed lots.

Crop performance was better in 1992 than in 1991 with the exception of the number of spike per plant (Table 4.3). Yield was higher in 1992 by 1 t $ha^{-1}$ compared to 1991. Such variation between the two growing seasons was due in large extent to climatic conditions. The 1992 growing season was cooler and wetter than 1991 (see Appendix Table 4). Cool weather increased the number of days to maturity by 33%. Grain filling and maturation was slow in 1992 leading to large and plump kernels.

**Table 4.1.** Mean squares from combined analyses of variance of 1991, 1992a and 1992b field tests.

| Source of variation | df | Field emergence | Spike number ($m^2$) | Spike number (plant) | Yield | Yield per spike | Yield per plant |
|---|---|---|---|---|---|---|---|
| Replicate | 5 | 941.8 † | 3618.4 | 0.81 | 0.12 | 0.03 | 0.88 |
| Year (Y) | 2 | 1409.8 | 3554.6 | 1.96 | 10.70 ** | 0.62 ** | 2.56 |
| Error A | 10 | 714.4 | 1938.2 | 0.64 | 0.05 | 0.01 | 0.63 |
| Contrasts on Y | | | | | | | |
| 1991 vs 1992a | 1 | 2734.3 ** | 847.3 | 2.92 ** | 16.85 ** | 0.88 ** | 3.42 ** |
| 1992a vs 1992b | 1 | 329.4 | 2913.4 | 0.00 | 0.01 | 0.005 | 0.06 |
| Combine (C) | 1 | 1931.2 ** | 6090.0 * | 0.63 | 0.26 ** | 0.008 | 0.97 ** |
| Cyl. Speed (S) | 2 | 618.1 * | 616.8 | 0.43 | 0.15 ** | 0.000 | 0.28 |
| C x S | 2 | 820.4 ** | 561.7 | 0.71 * | 0.00 | 0.004 | 0.63 ** |
| C x Y | 2 | 30.0 | 231.4 | 0.14 | 0.01 | 0.002 | 0.03 |
| S x Y | 4 | 84.1 | 1088.7 | 0.20 | 0.01 | 0.009 | 0.02 |
| C x S x Y | 4 | 50.4 | 323.2 | 0.06 | 0.02 | 0.003 | 0.08 |
| Error B | 75 | 153.0 | 1151.2 | 0.17 | | | |
| Error C‡ | 72 | | | | 0.01 | 0.005 | 0.12 |

† Mean squares followed by ** and by * are significant at the 1% and 5% probability level, respectively.
‡ In 1992, yield data from three plots were lost due to wheat streak mosaic virus.

**Table 4.2.** Mean squares from the combined analyses of variance of 1992a and 1992b field tests.

| Source of variation | df | Thousand kernel mass | Seed per spike | Seed per plant |
|---|---|---|---|---|
| Replicate | 5 | 0.17 † | 20.73 | 908.4 |
| Year (Y) | 1 | 0.04 | 4.32 | 49.3 |
| Error A | 5 | 0.66 | 8.45 | 248.7 |
| Combine (C) | 1 | 0.14 | 8.68 | 397.0 * |
| Cyl. Speed (S) | 2 | 0.38 | 2.51 | 120.1 |
| C x S | 2 | 0.35 | 2.40 | 240.0 |
| C x Y | 1 | 0.80 | 1.85 | 31.5 |
| S x Y | 2 | 0.60 | 3.79 | 28.3 |
| C x S x Y | 2 | 0.67 | 5.95 | 93.9 |
| Error B | 50 | 0.63 | 3.68 | 87.3 |

† Mean squares followed by ** and by * are significant at the 1% and 5% probability level, respectively.

**Table 4.3.** Mean comparison of seed lot performances between years.

| Years | Field emergence ($m^2$) | Spike number ($m^2$) | Spike number (plant) | Yield (t/ha) | Yield per spike (g) | Yield per plant (g) |
|---|---|---|---|---|---|---|
| 1991 | 124.9 a[Θ] | 485.9 a | 3.95 a | 3.86 b | 0.80 b | 3.16 b |
| 1992a | 137.2 a | 479.0 a | 3.55 a | 4.84 a | 1.02 a | 3.59 a |
| 1992b | 132.9 a | 466.3 a | 3.54 a | 4.81 a | 1.03 a | 3.65 a |
| Std. Error† | 6.29 | 10.37 | 0.189 | 0.052 | 0.028 | 0.187 |
| Std. Error‡ | | | | 0.055 | 0.030 | 0.195 |

† 36 values computed.
‡ 33 values computed due to missing data
Θ means followed by a different letter are significantly different at the 5% probability level.

Similar behaviour of seed lots harvested in 1990 and in 1991 leads to the following conclusion: no degradation occurred during 18 month of storage because seed lots threshed in 1990 performed similarly to the ones threshed in 1991. Similar response in cold germination tests conducted in February 1991 and February 1992 on 1990 harvested seed lots (Table 4.4).

**Table 4.4.** Mean comparisons between the cold germination tests results of February 1991 and February 1992 on seed samples threshed in 1990

| Cylinder Speed | Normal 1990 | Normal 1991 | Non germinated 1990 | Non germinated 1991 | Abnormal 1990 | Abnormal 1991 |
|---|---|---|---|---|---|---|
| Conventional | | | | | | |
| High | 69.4 d† | 70.0 d | 5.75 a | 6.25 a | 24.9 a | 23.8 ab |
| Optimum | 80.0 cd | 83.0 bc | 2.25 ab | 3.00 ab | 17.8 abc | 14.0 bcd |
| Low | 89.9 abc | 92.5 ab | 0.75 b | 1.25 b | 9.4 cde | 6.3 de |
| Rotary | | | | | | |
| High | 86.5 bc | 89.3 abc | 2.88 ab | 0.75 b | 10.6 cde | 10.0 cde |
| Optimum | 92.8 ab | 93.0 ab | 0.50 b | 0.25 b | 6.8 de | 6.8 de |
| Low | 97.7 a | 97.5 a | 0.25 b | 0.50 b | 2.1 e | 2.0 e |
| Std. Error | 1.59 | | 0.69 | | 1.63 | |

† means followed by a different letter are significantly different at the 5% probability level.

There were significant interactions between cylinder speed and combine type for emergence, spike number per plant and yield per plant (Table 4.1 and 4.2). Little variations in field emergence, spike number per plant and yield per plant were observed among seed lots threshed at different cylinder speeds with the rotary combine but large variations were observed for seed lots threshed at different cylinder speeds with the conventional combine (Figure 4.1a, 4.1c and 4.2b). The conventional combine at high cylinder speed had the lowest emergence but the highest number of spikes per plant and the highest yield per plant. The number of seeds per plant responded similarly to the yield per plant, even though the combine by cylinder speed interaction was not significant (Figure 4.2c).

Combine type used for threshing seeds led to significant variation in spike number $m^{-2}$ (Table 4.1). This variation resulted from low spike density for seed lots threshed with the conventional combine at optimum and high cylinder speed (Figure 4.1b).

Yield was reduced with seed lots threshed at high cylinder speed for both combines (Figure 2a). However, seed lots threshed with the conventional combine had the greatest difference between high cylinder speed threshing and low cylinder speed threshing.

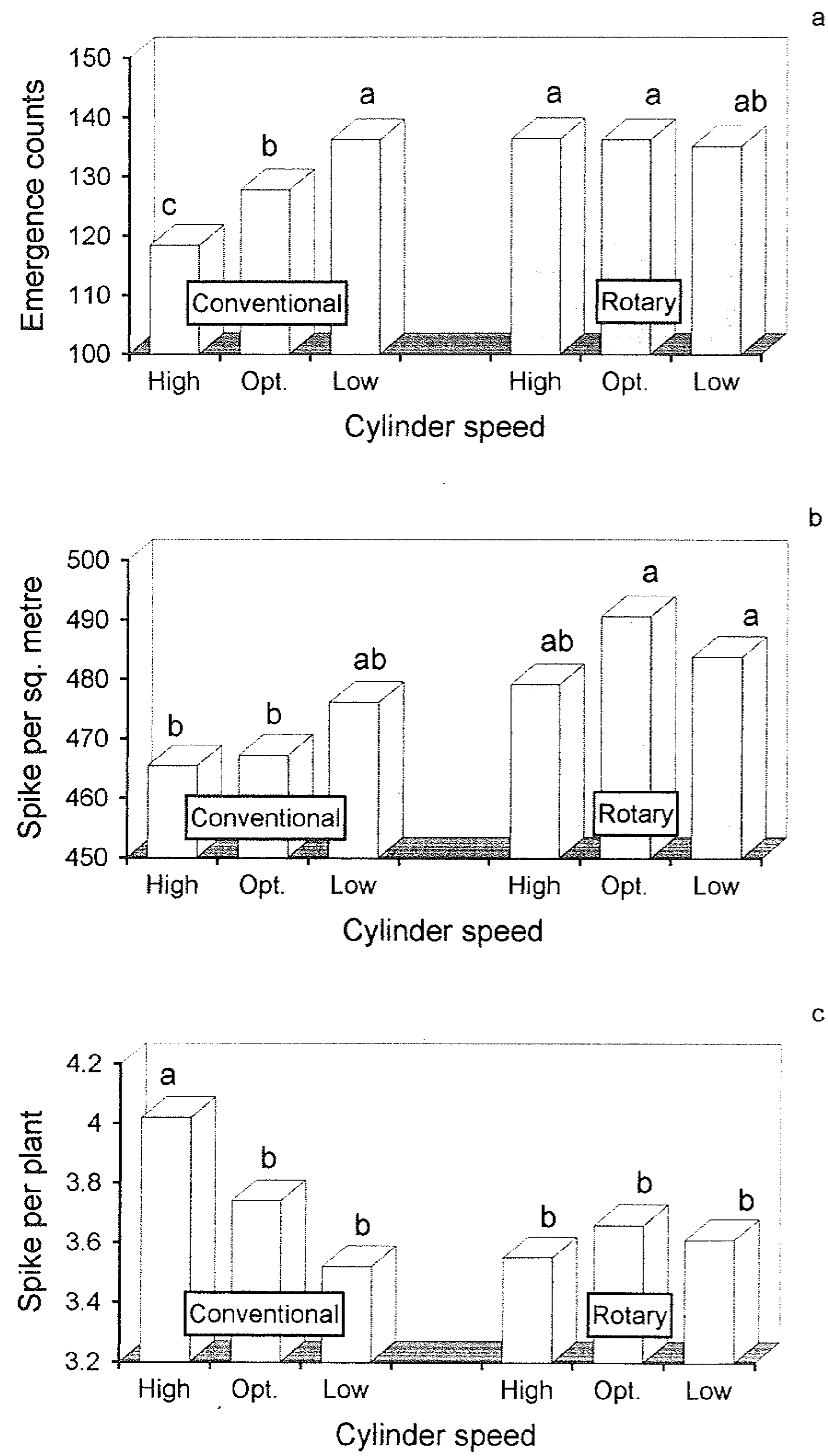


**Figure 4.1.** Effect of threshing conditions of seeds on (a.) field emergence, (b.) spike counts $m^{-2}$ and (c.) spike counts per plant. (Bars with different letters are different at $p<0.05$)

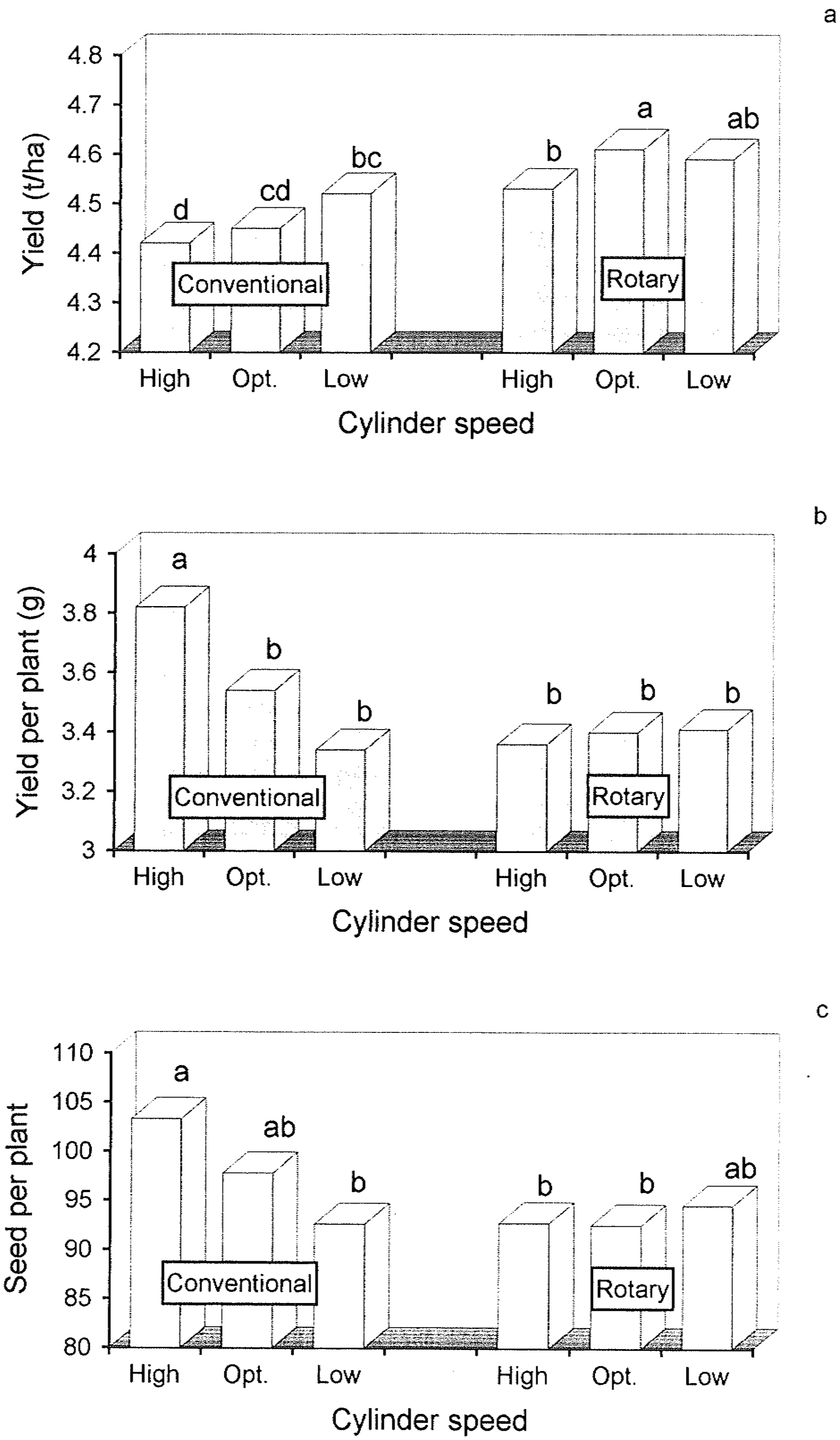


**Figure 4.2.** Effect of threshing conditions of seeds on (a.) yield in t $ha^{-1}$, (b.) yield per plant in g and (c.) seed number per plant. (Bars with different letters are different at $p<0.05$)

Comparisons between means of 1992b were made to determine difference among seed lots threshed with the commercial combines and with the belt thresher. Both field emergence and yield were reduced for the seed lots threshed with the conventional combine at high- and optimum-cylinder speed (Figure 4.3a and 4.3b). All other seed lots performed as well as the belt threshed seed lot.

Thousand kernel mass and seed number per spike were similar among treatments (Table 4.1 and 4.2). Thousand kernel mass was only correlated (negatively) to the number of seed per spike (Table 4.5).

Individual plants growing at a low density had more spikes per plant and more seeds per spike (Table 4.5). Tiller and seed setting only partially compensated for yield loss due to low plant density. The emergence count was the only yield component to be positively correlated with yield (Table 4.5).

Broken seed number in the threshed sample and leachate conductivity of the remaining sound seeds were negatively correlated with field emergence and grain yield (Table 4.6). Field emergence was positively correlated with the number of normal seedlings in the cold- or the standard-germination tests. However, yield was only positively correlated to the number of normal seedlings in the cold germination test.

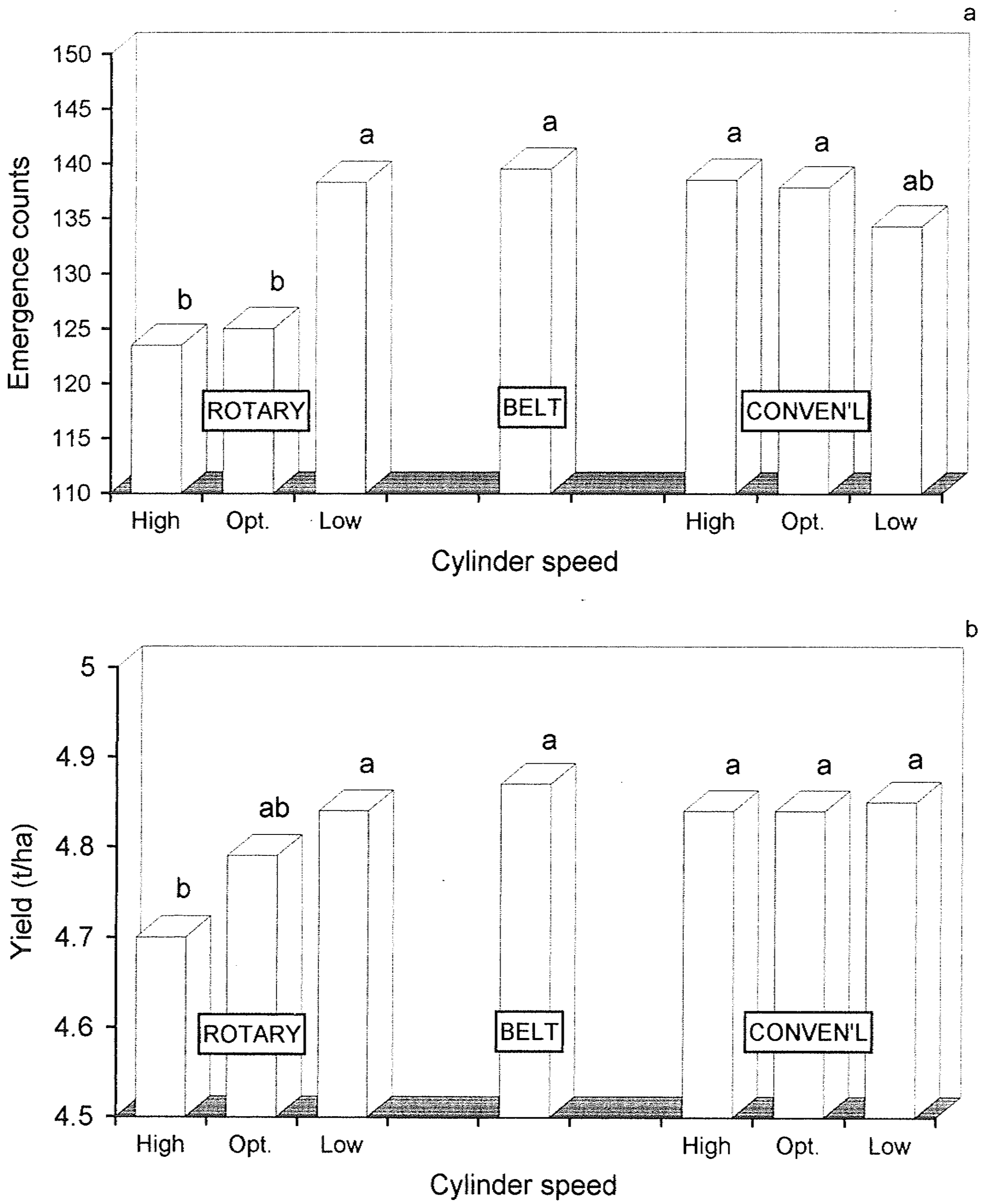


**Figure 4.3.** Effect of threshing conditions of seeds on (a.) field emergence and (b.) yield.
(Bars with different letters are different at $p<0.05$)

**Table 4.5.** Pearson correlation coefficients on combined observations from 1991, 1992a and 1992b.

| | OBS | EMG | SPK | SPK/PL | YLD | YLD/PL | YLD/SPK | TKM | SEED/PL |
|---|---|---|---|---|---|---|---|---|---|
| OBS | | 108 | 108 | 108 | 105 | 105 | 105 | 72 | 72 |
| SPK | 108 | 0.16 † | : | : | : | : | : | : | : |
| SPK/PL | 108 | -0.83 ** | 0.38 ** | : | : | : | : | : | : |
| YLD | 105 | 0.31 ** | -0.15 | -0.37 ** | : | : | : | : | : |
| YLD/PL | 105 | -0.70 ** | -0.27 ** | 0.52 ** | 0.44 ** | : | : | : | : |
| YLD/SPK | 105 | 0.11 | -0.68 ** | -0.48 * | 0.82 ** | 0.49 ** | : | : | : |
| TKW | 72 | 0.07 | 0.09 | -0.00 | 0.03 | -0.08 | -0.10 | : | : |
| SEED/PL | 72 | -0.94 ** | -0.24 * | 0.78 ** | 0.13 | 0.99 ** | 0.33 ** | -0.23 | : |
| SEED/SPK | 72 | -0.26 * | -0.88 ** | -0.28 * | 0.20 | 0.33 ** | 0.97 ** | -0.33 ** | 0.38 ** |

† Data followed by * and ** are significant at p=0.05 and p=0.01, respectively.

OBS: number of observations; EMG: emergence counts; SPK: spike counts; SPK/PL: spikes per plants; YLD: grain yield; YLD/PL and YLD/SPK: yield per plant and yield per spike, respectively; TKM: thousand kernel mass; and SEED/PL and SEED/SPK: seeds per plant and seeds per spike, respectively.

**Table 4.6.** Pearson correlation coefficients between indoor vigour tests, field emergence counts and grain yield.

| | Emergence counts | Yield |
|---|---|---|
| Observation | 108 | 105 |
| Broken seed | -0.37 **† | -0.20 * |
| Conductivity | -0.35 ** | -0.29 ** |
| Normal seedlings in: | | |
| - cold germination test | 0.35 ** | 0.23 * |
| - standard germination test | 0.37 ** | 0.12 |

† Data followed by * and ** are significant at p=0.05 and p=0.01, respectively.

## 4.4. Discussion

### 4.4.1. Seed threshing damage and field performance

Threshing damage to seed will vary depending on combine type and cylinder adjustment. This damage can reduce the yield potential of the seed. Seed threshed with the conventional combine at high- and optimum-cylinder speed had a low plant stand and yield compared to the other treatments.

In this study, little effect on emergence and yield was observed among seed lots threshed with the rotary combine. Seeds threshed with the rotary combine performed as well in the field as the seed threshed with the belt thresher. Harrison (1992) found that the use of a wide range of cylinder speeds in a rotary combine resulted in little seed breakage, although no field studies were conducted on the seed.

Seeds harvested at the low cylinder speed with the conventional combine performed as well as the seed harvested with the rotary combine. Nevertheless, earlier studies found that threshing losses were greatest with this treatment (Table 3.2 page 33; Vas and Harrison, 1969). Seed growers using a conventional combine should be prepared to lose seed during threshing to produce the best quality seed. A rotary combine, on the other hand, produced high vigour seed without affecting threshing losses (Table 3.2 page 33).

In this study, low field emergence was compensated by increased tillering and production of more seed per spike. Similar compensation was observed by (Ayre, 1980; Entz et al., 1991). Tekrony and Egli (1991) suggest that yield differences between seed lots of different vigour levels is often nullified by the compensation capacity of cereals. The plants that established from the low vigour seed lots have more space to develop. Studies found that tiller growth was influenced by light intensity reaching individual tillers (Jewiss, 1972). High plant density creates more shadow in the canopy which result in less tiller growth.

Differences in emergence between low- and high-vigour seeds may vary with the stress level (Graven and Carter, 1991; Ngoma, 1992). The stress level is difficult to predict at seeding time. Therefore, the target plant density can be obtained with the least variation due to the environment by planting high vigour seed (Graven and Carter, 1991).

Low vigour seeds produce non uniform or patchy plant stands (Ayre, 1980). In this study, no measurements on plant to plant variability within treatments were made. However, plant to plant variability could be observed visually in plots planted with seed threshed with the conventional combine at a high cylinder speed.. Seed lots containing 25% of seed producing abnormal seedlings (Table 4.4) appeared to have greater unevenness of emergence within a plot compared to seed lots with a high number of seed producing normal seedlings in the cold germination test. Gan et al. (1992) have demonstrated that plant to plant variability in emergence can lead to yield losses. Plants emerging late do not produce yields equivalent to early emerging plants. Such late emerging plants can be viewed as parasites (or weeds) because they take up resources without contributing to yield.

Ayre (1980) found that wheat plants growing from low vigour seeds had a slow development compared to wheat plants growing from high vigour seeds. The slow development may be related to tiller production for low density compensation. While plants growing in an optimum density focus their photosynthate toward spike development, the plants in low density focus their photosynthate in tiller production.

Optimum density of wheat can provide high yield with the least dockage (small seeds) as shown by Moes et al. (1992) in a study on the effect of seeding rate on yield. Wheat plants growing at a low plant density set more seed per spike than plants growing in optimum density (Tekrony and Egli, 1991; Ayre, 1980). High seed numbers per spike increase the sink number per spike and resources must be divided into more sink than with low seed numbers per spike.

Uneven and patchy plant stands favour weed establishment that can reduce the crop yield by competing for resources (Evans et al., 1991). Planting high vigour seed will produce a more uniform stand that can increase the crop competitive ability with weeds. "The best weed killer is a good crop" (Fryer, 1981)

## 4.4.2 Relation among vigour tests and field performances

Seed lots with the lowest vigour test results (Figure 3.1 and 3.2, page 39-40) had the lowest plant establishment in the field. Similar observations were made by (DasGupta and Austenson, 1973; Ayre, 1980; Sonntag, 1989; Empey, 1992). Yield was correlated to seed vigour tests, although with less precision than field emergence.

The amount of broken seed in a sample was negatively correlated with the performance of the seed lot. A similar observation was made by Mitchell (1955). Impact forces necessary to separate seeds from plant material may create microscopic or visual fracture in some kernels. The amount of broken seed in a sample is proportional to the impact forces applied to the seed and, to a degree, to the extent of internal damage (Mohsenin, 1986). Internal damage in seed, such as microscopic fractures in the pericarp or bruised embryo, reduces the number of germinating normal seedlings (Kolowca and Slipek, 1978). Microscopic fractures measured indirectly by leachate conductivity test, were severe in seed lots threshed at high cylinder speed

Figure 4.4 shows a hypothetical distribution of seed damage categories under increasing impact forces. While broken seed increases slightly, the damaged seed (internal damaged and embryo bruising) increases sharply. A high percentage of damaged seed reduces the normal seedling percentage and field emergence uniformity.

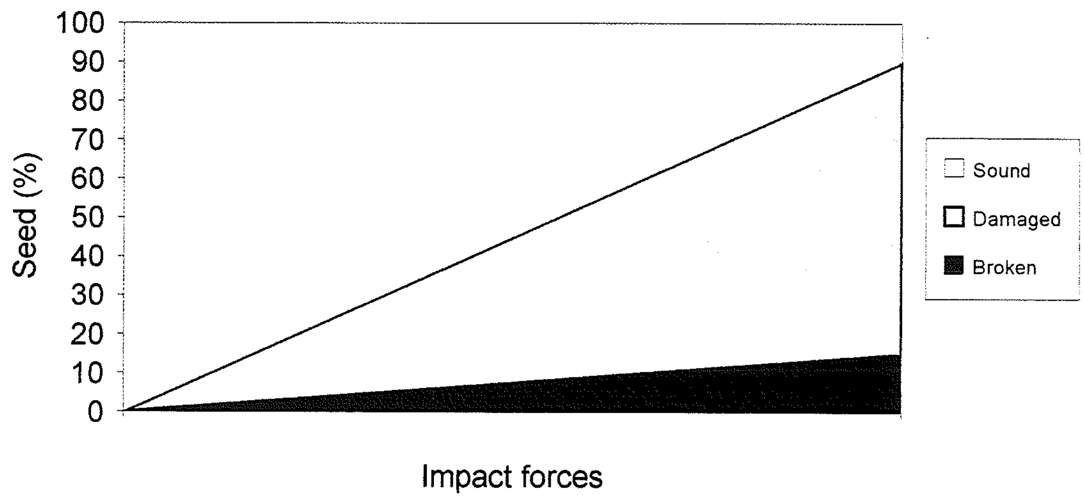


**Figure 4.4.** Hypothetical distribution of sound, damaged and broken seed with increasing impact forces.

Seed growers should pay more attention in the number of broken seed in threshed samples when they adjust their combine. Such a recommendation can also be applied to seed cleaning units which can damage seed (Pierce and Hanna 1985). Reducing impact damage and, thereby, reducing the number of broken seed, will ensure high vigour seed with high yield potential.

## 4.5. Conclusion

Combine by cylinder speed interaction was significant for most field performance of the seed lots. Threshing with an axial flow rotary combine (single rotor) was gentler on seed across a wider range of cylinder speeds than with a conventional combine.

Threshing at high cylinder speeds with the conventional combine damages wheat seeds resulting in fewer plants in the field. Yield potential was reduced for seed lots threshed at high cylinder speeds.

Emergence was reduced with low vigour seed. High tiller production and high seed setting compensated for reduced plant population in plots planted with low vigour seeds but not sufficiently to nullify yield differences.

Field emergence and yield are reduced when seed lots that contained a large number of broken seed at harvest, are planted. Therefore, broken seed should be used as a sign indicating that cylinder speed is greater than necessary. Broken seed number should be kept to a minimum (no greater than 0.5%).

Only high vigour seed should be planted to ensure uniform plant establishment. Such seed can produce a uniform and competitive crop under a great range of environmental conditions. The crop makes efficient use of the resources resulting in high yield

# 5. Vigour loss of wheat seed caused by threshing: III. Kernel water content at harvest and kernel physical characteristics influence on threshing damage.

## 5.1. Introduction

The resistance of individual seeds to impact forces changes with different KWC (Mitchell and Roundthwaite, 1964). Wheat seeds with KWC above 20% are plastic under an impact force, therefore, are likely to be deformed, but less likely to break compared to seed with KWC below 20% (Bilanski, 1966). High velocity impact may break or deform seeds (internal damage) with low and high KWC, respectively (King and Riddolls, 1962; Entz et al., 1991; Mitchell, 1955). The same authors found a reduction of seed vigour in seed lots threshed at high velocity impact.

Mitchell and Roundthwaite (1964) found that wheat cultivars did not respond similarly to threshing damage. Seed characteristics such as hardness, glassiness or mass contribute to reduce the physical resistance of the seed to impact forces. Studies on rice demonstrated the importance of kernel germplasm as well as kernel shape for resistance to impact forces (Dilday, 1989). Long seeds were less resistant to impact forces than round seeds, though great variation in resistance occurred among cultivars producing long seeds.

The objectives of this study were: (1) to determine the effect of KWC at harvest on seed vigour and field performance; (2) to determine the relationship between seed characteristics of different cultivars, with seed vigour and field performance; and (3), to determine the strength of the regression equation (section 3.3.4) to predict the number of normal seedlings from the percentage of broken seeds in seed lots threshed at various KWC and of various cultivars.

# 5.2. Materials and Methods

## 5.2.1. Crop establishment for the threshing studies

Six wheat cultivars were planted at Portage la Prairie on May 15 and 16, 1991 in 3 ranges of 1.53, 0.78 and 0.45 ha. The experiment was set up in a randomized complete block design and each range was considered a block. The plot area was 9 m in width and 255, 130 and 106 m in length for range 1, 2 and 3, respectively. Soil types were Neuhorst clay loam for range 1 and Dugas clay for range 2 and 3.

The cultivars were Katepwa, Neepawa, Roblin and Sceptre; the first three are classified as Hard Red Spring Wheat (HRS) and Sceptre as an Amber durum. The cultivars were selected on the basis of kernel size, kernel glassiness and kernel shape. Sceptre produces the largest, longest and most glassy kernels among the four cultivars. Glassiness is similar among the three HRS wheat. Roblin produces the largest kernels among the three HRS wheat. Neepawa and Katepwa have similar size kernels but Neepawa has rounder kernels than Katepwa.

The wheat was planted on wheat stubble. Fertilizers were applied as required (Appendix Table 2) and followed by a shallow cultivation. Three passes of a 3 m wide Amazone drill[1] was used for planting each cultivar in each range. Certified seeds were planted at

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1 Amazone-Werke, model CCD, Hasbergen-Gaste, Germany

a rate of 300 seeds $m^{-2}$ for Sceptre and Roblin, and 250 viable seeds $m^{-2}$ for Neepawa and Katepwa. Viability was determined by standard germination test in four petri dishes of 50 seeds per cultivar (AOSA, 1983).

Pesticides were applied as required (Appendix Table 3).

The crop was swathed August 17 for range 3, August 18 for range 1 and August 19 for range 2 with a 9 m wide swather. The ranges were swathed at different dates to create variation in KWC. Dry- and hot-weather prevailed during the period the crop was swathed.

Each swath was harvested using a conventional combine[2]. From each swath an unthreshed sample was collected, air dried and threshed using a belt thresher[3].

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2 John Deere, 9000 series, Regina, SASK.
3 Agriculex, model SPT-1, Guelph, ONT.

## 5.2.2. Threshing studies

### 5.2.2.1. Sampling procedures

- **Experiment 1**. Effect of KWC on the resistance to threshing damage of Katepwa wheat

A conventional combine was used with a concave clearance of 10 mm (front) and 5 mm (back), and a cylinder speed of 850 RPM (29.4 m $s^{-1}$ peripheral cylinder speed). Forty-three Katepwa samples were taken randomly over the three ranges with a pail from the hopper loading auger of the combine for KWC determination. Each seed sample weighed an average of 500 g.

KWC of the samples was measured with a Labtronic model 919 moisture meter[4]. KWC ranged from 13.8 to 22.6%. Seed lots were grouped within 5 KWC groups -- 14%, 15.7%, 17.1%, 19.7% and 22.5% -- and 3 samples were kept within each KWC group for analyses except the 22.5% KWC group, which had only 2 samples. Samples within a group had KWC differences smaller or equal to 0.2%. Samples in the 19.7% KWC and 22.5% KWC groups, were spread out to air dry (air temperature below 25$^{o}$C).

KWC at harvest for Sceptre, Roblin and Neepawa were uniform, and the effect of KWC on threshing damage could not be determined.

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4 Labtronic, Winnipeg, Manitoba.

- **Experiment 2**. Seed damage comparison between a belt thresher and a conventional combine

Wheat plants were harvested randomly from all the swaths before threshing. These plants were threshed with a belt thresher to provide zero damage reference seed lots. Seed lots from the belt thresher were compared to seed lots threshed with the conventional combine. Sampling on the conventional combine occurred during the entire time of threshing a particular swath. Ten to 20 samples were recovered from each swath. The cylinder speed of the conventional combine was 850 RPM (29.4 m $s^{-1}$ peripheral cylinder speed) for all cultivars except Sceptre durum which was threshed with a cylinder speed of 800 RPM (27.6 m $s^{-1}$ peripheral cylinder speed). Concave adjustments were the same as used for threshing the Katepwa wheat.

KWC was determined with a Labtronic model 919 for all samples. One sample per cultivar and per range, within a KWC range of 13 to 14%, was kept for comparison with the belt threshed sample.

5.2.2.2. Sample procedure and laboratory seed vigour tests

A similar procedure was applied for seed lots of both experiments. Sample processing started two weeks after threshing. The sample size was reduced to around 400 g by using a conical sample divider. After sieving through a 2.2 by 19 mm and 3.2 by 19 mm slotted sieves, all sieved fractions were hand sorted into broken, sound and unthreshed seeds larger than 2.2 mm.

Cold germination test was conducted at 5°C on sound seeds. Four replicates of 50 seeds were placed on two layers of filter paper (Whatman #1) in 9 cm petri dishes and soaked with 6 ml of distilled water. Germination was evaluated two weeks after the test was initiated. Seeds were classified as non germinated or producing a normal or abnormal seedling. A seedling that had one visible shoot and three distinct, symmetrical roots was considered normal. A similar procedure was used for the standard germination with the exception of temperature (20°C). Germination was evaluated four days after the test was initiated.

Three replicates of 100 seeds were soaked in 75 ml of distilled water for the leachate conductivity test. The flasks were held at 20°C for one day. The leachate conductivity was then measured with a reversed ohmmeter, and expressed in mhos ($ohm^{-1}$). The solution was agitated before the reading. The electrode was held in the solution until the reading stabilized. Between each sample the electrode was cleaned with distilled water.

The belt threshed samples were used to determine kernel characteristics among cultivars. Protein content was measured with a NIR analyzer[5]. Thousand kernel mass was determined by weighing four subsamples of 100 seeds.

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5 Dickey-John Canada Inc, model Instalab 800, Devon, AB

A computerized image analyzer system[6] was used to measure the seed area (in $mm^2$), seed length (in pixel) and the circularity factor. Fifty seeds of each replicate and treatment were placed under the computer camera. The computer digitized the image and computed length, width and circularity factor for each seed. The circularity factor was obtained by dividing the smallest width by the longest length (both width and length pass through the centre of the object). A round object tends to have a circularity factor close to 1 (Lamari, personal communication). Average length and circularity factor were calculated among the 50 seeds of each replicate and treatment for further analyses.

5.2.2.3. Field performances of the seed lots

The seed lots from both experiments were planted into canola stubble at the Plant Science Field Research station at Portage la Prairie, Manitoba on May 7, 1992. The soil type was a Neuhorst clay loam.

Seed rates were 200 seed $m^{-2}$ for Katepwa and Neepawa and 250 seed $m^{-2}$ for Roblin and Sceptre. Fertilizer and pesticide applications are presented in Appendix Tables 2 and 3.

The experimental design for each cultivar was a randomized complete block design with 6 replicates. Katepwa had 6 treatments (5 KWC levels and one belt threshed treatment), whereas, the other

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6 IBM 386DX with colour video card

cultivars had only 2 treatments (conventional combine vs belt thresher).

Field emergence, head counts, yield and thousand kernel mass were recorded following the procedure described in 4.2.3.2. page 56. Yield per spike, yield per plant, seed per spike and seed per plant were calculated from the above measurements.

### 5.2.3. Statistical analyses

Statistical analyses were performed using SAS procedures (SAS Institute, 1982). Differences with $P<0.05$ were considered meaningful, and least significant differences ($P=0.05$) were used as basis of comparison among treatments. The laboratory results were analyzed following a procedure of a completely randomized design for experiment 1 and of a randomized complete block design for experiment 2.

The field results were analyzed following randomized complete block design for experiment 1 and experiment 2. The four cultivars in experiment 2 were analyzed in a combined ANOVA following a procedure described in Gomez and Gomez, page 335 (1984). Simple correlation analyses were performed to determine the strength of relationship among vigour tests and seed characteristics.

## 5.3. Results and Discussion

### 5.3.1. Experiment 1

There were no significant differences in the number of broken seed among seed lots of the five KWC groups (Table 5.1). However, samples threshed with a low KWC tended to have the highest number of broken seed. Brittleness of wheat kernels increases as the KWC decreases (Zoerb and Hall, 1960; Mitchell and Roundthwaite, 1964; Bilanski, 1966; Mohsenin, 1986).

The leachate conductivity increased with a decrease in KWC, suggesting that seed threshed with low KWC had more pericarp micro fractures than seed threshed with high KWC (Table 5.1). Such fractures are pathways for pathogens (Caldwell and Davies, 1957), affect the enzyme activity in the aleurone layer and cause leakage of nutrients from the endosperm (Livesley and Bray, 1991).

In the cold germination test, wheat threshed at a high KWC had the lowest number of normal seedlings due to an increase in the number of non germinated seeds and abnormal seedlings (Table 5.1). A similar trend was noted using the standard germination test, although the difference between seed threshed at low and high KWC was not as pronounced.

**Table 5.1.** Means of laboratory vigour tests of seed lots threshed at different KWC.

| KWC | Percent broken seeds | Conduc-tivity | Cold germination test Seedling types | | | Standard germination test Seedling types | | |
|---|---|---|---|---|---|---|---|---|
| | | | Normal | Non germ. | Abnormal | Normal | Non germ. | Abnormal |
| (%) | (%) | (mhos) | ........ | ........ | ........ (%) | ........ | ........ | ........ |
| 14 | 1.35 a† | 86.6 ab | 81.3 ab | 2.7 c | 16.0 ab | 85.3 a | 5.4 b | 9.3 a |
| 15.7 | 1.28 a | 88.1 a | 84.3 a | 4.3 c | 11.3 b | 83.3 a | 5.1 b | 11.6 a |
| 17.1 | 0.91 a | 81.9 ab | 74.7 bc | 9.0 b | 16.3 ab | 80.5 ab | 8.2 b | 11.3 a |
| 19.7 | 0.86 a | 78.5 b | 69.0 cd | 9.7 b | 21.3 a | 78.9 ab | 8.4 b | 12.7 a |
| 22.5 | 0.97 a | 78.1 b | 63.0 d | 13.5 a | 23.5 a | 74.0 b | 12.7 a | 13.4 a |
| Sdt Error | 0.22 | 3.77 | 3.70 | 1.47 | 3.75 | 3.82 | 1.83 | 2.39 |

† Means within a column followed by a different letter are significantly different at the 5% probability level.

A noticeable reduction in normal seedling number was observed for samples threshed over 17% KWC (Table 5.1). Mitchell (1955), King and Riddolls (1962) showed that the number of non germinated seed increased rapidly in samples threshed over 22% KWC. The results from this experiment show that KWC below 22% can have a significant negative effect on seed quality.

The results of the leachate conductivity test suggest that seed threshed at high KWC have the highest vigour, as opposed to the results of the germination tests. Broken seed proportion was not correlated to the germination tests but positively correlated to the leachate conductivity (Table 5.2). The leachate conductivity test and the number of broken seed were poor indicators of seed vigour among seed lots threshed with KWC greater than 16% in this study.

The best indicator of vigour among seed lots threshed at various KWC was the number of non germinated seed in the cold and standard germination tests (Table 5.2). The number of abnormal seedlings was also positively correlated with KWC. However, the abnormal seedlings/non germinated seed ratio (data not shown) decreased as KWC increased, suggesting a greater effect of KWC on non germinated seed than on abnormal seedlings.

**Table 5.2**. Correlation analyses among vigour results of seed lots threshed at different KWC.

| | KWC | CDC | NCG | DCG | ACG | NSG | DSG | ASG |
|---|---|---|---|---|---|---|---|---|
| BRK | -0.54 *† | 0.72 ** | 0.37 | -0.50 | -0.20 | 0.15 | -0.27 | 0.02 |
| KWC | | -0.66 ** | -0.85 ** | 0.90 ** | 0.63 * | -0.70 ** | 0.77 ** | 0.48 |
| CDC | | | 0.67 ** | -0.61 * | -0.57 * | 0.36 | -0.49 | -0.13 |
| NCG | | | | -0.83 ** | -0.91 ** | 0.74 ** | -0.79 ** | -0.52 |
| DCG | | | | | 0.52 | -0.67 ** | 0.75 ** | 0.45 |
| ACG | | | | | | -0.63 * | 0.66 * | 0.47 |
| NSG | | | | | | | -0.91 ** | -0.88 ** |
| DSG | | | | | | | | 0.62 * |

† Correlation coefficients followed by * and ** are significant at the 5 and 1% probability level, respectively.

KWC: kernel water content; BRK: per cent broken seed; CDC: leachate conductivity; NCG, DCG and ACG; normal seedlings, non germinated seeds and abnormal seedlings in the cold germination test, respectively; and NSG, DSG and ASG; normal seedlings, non germinated seeds and abnormal seedlings in the standard germination test, respectively.

Seed vigour loss with high or low KWC depends on the impact forces (cylinder speed) absorbed by the seed (Mitchell and Roundthwaite, 1964; Mitchell, 1955). Generally, higher cylinder speeds must be used to thresh seeds from a "tough crop" (high KWC), resulting in greater vigour loss compared to a dry crop.

Field emergence was significantly reduced for seed threshed at high KWC compared to seed threshed at low KWC (Table 5.3), but by the end of the season the spike number per unit area was the same. Tiller number was greater in plots planted with seed threshed with high KWC than with seed threshed with low KWC, which indicates compensation for low plant density. This experiment was conducted under weed-free conditions, allowing for stands with low densities to produce tillers.

The density of plants grown from low vigour seed lots was low and the plant to plant variability was high. This variability was observed until heading. Plant to plant variability may account for yield difference (Gan et al., 1992). Spike development in tillers is delayed compared to the main culm (Jewiss, 1972; Dewey and Albrechtsen, 1985), therefore, high tillering in low density plot may have emphasized the unevenness of the crop.

Yield was the lowest for seed lots threshed at 22.5% KWC despite higher yield per plant and higher number of seed per plant produced in plots planted with seed threshed with high KWC compared to low KWC (Table 5.3).

**Table 5.3**. Field performance of seed lots threshed at different KWC.

| KWC | Field emergence | Spike number | Yield | Yield per spike | Yield per plant | Thousand kernel mass | Seed per spike | Seed per plant |
|---|---|---|---|---|---|---|---|---|
| (%) | .......... ($m^{-2}$) | .......... | ($t.ha^{-1}$) | .................... | (g) | .................... | | |
| 14 | 137.2 a† | 469.3 a | 4.72 ab | 1.01 a | 3.45 b | 37.8 a | 26.9 a | 91.6 b |
| 15.7 | 137.2 a | 462.5 a | 4.80 a | 1.04 a | 3.52 ab | 38.2 a | 27.3 a | 92.0 b |
| 17.1 | 128.2 ab | 457.8 a | 4.71 ab | 1.03 a | 3.70 ab | 38.2 a | 27.0 a | 96.9 ab |
| 19.7 | 128.0 ab | 463.0 a | 4.70 ab | 1.02 a | 3.78 ab | 38.2 a | 26.7 a | 98.6 ab |
| 22.5 | 118.3 b | 441.8 a | 4.59 b | 1.05 a | 3.89 a | 38.1 a | 27.5 a | 102.0 a |
| Std. error | 6.38 | 18.08 | 0.095 | 0.042 | 0.19 | 0.47 | 1.02 | 4.58 |

† Means within a column followed by a different letter are significantly different at the 5% probability level

Thousand kernel mass and seed number per spike were not different among plots planted with seed threshed with different KWC (Table 5.3)

## 5.3.2. Experiment 2

Katepwa and Neepawa had similar kernel characteristics, except that Neepawa had rounder kernels than Katepwa (circularity factor, Table 5.4). Roblin had a similar protein content than Neepawa and Katepwa, but had greater mass and size. Seed samples of Roblin contained more broken seed than samples of the other HRS wheat suggesting that large kernels are more subject to breakage under impact than small kernels (Bilanski, 1966).

The durum wheat (Sceptre) had long and heavy kernels relative to the other cultivar tested in this study (Table 5.4). Sceptre seed lots contained a large proportion of broken seed, probably due to the seed size and also seed glassiness. Sceptre seeds were more glassy than the HRS wheat. Glassiness is caused by a high gluten content and by a high cohesion of starch granules (Kolowca and Slipek, 1978) which increase hardness (Bennett, 1950) and kernel brittleness under impact forces (Kolowca and Slipek, 1978).

**Table 5.4.** Kernel physical characteristics of four wheat cultivars.

| Cultivar | Circu-larity factor | Protein content | Thousand Kernel mass | Broken seed | Kernel Area | Maximum Kernel Length |
|---|---|---|---|---|---|---|
| | | (%) | (g) | (%) | ($mm^2$) | (Pixel) |
| Katepwa | 0.57 b† | 15.3 a | 34.0 b | 1.27 bc | 11.7 b | 44.2 b |
| Neepawa | 0.63 a | 15.5 a | 34.0 b | 1.19 c | 11.6 b | 41.9 c |
| Roblin | 0.59 ab | 15.7 a | 35.2 b | 1.84 ab | 12.3 b | 44.6 b |
| Sceptre | 0.45 c | 13.7 b | 41.9 a | 2.03 a | 13.7 a | 54.1 a |
| Std. Error | 0.021 | 0.25 | 0.68 | 0.23 | 0.35 | 0.85 |

† Means followed by * and ** are significant at p=0.05 and p=0.01, respectively.

Vigour test results were different among cultivars and between the conventional combine threshed seed lots and the belt threshed seed lots (Table 5.5). The response of cultivar to threshing damage (interaction C x T) was significantly different for a number of parameters including the number of normal and abnormal seedlings in the cold germination test and the number of non germinated and abnormal seedlings in the standard germination test. Variations in vigour among cultivars may result from different genotypes (Roberts and Osei-Bonsu, 1990).

**Table 5.5.** Mean squares from the vigour test analyses of variance of seed lots of different cultivars threshed with a conventional combine and a belt thresher..

| Source of variation | df | Conductivity | Cold germination test Seedling types: Normal | Non germ. | Abnormal | Standard germination test Seedling types: Normal | Non germ. | Abnormal |
|---|---|---|---|---|---|---|---|---|
| Replicate | 2 | 45.6 *† | 19.0 | 9.38 | 22.2 | 11.1 | 8.2 | 0.5 |
| Cultivar (C) | 3 | 2640.7 ** | 206.9 ** | 11.28 | 135.2 ** | 455.9 ** | 110.3 ** | 117.2 ** |
| Error A | 6 | 21.97 | 8.10 | 3.15 | 5.94 | 9.52 | 2.60 | 4.35 |
| Thresher (T) | 1 | 2035.0 ** | 1488.4 ** | 73.50 ** | 900.4 ** | 595.0 ** | 28.6 * | 362.7 ** |
| C x T | 3 | 78.3 | 113.2 * | 5.50 | 78.2 * | 19.3 | 26.4 ** | 23.6 * |
| Contrasts: | | | | | | | | |
| T in C=Katepwa | 1 | 308.2 ** | 253.5 ** | 13.50 | 150.0 * | 253.5 ** | 28.6 * | 111.8 ** |
| T in C=Neepawa | 1 | 254.8 ** | 73.5 | 1.50 | 54.0 | 36.0 | 1.0 | 25.6 |
| T in C=Roblin | 1 | 454.1 ** | 352.7 ** | 37.50 ** | 160.2 * | 212.4 ** | 64.7 ** | 42.7 * |
| T in C=Sceptre | 1 | 1252.8 ** | 1148.2 ** | 37.50 ** | 770.7 ** | 151.0 ** | 13.5 | 253.5 ** |
| Error B | 8 | 21.97 | 16.08 | 2.63 | 18.08 | 9.55 | 2.93 | 4.84 |

† Means squares followed by * and ** are significant at the 5 and 1% probability level, respectively.

Results of contrast analysis underlined variation in the response of each cultivar to threshing damage (Table 5.5). All cultivars had significant difference in leachate conductivity between conventional combine threshed samples and belt threshed samples. There were no differences in germination test results between threshing methods for Neepawa. Vigour of the other cultivars was significantly affected by threshing methods.

Leachate conductivity was greater with conventional combine threshed seed than with belt threshed seed across the four cultivars (Table 5.6). The conventional combine submitted the seed to greater impact forces than the belt thresher, resulting in more severe pericarp damage.

Results of the germination tests also indicated less damage with the belt thresher (Table 5.6). Seed threshed with the belt thresher had a greater percentage of normal seedlings, fewer non germinated seeds and fewer abnormal seedlings across the four cultivars, except for the number of non germinated seed in the standard germination test with Sceptre durum. The presence of dormancy in Sceptre seed may have been broken in the cold germination test (AOSA, 1983) but not in the standard germination test, resulting in fewer non germinated seed in the cold than in the standard germination test.

**Table 5.6.** Results of the seed vigour tests of four cultivars threshed with a conventional combine and a belt thresher.

| Treatments | | Conduc-tivity | Cold germination test Seedling types | | | Standard germination Seedling types | | |
|---|---|---|---|---|---|---|---|---|
| | | | Normal | Non germ. | Abnormal | Normal | Non germ. | Abnormal |
| Katepwa | Belt α | 74.0 b † | 96.7 a | 0.67 a | 2.7 b | 97.7 a | 1.00 b | 1.3 b |
| | Conven'l ß | 88.3 a | 83.7 a | 3.67 a | 12.7 a | 84.7 b | 5.37 a | 10.0 a |
| Neepawa | Belt | 74.4 b | 94.7 a | 3.00 a | 2.3 a | 92.0 a | 3.67 a | 4.3 a |
| | Conven'l | 87.5 a | 87.7 a | 4.00 a | 8.3 a | 87.1 a | 4.47 a | 8.5 a |
| Roblin | Belt | 80.9 b | 96.7 a | 1.33 b | 2.0 b | 96.3 a | 0.33 b | 3.3 b |
| | Conven'l | 98.3 a | 81.3 b | 6.33 a | 12.3 a | 84.4 b | 6.90 a | 8.7 a |
| Sceptre | Belt | 110.6 b | 92.3 a | 3.00 b | 4.7 b | 78.0 a | 13.67 a | 8.3 b |
| | Conven'l | 139.5 a | 64.7 b | 8.00 a | 27.3 a | 68.0 b | 10.67 a | 21.3 a |

† Means within a cultivar followed by a different letter are different at the 5% probability level.
α Seed lots threshed with the conventional combine.
ß Seed lots threshed with the belt thresher.

Differences in vigour loss between threshing methods among cultivars were related to seed mass, size and shape. Thousand kernel mass, seed area and seed length were negatively correlated with the number of normal seedling in cold or standard germination (Table 5.7). In contrast, leachate conductivity and broken seed proportion were positively correlated with thousand kernel mass, seed area and seed length. The results from this study show that long and heavy seeds were more susceptible to vigour loss during threshing than small and light seeds. Large seeds with a high specific mass have a smaller mechanical strength than small seeds (Bilanski, 1960).

By contrast to the other physical parameters, circularity factor was positively correlated with normal seedling number in germination tests and negatively correlated with broken seed and leachate conductivity (Table 5.7). Round seed such as Neepawa, was less damaged by threshing than long seed such as Katepwa, Roblin or Sceptre (Table 5.4). These results are similar to Dilday (1989), who observed that long grain rice was more susceptible to threshing damage than short grain rice.

The differential response to threshing damage by the four cultivars may also be related to protein and starch arrangement in kernels (Bennett, 1950). Studies on rice, wheat and corn, found a great variation in kernel hardness and elasticity between cultivars due to protein and starch arrangement (Bennett, 1950; Mitchell and Roundthwaite, 1964; Dilday, 1989).

**Table 5.7.** Correlation analyses between vigour tests and kernel physical characteristics.

| | NCG | NSG | CDC | BRK |
|---|---|---|---|---|
| TKM | -0.90 **† | -0.92 ** | 0.99 ** | 0.72 ** |
| AREA | -0.95 ** | -0.93 ** | 0.92 ** | 0.73 ** |
| LTH | -0.90 ** | -0.94 ** | 0.97 ** | 0.72 ** |
| CIRC | 0.83 ** | 0.89 ** | -0.90 ** | -0.65 * |

† Data followed by * and ** are significant at the 5 and 1% probability level, respectively.

NCG and NSG: normal seedlings in the cold and standard germination tests respectively; CDC: leachate conductivity; BRK: percentage broken seed; TKW: thousand kernel mass; AREA: kernel size; LTH: kernel length; and CIRC: circularity factor.

Among cultivar tested here, Sceptre durum had the greatest difference in field emergence, yield and thousand kernel mass between belt threshed samples and conventional threshed samples (Table 5.8). Sceptre durum seed lots threshed with the belt thresher had a higher emergence, yield and thousand kernel mass than seed lots threshed using a conventional combine.

Low plant density of Sceptre durum was compensated by high seed set per spike (Table 5.8). Durum spikes from plants growing at a low density produced 3.5 more seeds on average than spikes from plants growing at a high density. Spike number per plant was identical at all densities, in contrast to HRS wheat (Figure 4.1, page 64; Entz et al., 1991) and winter wheat (Ayre, 1980), where spike number per plant was negatively correlated with plant density.

**Table 5.8.** Mean comparison between threshing methods within the four cultivar on field performances.

| Treatments | Field emergence | Spike number | Yield | Yield per spike | Yield per plant | Thousand kernel mass | Seed per spike | Seed per plant |
|---|---|---|---|---|---|---|---|---|
| | ......... ($m^{-2}$) | ......... | ($t.ha^{-1}$) | ................ | (g) | ................ | | |
| **Katepwa** | | | | | | | | |
| Belt α | 138.7 a† | 512.3 a | 4.83 a | 0.94 a | 3.49 a | 38.1 a | 24.9 a | 91.6 a |
| Conven'l ß | 137.2 a | 469.3 b | 4.72 a | 1.01 a | 3.45 a | 37.7 a | 26.9 a | 91.6 a |
| **Neepawa** | | | | | | | | |
| Belt | 136.3 a | 517.8 a | 4.59 a | 0.89 a | 3.39 a | 37.6 a | 23.6 a | 90.0 a |
| Conven'l | 135.7 a | 498.2 a | 4.59 a | 0.93 a | 3.43 a | 37.9 a | 24.5 a | 90.5 a |
| **Roblin** | | | | | | | | |
| Belt | 169.0 a | 484.3 a | 4.58 a | 0.95 a | 2.73 a | 37.4 b | 25.3 a | 72.9 a |
| Conven'l | 161.8 a | 465.7 a | 4.48 a | 0.96 a | 2.79 a | 38.7 a | 24.9 a | 72.3 a |
| **Sceptre** | | | | | | | | |
| Belt | 164.3 a | 429.7 a | 5.47 a | 1.28 b | 3.34 a | 44.3 a | 28.9 b | 75.4 b |
| Conven'l | 140.8 b | 374.2 b | 5.28 a | 1.41 a | 3.80 a | 43.5 b | 32.4 a | 87.4 a |

† Means within a cultivar followed by a different letter are different at the 5% probability level.
α Seed lots threshed with the belt thresher.
ß Seed lots threshed with the conventional combine.

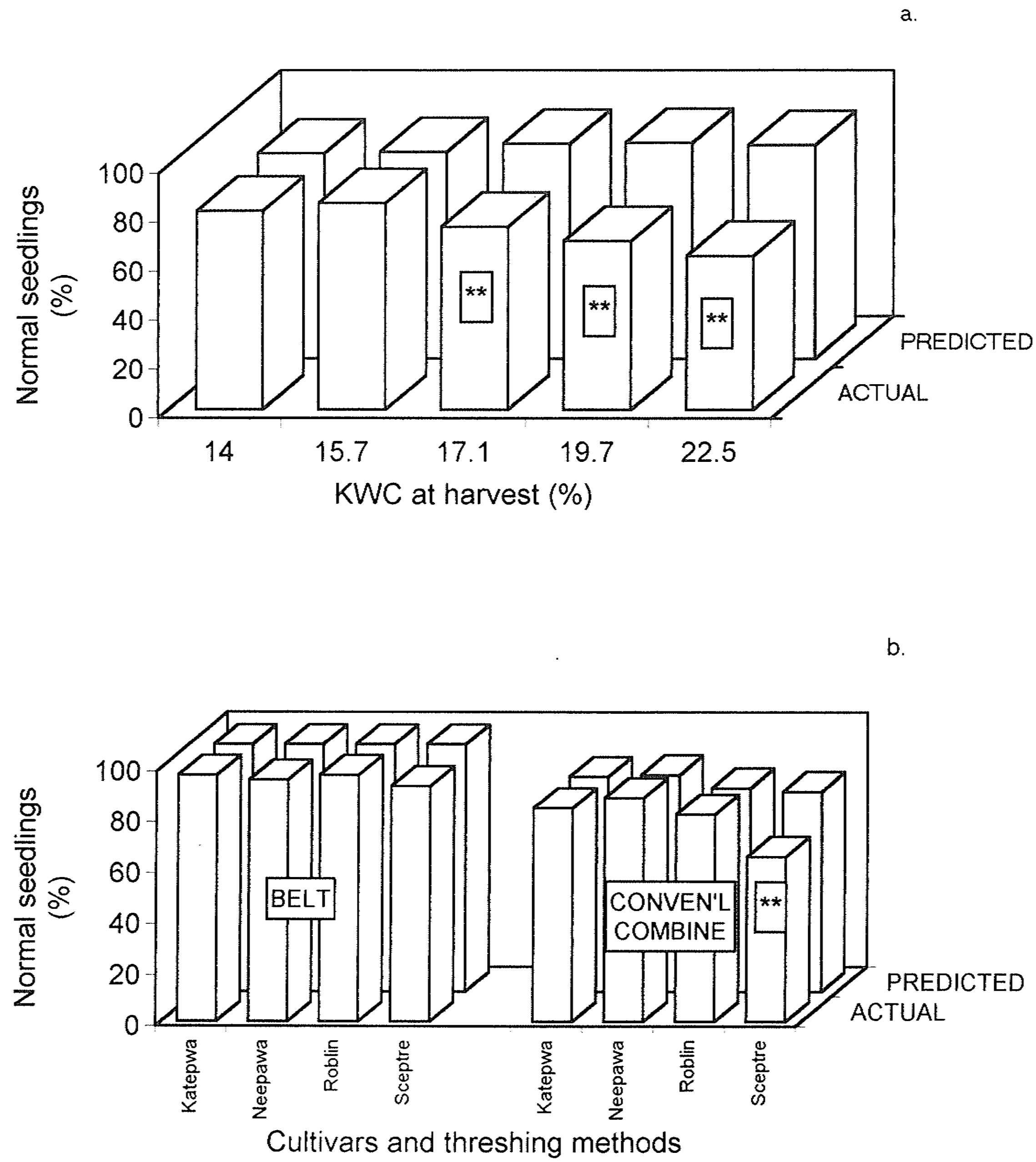
Thousand kernel mass of Sceptre durum was significantly reduced in plots planted with low vigour seeds. The reduction in kernel mass was a consequence of high seed number per spike to compensate for low plant density. A similar nutrient pool (source) was divided into a greater number of seed (sink) for plants growing in low density compared to plants growing in high density. As a result, Sceptre yield was decreased by 200 kg $ha^{-1}$ and the seeds were smaller when low vigour seed was planted compared to high vigour seed. Target plant density in Sceptre durum to ensure high yield with large kernels is achieved by using high vigour seed.

Emergence counts and yields were always equal or higher for the belt threshed seed lots compared to the conventional combined seed lots for the three HRS wheat, although differences were not significant (Table 5.8). Neepawa field performance was the least affected by threshing damage. Vigour tests results also suggested that Neepawa was the least affected by threshing damage in the conventional combine compared to the belt thresher. Although Katepwa and Roblin were less vigorous when threshed with the conventional combine compared to the belt thresher, no vigour difference was observed in field performances.

## 5.4. Relation between KWC, seed characteristics, threshing and vigour

A regression equation (Figure 3.3a, page 48) was developed to predict the percentage of normal seedlings from seed lots with varying percentage of broken seed. This equation can be used to provide a rapid estimation of the vigour of threshed sample. The equation was established with Katepwa wheat threshed at a KWC ranging from 12 to 16%.

The predicted and actual proportion of normal seedlings in the cold germination was compared using Katepwa seed lots threshed at different KWC (Figure 5.1a). The predicted and actual values were not different for the 14 and 15.7% KWC groups. However, the predicted values overestimated the percentage of normal seedlings for KWC equal or greater than 17.1%. These results suggest that the proportion of broken seed in a sample can be used to predict seed vigour only within a particular KWC. Mitchell (1955) found that the proportion of broken seed was related to seed vigour within small KWC range, but the proportion of broken seed was not related to seed vigour among KWC groups.




** Significant at p=0.05.

**Figure 5.1.** Difference between the predicted and actual number of normal seedlings in cold germination test for seed lots threshed at various KWC (a.) and for seed lots of four cultivars threshed with a belt thresher or a conventional combine (b.).

Figure 5.1b compares the predicted and actual proportion of normal seedlings in the cold germination test conducted on the four cultivars threshed with a belt thresher and a conventional combine. Samples threshed with the belt thresher had similar predicted and actual proportion of normal seedlings. Likewise, the HRS wheat threshed with the conventional combine had similar predicted and actual proportion of normal seedlings. Sceptre durum threshed with the conventional combine had a lower proportion of normal seedlings than predicted. These results suggest that the loss of seed vigour due to threshing damage is more important with durum wheat than with HRS wheat. Therefore, seed growers should give the greatest care in adjusting their combines when threshing durum wheat. The cylinder speed should be reduced until no broken kernels can readily be found in the threshed sample.

## 5.5. Conclusion

High KWC at harvest reduced the resistance of seed to impact damage, resulting in poor vigour in the cold germination test, poor field emergence and poor yield. The greatest damage occurred for seed threshed at an average KWC of 22.5%, although vigour and field performance were reduced for seed lots threshed at KWC equal or higher than 17.1% as well. Results of this study suggest that for optimum quality, seed must be threshed at a KWC below 16%. At such KWC, the percentage of broken kernel in a seed sample was found to be an excellent predicator of the extent of vigour loss caused by threshing.

Conductivity was not always a reliable test to determine wheat seed vigour and field performance. Seed threshed at high KWC had low vigour based on the cold germination test but were classified as vigorous by the conductivity test. The cold germination test was the most reliable test to determine seed vigour when seed lots were threshed at different KWC.

Large and heavy seeds were the least resistant to impact damage. Improving threshing efficiency by increasing cylinder speed will increase damage to the largest and heaviest seed. Round seeds were found to be the least susceptible to threshing damage in this study. Long and heavy seeds of Sceptre were the most damaged by threshing compared to the other cultivars.

There was no broken seed in samples threshed with the belt thresher. The belt thresher should, therefore, be used as a standard in all threshing studies.

# 6. General Discussion

Results of this study indicated that combine cylinder speed had a negative effect on wheat seed vigour. Seed lots threshed at high cylinder speed and between 13 and 15% KWC contained more broken seed, had a higher leachate conductivity, fewer normal seedlings, fewer plants emerging in the field and lower yield than seed lots threshed at lower cylinder speeds. The effect of high cylinder speed was more important for the conventional combine than for the rotary combine. The samples threshed with the rotary combine at any cylinder speed, performed as well as samples threshed with the belt thresher. On the basis of this study, the axial flow rotary combine (single rotor) is gentler on seed than the conventional combine. This supports a similar conclusion by Harrison (1992).

Threshing at high KWC resulted in a loss of vigour in similar proportion to those reported by Mitchell (1955) and King and Ridolls (1960 and 1962). The proportion of broken seed and leachate conductivity were not related with the germination of normal seedlings in germination tests. At low KWC, vigour loss was mainly attributed to seed coat microscopic fractures. At low KWC, the embryo is protected within the hard (non plastic) kernel. At high KWC, the kernel is plastic. The kernel is deformed without breaking but the embryo inside the kernel can be damaged. As a result, high numbers of non germinated seed were found in samples threshed over 20% KWC. Seed vigour loss from low KWC threshed seed can be readily assessed by broken seed counts, whereas, no such assessment on vigour loss can be made with seed threshed at high KWC. Cold germination was the most reliable vigour test for seed threshed at different KWC. Results of the cold germination test were positively correlated with field emergence and yield for seed threshed at different KWC.

Large and glassy seed such as durum wheat kernels were more affected by threshing damage than HRS wheat.

Threshing efficiency was the only positive factor for threshing with a high cylinder speed. Therefore, to produce high vigour seed, the seed grower must be prepared to lose threshing efficiency. In this regard, farmers should consider different combine settings when threshing grain than when threshing seed. High impact forces to maximize threshing efficiency should be considered for threshing wheat grain but not for wheat seed. In this study, we obtained highest yield of vigorous seed with the axial flow rotary combine (single rotor).

To reduce the severity of threshing damage to wheat seed, any type of combine should be set at a low cylinder speed (30 $m.s^{-1}$) and wheat must be threshed at a KWC lower than 16%. Cylinder speed should be further decreased when wheat samples contain more than 1% broken seeds for HRS wheat. The proportion of broken seed should be less than 0.5% in case of Durum wheat.

Field studies were conducted under weed-free conditions, which may have favoured tiller production in low density plots. Yield difference between low and high vigour seed lots may be greater under weedy conditions because plants grown from low vigour seed lots may not compensate low plant density by tiller production.

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**Appendix Table 1.** Means from 1990 and 1991 laboratory vigour tests (LSD, alpha=5%)

| Cylinder speed | Broken seed | Cold germination test Seedling types Normal | Non-germ. | Abnormal | Standard germination test Seedling types Normal | Non-germ. | Abnormal | Conduc-tivity |
|---|---|---|---|---|---|---|---|---|
| | ........ | ........ | ........ | % | ........ | ........ | ........ | (mhos) |
| **Conven'l Combine 1990** | | | | | | | | |
| High | 4.35 a | 69.4 e | 5.75 a | 24.9 a | 85.1 d | 3.50 a | 11.4 a | 104.1 a |
| Optimum | 1.87 b | 80.0 d | 2.25 b | 17.8 b | 92.5 c | 1.63 b | 5.9 b | 86.2 b |
| Low | 0.45 c | 89.9 bc | 0.75 c | 9.4 cd | 96.4 b | 0.75 bc | 2.9 c | 80.9 c |
| **Rotary Combine 1990** | | | | | | | | |
| High | 0.62 c | 86.5 c | 2.88 b | 10.6 c | 94.3 c | 1.50 b | 4.3 bc | 81.9 c |
| Optimum | 0.34 c | 92.8 b | 0.50 c | 6.8 d | 96.3 b | 0.13 c | 3.6 bc | 74.4 d |
| Low | 0.16 c | 97.6 a | 0.25 c | 2.1 e | 98.5 a | 0.25 c | 1.3 c | 72.9 d |
| Std. error | 0.29 | 1.68 | 0.63 | 1.64 | 0.88 | 0.56 | 1.11 | 1.65 |
| **Conven'l Combine 1991** | | | | | | | | |
| High | 1.93 a | 80.4 c | 4.58 a | 15.0 a | 87.5 d | 1.67 a | 10.8 a | 82.9 a |
| Optimum | 1.03 b | 87.8 b | 3.08 b | 9.5 b | 92.1 c | 2.09 a | 5.8 b | 78.0 b |
| Low | 0.64 c | 90.6 b | 2.84 bc | 6.6 c | 94.3 b | 1.92 a | 3.8 c | 75.3 c |
| **Rotary Combine 1991** | | | | | | | | |
| High | 0.51 cd | 90.9 b | 2.42 bcd | 6.7 c | 95.3 b | 0.92 a | 3.8 c | 73.7 d |
| Optimum | 0.34 de | 94.6 a | 1.50 cd | 3.9 d | 95.5 b | 1.75 a | 2.8 c | 74.0 cd |
| Low | 0.20 e | 96.2 a | 1.42 d | 2.4 d | 97.7 a | 1.42 a | 0.8 d | 68.1 e |
| Std. error | 0.13 | 1.73 | 0.64 | 1.17 | 0.92 | 0.61 | 0.65 | 1.12 |

**Appendix Table 2.** Spring broadcasted supplimentary nutrients.

| Year | Nitrogen (kg/ha) | Phosphorous (kg/ha) | Potassium (kg/ha) |
|---|---|---|---|
| 1991 | 130 | 30 | 0 |
| 1992 | 95 | 20 | 0 |

**Appendix Table 3.**

a. Weed, disease and insect control practices (1991)

| Date | Treatment | Application method | Rate |
|---|---|---|---|
| May 17 | Roundup[1] | Pre-emergence | 1.75 kg/ha |
| June 5 | Hoe-grass II[2] | Post-emergence | 1 kg/ha |
| | MCPA amine | (tank-mixed) | 34 g/ha |
| June 28 | Tilt[3] | Post-emergence | 125 g/ha |

1 Manufactured by Monsanto Canada Inc.
2 Manufactured by Hoechst
3 Manufactured by Ciba-Geigy

b. Weed, disease and insect control practices (1992)

| Date | Treatment | Application method | Rate |
|---|---|---|---|
| May 15 | Roundup[1] | Pre-emergence (spot-treatment) | 1.75 kg/ha |
| May 26 | Hoegrass 284[2] | Post-emergence | 1 kg/ha |
| June 9 | Lontrel[3] | Post-emergence | 200 g/ha |
| | Refine[4] | (tank-mixed) | 12 g/ha |
| July 9 | Tilt[5] | Post-emergence | 125 g/ha |
| August 4 | Tilt[5] | Post-emergence | 125 g/ha |
| | Malathion | (tank-mixed) | 500 g/ha |

1 Manufactured by Monsanto Canada Inc.
2 Manufactured by Hoechst
3 Manufactured by DowElanco Canada Inc.
4 Manufactured by DuPont Canada Inc.
5 Manufactured by Ciba-Geigy

**Appendix Table 4.** Weather data recorded at Portage la Prairie, Manitoba.

| | | Growing days† | Precipitation | | Soil temp. (10cm) | Air temperature Min | Air temperature Max | Air temperature Avg | GDD‡ |
|---|---|---|---|---|---|---|---|---|---|
| | | | (mm) | number | °C | °C | °C | °C | |
| May | Normal^Θ | 31 | 31.0 | - | - | 4.6 | 17.0 | 10.8 | - |
| | 1991 | 19 | 34.0 | 5 | 14.3 | 10.1 | 24.6 | 17.3 | 263.8 |
| | 1992 | 24 | 12.0 | 3 | 11.9 | 5.5 | 21.8 | 13.7 | 204.3 |
| June | Normal | 30 | 81.0 | - | - | 10.6 | 22.9 | 16.8 | - |
| | 1991 | 30 | 75.0 | 7 | 18.1 | 12.4 | 25.2 | 18.8 | 409.9 |
| | 1992 | 30 | 44.0 | 8 | 15.4 | 9.0 | 22.0 | 15.4 | 311.2 |
| July | Normal | 31 | 77.4 | - | - | 13.5 | 25.6 | 19.6 | - |
| | 1991 | 31 | 95.0 | 15 | 20.3 | 13.6 | 25.9 | 19.5 | 456.5 |
| | 1992 | 31 | 109.0 | 13 | 17.1 | 10.8 | 22.1 | 16.3 | 348.7 |
| August | Normal | 31 | 80.0 | - | - | 12.0 | 24.7 | 18.4 | - |
| | 1991 | 21 | 5.0 | 3 | 20.4 | 12.5 | 27.6 | 20.4 | 314.3 |
| | 1992 | 31 | 49.0 | 9 | 17.0 | 9.9 | 23.2 | 16.3 | 350.9 |
| September | Normal | 30 | 50.0 | - | - | 6.0 | 18.0 | 12.0 | - |
| | 1991 | 0 | - | - | - | - | - | - | - |
| | 1992 | 12 | 25.0 | 2 | 12.5 | 5.5 | 18.3 | 11.7 | 80.9 |
| Season | 1991 | 101 | 209.0 | - | 18.3 | 12.2 | 25.8 | 19.0 | 1438.5 |
| | 1992 | 128 | 239.0 | - | 14.8 | 8.1 | 21.5 | 14.7 | 1296.1 |
| | | (sum) | (sum) | | (avg) | (avg) | (avg) | (avg) | (sum) |

† Weather data are recorded from the day of seeding to the day of harvest for each year.
‡ GDD: Growing degree days or the sum of daily mean temperatures above 5°C.
Θ Long-term average temperature and rainfall at Portage la Prairie (source: Environment Canada).

**Appendix Table 5.** Mean comparison between treatments from 1991, 1992a and 1992b field experiments (LSD, alpha=5%)

| Treatments | Field emergence | Spike number | Spike number | Thousand kernel mass | Seed per spike | Seed per plant |
|---|---|---|---|---|---|---|
| | ($m^2$) | ($m^2$) | (plant) | (g) | | |
| **Conven'l C.** | | | | | | |
| High | 118.4 c | 465.4 b | 4.02 a | 37.59 a | 27.7 a | 103.3 a |
| Optimum | 127.8 b | 467.2 b | 3.74 b | 37.97 a | 27.7 a | 97.8 ab |
| Low | 136.2 a | 476.1 ab | 3.52 b | 37.96 a | 26.8 a | 92.6 b |
| **Rotary C.** | | | | | | |
| High | 136.4 a | 479.2 ab | 3.55 b | 37.92 a | 27.1 a | 92.7 b |
| Optimum | 136.2 a | 490.6 a | 3.66 b | 38.05 a | 26.3 a | 92.5 b |
| Low | 135.1 ab | 483.8 a | 3.61 b | 37.81 a | 26.7 a | 94.5 ab |
| Std. Error† | 4.13 | 11.31 | 0.139 | | | |
| Std. Error‡ | | | | 0.323 | 0.783 | 3.814 |

† 18 observations
‡ 12 observations (thousand kernel mass was not determined in 1991)

**Appendix Table 5. ...(con't)...**

| Treatments | Obser-vations | Yield | Yield per spike | Yield per plant |
|---|---|---|---|---|
| | | (t/ha) | (g) | (g) |
| **Conven'l C.** | | | | |
| High | 17 | 4.42 d | 0.96 a | 3.82 a |
| Optimum | 18 | 4.45 cd | 0.96 a | 3.54 b |
| Low | 18 | 4.52 bc | 0.95 a | 3.34 b |
| **Rotary C.** | | | | |
| High | 17 | 4.53 b | 0.95 a | 3.36 b |
| Optimum | 17 | 4.61 a | 0.94 a | 3.40 b |
| Low | 18 | 4.59 ab | 0.95 a | 3.41 b |
| Std. Error | 18 | 0.041 | 0.022 | 0.116 |
| Std. Error | 17 | 0.042 | 0.023 | 0.119 |