MECHANICALLY DEVITALIZING CHEAT

(*Bromus secalinus* L.) SEED TO

REDUCE GERMINATION

By

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LIST OF SYMBOLS

ρ_f	Mass density of air (kg/m^3)
ρ_p	Mass density of particle (kg/m^3)
A_p	Projected area normal to the direction of motion (m^2)
BRE	Seed with broken or missing embryo
BRS	Broken seed
C	Drag coefficient (dimensionless)
DI	Damage index
DIF	Damage index factor
DPCK	Seed with deep cracks
HM	Hammer mill
NAD	Seed with no apparent damage
RM	Roller mill
SHCK	Seed with shallow cracks
TMRK	Seed with teeth marks
VIF	Viability index factor
V_t	Terminal velocity (m/s)
WPD	Whole or partially dehulled seed with embryo present

To my dear Dad,

Hauhouot Assamoa Diambra Odi Appolinaire Denis

CHAPTER I

INTRODUCTION

Bromus secalinus L., a winter annual grass with the common name of cheat belongs to the Poaceae family, and Pooideae subfamily of the Bromeae tribe. It germinates in the fall, grows through the winter, and flowers in the spring. There are more than 150 species of Bromus and they are mostly found in north temperate regions, South America, and the mountains of the Tropics. Cheat is a C3 photosynthetic grass. It infests many hectares of red winter wheat each year in the Great Plains of the USA. In Oklahoma, USA, cheat and other *Bromus* species infest over 1,000,000 hectares of wheat fields per year and can reduce the yield by 50% or more. It is a serious threat to Oklahoma farmers because wheat is a major regional crop. Weed control becomes a very important issue affecting economic returns and sustainability of wheat production.

Many solutions have been suggested or tried to control these weeds. They include annual application of herbicides, moldboard plowing to bury the seeds, burning of wheat stubble, and rotation to summer crops. They are only partially successful and have potential adverse environmental effects. Alternative solutions with potential reduction of herbicides costs and minimization of adverse environmental effects are needed.

The overall goal of this research was to study the feasibility of using a mechanical device to damage seed of *Bromus secalinus* L. to reduce its viability. Such a device selected could be mounted on a combine to damage weed seed during the grain harvesting process. The design would require that the cheat seed be separated from the wheat within the combine before the damage process. The damaged seed could be deposited on the ground or collected for animal feed.

The overall objective was accomplished by completing the following specific objectives:

1. Evaluating existing devices for mechanical damage to weed seeds.
2. Determining effects of operating parameters of the mechanical devices on seed viability.
3. Quantifying mechanical injury to the seeds.
4. Establishing a physical injury index and its relation to seed vitality.

In Chapter II, the physical characteristics and the aerodynamic properties of cheat seed were measured and compared to those of wheat seed. In Chapter III, two devices, a roller mill and a hammer mill were evaluated for their suitability to process cheat seeds in order to induce a reduction in the seed viability. Seed viability was directly measured by laboratory and field germination tests. In Chapter IV, parameters of the hammer mill (screen opening sizes, motor shaft speed, feed rate, and number of hammers) were tested for their effect on cheat seed viability. In Chapter V, three roller mill speed differential ratios (1:1, 1:1.1, 1:1.27) were analyzed for their effect on the seed germination. In Chapter VI, the damaged seed of *Bromus secalinus* L. were classified under a magnifying lamp after being stained with a Fast Green (FCF) solution and growth chamber germination tests were run to verify the viability of the seed in each damage class. A physical injury and viability index were created and related to seed viability. In Chapter VII, overall conclusions were drawn from the different investigations.

CHAPTER II

PHYSICAL CHARACTERISTICS AND AERODYNAMIC PROPERTIES OF CHEAT SEED

ABSTRACT

Cheat (*Bromus secalinus* L.) and similar weeds infest wheat (*Triticum aestivum* L.) producing areas throughout the world. Cheat is one of the most severe of all weed pests and can infest as much as 50% of the wheat planted certain years in the Great Plains of the U.S.A. To improve the economic returns and enhance the sustainability of wheat production, weed control is an important issue. Previous solutions to cheat control such as annual applications of herbicides, moldboard plowing to bury the seeds, burning wheat stubble, or rotation of summer crops have been partially successful, and most have adverse environmental effects. An alternative approach to cheat control is mechanically damaging cheat seed during harvest to prevent reinfestation in subsequent years. To design machines to separate cheat from wheat and damage cheat seeds, physical characteristics (dimensions, weight, bulk density) and aerodynamic properties (terminal velocity, drag coefficient) of cheat seed were measured and compared to those reported for wheat. Cheat seeds were 6.85 mm long, 1.35 mm wide, and 1.24 mm thick compared to wheat seeds being 6.02 mm long, 2.79 mm wide, and 2.54 mm thick. The coefficient of variation ranged from 3.1% to 13.3% for both seeds. The average weight of 1000 cheat seeds was 5 g compared to 40 g for wheat. The bulk density of cheat was 210 kg/m^3 compared to 772 kg/m^3 for wheat. Cheat seeds had an average terminal velocity of 3.14 m/s compared to 7.84 m/s for wheat; leading to a drag coefficient of 1.05 for cheat seed compared to 0.74 for wheat.

Keywords: Cheat (*Bromus secalinus* L.), Weed control, Physical Characteristics, and Aerodynamic Properties.

INTRODUCTION

Cheat (*Bromus secalinus* L.) is a winter annual of the tribe Bromeae and Pooideae subfamily of the Poaceae family (Clayton and Renvoize 1986). There are more than 150 Bromus species distributed mainly in the North Temperate Zone, South America, and the mountains of the tropics (Hackel 1890; Hitchcock 1922; Tsvelev 1983, and Watson and Dallwitz 1992). Watson and Dallwitz (1992) described the use of Bromus species as weeds (*B. secalinus*, *B. arvensis*, *B. inermis*, etc.), cultivated fodder (B. *unioloides*), pasture (*B. danthoniae*, *B. carinatus*), and even crop species (*B. mango* formerly grown in as a cereal in Chile). Cheat was once used in Washington and Oregon, USA, as hay (Hitchcock 1922), but now is considered as a weed in winter wheat, rye, barley and other crops. It infests winter wheat fields and can greatly reduce wheat yield.

Cheat's phenology is similar to winter wheat (Finnerty and Klingmann 1962). The caryopses of cheat germinate in the fall, grow during the winter, and flower in the spring. Figure 1 shows an open floret of cheat seed composed of two bracts: the lemma (outer bract) and palea that cover the whole caryopsis or fruit. The lemma has a bifid apex with an awn. The palea is enveloped in the lemma and tightly holds the caryopsis. The caryopsis is composed of the embryo, the endosperm (food reserve), and the scutellum that conveys hydrolyzed food reserve to embryo for plant growth. The embryo and the endosperm are enclosed within a fused pericarp and testa (Watson and Dallwitz 1992; Bradbeer 1988). The embryo is small. The endosperm is hard, without lipid, containing only simple starch grains (Watson and Dallwitz, 1992).

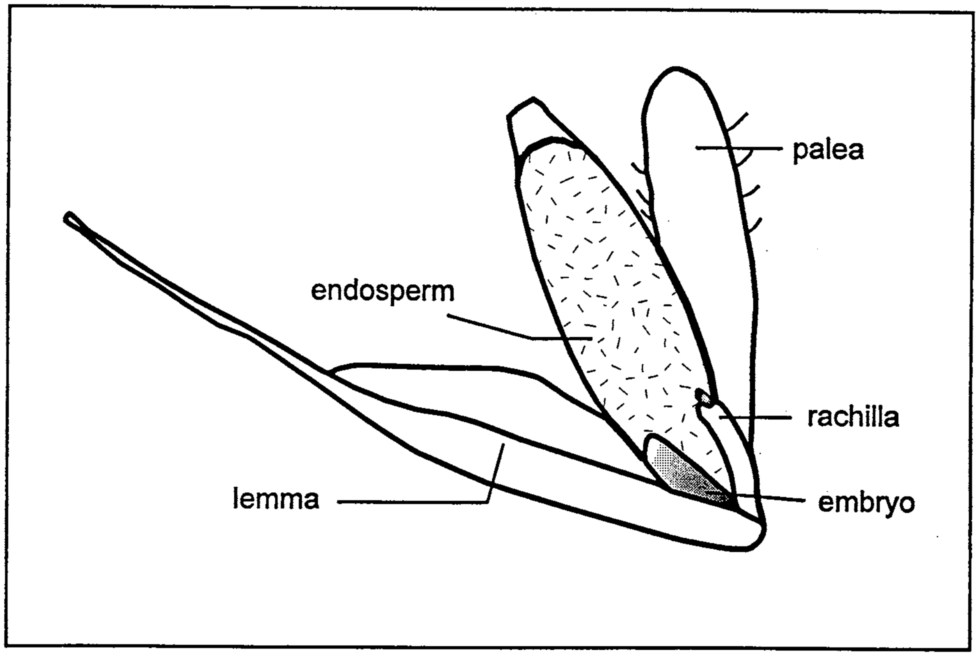

Figure 1. Open floret of cheat (*Bromus secalinus* L.)

Cheat infestation has been a serious problem for wheat growers for many years. In Oklahoma, USA, cheat and other Bromus species infest over 1,000,000 hectares of wheat fields and can reduce the yield 50% or more. Faced with this problem, farmers and researchers have tried many solutions such as applying herbicides annually, moldboard plowing to bury the seeds, burning the wheat stubble, or rotating to summer crops.

Wacker (1993) described different ways to control weed seeds while harvesting. Among them, removal of non-grain components by collecting them in a trailer, adjusting settings on the combine to collect weed seeds, and destroying or reducing the viability of weed seeds by grinding or crushing in the cleaning and separation phase. Another approach being studied by researchers is to either remove the weed seeds at the time of harvest, or to mechanically destroy their viability during the harvest process. Hauhouot et al. (1997) studied the feasibility of using a roller mill or a hammer mill to mechanically devitalize (produce non-viable seeds) seeds of *B. secalinus* L. Cheat seed were crushed between the rolls with gaps varying from 1.1 mm to 0.1 mm. Seed fed into a hammer mill were struck by hammers until they were small enough to go through the selected screen. Germination tests were run on damaged seeds to verify their viability. They found that both mills reduced the seed viability 95% or more. Either of these machines could be mounted on a combine harvester. Damaged weed seed could be collected for animal feed or deposited on the ground with assurance that it would not germinate and cause a severe infestation the following year.

Physical characteristics of the seed such as dimensions, weight, and bulk density are necessary to establish machine operating variables for the roller mill and the hammer mill. Knowing the seeds dimensions can help in selecting the optimum gap between the rolls to crush the seed and the optimum screen opening size for the hammer mill. The bulk density and the weight will be necessary in sizing machine components, and related grain conveyors.

Rather than mechanically damaging the wheat-weed mixture, the weed should first be separated from the wheat in a cleaner. Separation can be accomplished by using pneumatic seed separation, screen cleaners, or gravity separators. Many commercial cleaners incorporate more than one of these cleaning methods. To best utilize any of these methods, it is helpful to first know the characteristics of both the grain and weed seed. Characteristics that dictate pneumatic separation are usually described by either terminal velocity or drag coefficient (Grochowicz, 1980). Likewise, shape and size are major considerations in selection and design of a screen cleaning system. A gravity system relies on differences in weight between kernels to facilitate separation.

OBJECTIVES

The first objective of this investigation was to measure physical characteristics of cheat seed to adjust or design a machine that will mechanically devitalize the seeds. The second objective was to compare properties of cheat and wheat seeds to facilitate the development of a combine harvester mounted separation process.

MATERIALS AND METHODS

Physical Characteristics

Cheat seed used in these experiments was collected from screenings of combine harvested wheat in Oklahoma, USA. The moisture content was approximately 12% wet basis.

Dimensions. The dimensions of the seed were measured in three directions using a digital caliper gauge (± 0.01 mm). The major diameter was the length of the seed, the intermediate diameter was the width, and the minor diameter was the thickness of the seed. The minor diameter was taken perpendicular to the intermediate diameter. The caliper was held perpendicular to the direction of the dimension being measured. Length was measured on 200 seeds, and width and thickness on 50 seeds. The average dimensions were computed and descriptive statistics realized.

Weight. The number of seeds in twenty samples weighing approximately 0.5 g was determined. The results were reported in weight per 1000 seeds.

Bulk density. The bulk density of cheat seed was determined on 10 samples. Cheat seeds were poured into cylindrical can (7.22 cm inside diameter by 10.87 cm depth) and weighed on a digital scale. The bulk density was computed by dividing the average measured weight by the volume of the cylinder.

Aerodynamic Properties

Terminal velocity. The terminal velocity, or critical velocity, of cheat seeds was computed on fifty samples. A vertical air tunnel made from a long plexiglass tube (L > 10D) and a hot wire anemometer were used to determine terminal velocity (Mohsenin, 1986). The apparatus is shown in figure 2. Two or three cheat seeds were placed on a mesh screen in the bottom of the vertical tube. Input air was adjusted with a slide gate until the seeds began to float. The velocity at which the particles became suspended was considered the terminal velocity. The velocity was measured with a hot wire anemometer VelociCalc Model 8357 (TSI Inc., St Paul, MN) through small holes (10D from the screen) in the tube wall.

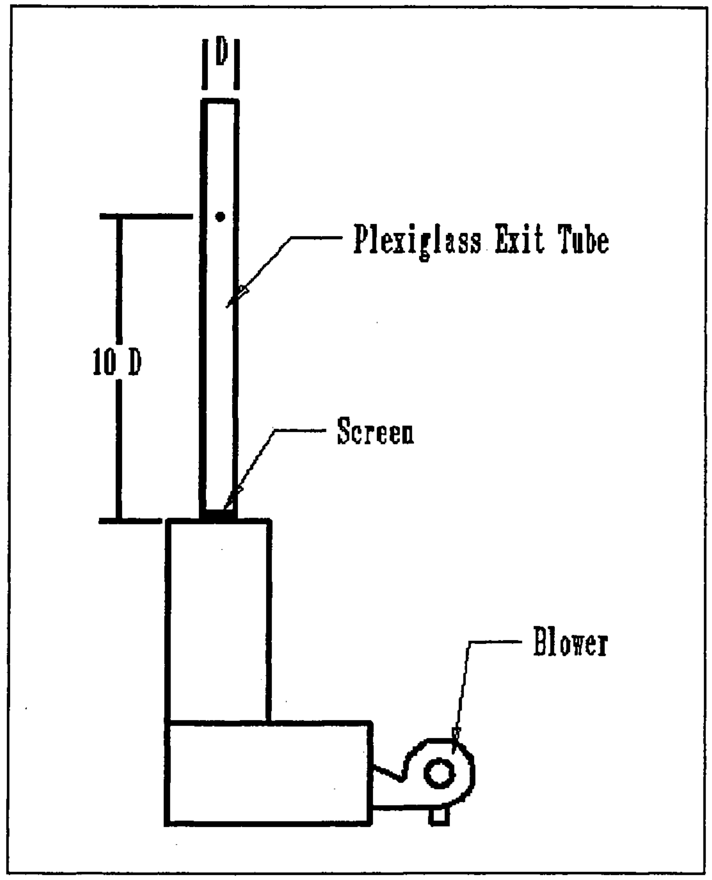

Figure 2. Vertical air tunnel velocity measurement device

Drag coefficient. The drag coefficient of cheat seed was calculated from the experimental terminal velocity using the equation below (Mohsenin, 1986):

$$C = \frac{2W(\rho_p - \rho_f)}{V_t^2 A_p \rho_p \rho_f} \tag{1}$$

where:

W: mass of particle (kg)

ρ_p: mass density of the particle (kg/m^3)

ρ_f: mass density of the air (kg/m^3) at 21°C from Table 9.2. Mohsenin (1986)

V_t: terminal velocity (m/s)

A_p: projected area normal to the direction of motion (m^2) with $A_p = (\pi /4) L_1L_2$.

(L_1, L_2 are the two largest dimensions of the seed.)

The drag coefficient is dimensionless.

RESULTS AND DISCUSSION

Physical Characteristics

Dimensions. The cheat seeds averaged 6.85 mm long, 1.35 mm wide, and 1.24 mm thick which agree with Grochowicz (1980) (Table 1). The distributions for length, width, and thickness were approximately normally distributed. The standard deviations were 0.44, 0.12, and 0.12 respectively. The coefficients of variation were 6.5%, 8.9%, and 9.9% respectively. Cheat seeds were longer and thinner than wheat seeds which have a 6.02 mm length, 1.79 mm width, and 2.54 mm thickness with 6.8%, 13.3%, and 3.1% coefficients of variation respectively (Stroshine and Hamann, 1994). The differences in dimensions between cheat and wheat are important in selecting screens (size and shape of holes) to separate cheat from wheat.

The width and the thickness of the cheat seed are important in setting the gap between the rolls to crush or crimp the seeds. During the tests run to mechanically damage cheat seeds with the roller mill, the gap between the rolls was varied from 0.1 mm to 1.1 mm. As a general trend, the damage was greater with smaller roll gaps (Hauhouot et al., 1997).

Cheat seed dimensions are also essential in choosing the appropriate screen size for the hammer mill. Hammer mill screen sizes of 3.18 mm (8/64 in.), 3.97 mm (10/64 in.), and 4.76 mm (3/16 in.) successfully devitalized cheat by mechanically damaging the seed without grinding it.

Table 1-Physical characteristics of cheat and wheat seed.

Material	Seed Dimensions			Weight of 1000 seeds (g)	Bulk Density (kg/m³)
	Length (mm)	Width (mm)	Thickness (mm)		
Cheat (experim.)	6.85 (0.44) 5.70- 8.05≠	1.35 (0.12) 1.07-1.71	1.24 (0.12) 0.95-1.56	5.0 (0.18) 4.61 - 5.31	210 (0.01) 200 - 220
Cheat (reported)¨	6.0 – 8.40	1.40 - 2.40	1.20 - 2.0	5.0	230
Wheat (reported)§	6.02 (0.41)	2.79 (0.37)	2.54 (0.08)	40.0	772

- ···Standard deviation value in ( )
- ≠ Minimum - Maximum
- ¨ Data from Grochowicz.(1980). pp.42-44 Table 3.6
- § Data from Stroshine et al. (1994) pp.11 Table 2.1

Weight. The weight of 1000 cheat seeds was 5 g with a standard deviation of 0.18, compared to 40 g for the same number of wheat seeds (Table 1). Wheat kernels are generally 8-10 times heavier than cheat. Moreover the specific gravity of cheat seed ranged from 0.3 to 0.4 compared to 1.2 – 1.5 for wheat (Grochowicz, 1980). Therefore, gravity separation could likely be used to separate these two materials.

Bulk density. The bulk density of the cheat was 210 kg/m^3 compared to the reported 230 kg/m^3 (Grochowicz 1980). The standard deviation was 0.01 and the range between 0.20 and 0.22. The reported wheat bulk density of 772 kg/m^3 (Stroshine et al., 1994) shows that wheat is 3.4 to 3.7 times more dense than cheat, figures useful in bin design.

Aerodynamic Properties

Terminal velocity. Measured terminal velocities for cheat seeds ranged from 1.8 m/s to 4.5 m/s, with a mean of 3.14 m/s and a standard deviation of 0.82. Measured terminal velocity for wheat had a mean of 7.84 m/s and a standard deviation of 0.91. The range was from 5.8 m/s to 9.8 m/s. This is lower than the 8.9 m/s to 11.5 m/s range reported by Grochowicz (1980). The ranges of terminal velocity for cheat and wheat do not overlap. Consequently, aerodynamic separation is theoretically possible. A terminal velocity of 5.5 m/s was selected to test a multiple stage aspirator for a combine harvester mounted wheat separator. A summary of aerodynamic properties including the experimental results and referenced material are shown in table 2.

Drag coefficient. Drag coefficients, needed in design calculations to describe aerodynamic properties, were calculated from the experimental terminal velocities. Drag coefficient for wheat was calculated as 0.74, based on the average experimental terminal velocity. Likewise the experimental drag coefficient for cheat was 1.05.

Table 2-Aerodynamic properties of cheat and wheat seed.

Material	Terminal velocity (m/s)	Drag coefficient
Cheat (Experimental)	3.14 (0.82)··· 1.79 - 4.46≠	1.05 0.52 - 3.4
Wheat (Experimental)	7.84 (0.91) 5.79 - 9.81	0.74 0.47 - 1.36
Wheat (Reported)··	8.9 - 11.5	0.34 - 0.58

- ···Standard deviation value in ( )
- ≠ Minimum - Maximum
- ·· Data from Grochowicz.(1980). pp.42-44 Table 3.6

CONCLUSIONS

Cheat seeds were 6.85 mm long, 1.35 mm wide, and 1.24 mm thick whereas wheat seeds were being 6.02 mm long, 2.79 mm wide, and 2.54 mm thick. The distribution of cheat seed dimensions was approximately normal and the standard deviations were 0.44, 0.12, and 0.12, respectively. The average weight of 1000 cheat seeds was 5 g compared to 40 g for wheat. The bulk density of cheat was 210 kg/m^3 compared to 772 kg/m^3 for wheat. These physical characteristics are important in selecting machine design variables. The gap between the rolls of the roller mill and the screen opening size of the hammer mill can be selected from the physical characteristics of cheat seed. Cheat seeds had an average terminal velocity of 3.14 m/s and a standard deviation of 0.82, compared to an average of 7.84 m/s and standard deviation of 0.91 for wheat; leading to a drag coefficient of 1.05 for cheat seed compared to 0.74 for wheat. There is a considerable difference between terminal velocities of cheat and wheat seed, which suggests that aerodynamic separation of cheat and wheat is possible.

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CHAPTER III

ROLLER AND HAMMER MILLING CHEAT *(Bromus secalinus* L.) TO REDUCE GERMINATION

ABSTRACT

Improvement of the economic return and the enhancement of the sustainability of wheat production depend on weed control. Cheat, *Bromus secalinus* L., is one of the most serious weeds infesting winter wheat (*Triticum aestivum* L.) fields. Two mills, a roller mill and a hammer mill, were investigated for their ability to damage, but not grind cheat seed to reduce its viability. Milling effects on cheat germination were evaluated in greenhouse pots, in a laboratory growth chamber, and in the field. Roller mill variables tested were gap between the rolls (from 0.1 mm to 1.1 mm) and density of the teeth on the rolls (5, and 8 teeth/cm). Germination decreased with decreasing roll gap and increasing

number of roll teeth. The hammer mill dehulled the seed and fractured 92% of the seed embryos. Hammer milled seed had lower germination than most roller milled seed treatments. With the roller mill, the combination of narrow roll gap and high tooth density reduced germination as much as the hammer mill treatment. Field tests results were similar to the laboratory tests, but seedling emergence in the field was lower because of intervening natural factors. Results demonstrated the feasibility of substituting mechanical seed devitalizing for herbicides to control weeds in wheat.

INTRODUCTION

Wheat is the largest crop grown in the U. S. Great Plains in terms of acreage and value. Weed control is an important issue in efforts to improve the economic returns and enhance the sustainability of wheat production. Cheat and other *Bromus* species infest many hectares of wheat per year and can reduce wheat yield by 50% or more. These and similar weeds infest wheat producing areas throughout the world.

Many solutions have been suggested or tried to control these weeds such as: annual applications of herbicides, moldboard plowing to bury the seeds, burning the wheat stubble, or rotation to summer crops. All these methods have been only partially successful and can have potential adverse environmental effects.

An alternative solution, with potential to reduce costs and minimize adverse environmental effects, is to mechanically kill the weed seed during harvest to prevent reinfestation in subsequent years. This study investigates the use of a roller mill and a hammer mill to sufficiently damage the weed seed to prevent germination or emergence of these weeds.

LITERATURE REVIEW

"Germination begins with water uptake by the seed (imbibition) and ends with the start of elongation by the embryonic axis, usually the radicle "(Bewley and Black, 1994).

During germination, storage reserves are hydrolyzed to provide the growing embryo with nutrients until it establishes itself as an independent seedling. Nevertheless, the stage of germination that we can measure is the emergence of the axis (radicle) from the seed. Bradbeer (1988) described germination as a process that commences with sequences of events at the molecular and cellular level and proceeds to the growth of a radicle. An important sign of germination is the protrusion of the radicle through the seed coat.

Mechanical damage of seed has been studied by many researchers, because it affects the milling quality of seeds, the market value of the grains, lowers the germination, and inhibits seedling development. Mohsenin (1986) defined damage "as the failure of a product under excessive force deformation, when it is forced through fixed clearances or excessive forces when it is subjected to impact." Grunda (1994) defined mechanical damage "as a state of disturbance of the natural continuity of particular cells and tissues of the kernels, resulting from the destructive effect of external forces (harvest, transport) and/or internal strength, which may be caused by gradient of moisture in the process of dry grain wetting or drying wet ones." Usually, mechanical damage is referred to as the damage that occurs during threshing, as well as, by screw conveyors, or other mechanical equipment. The damage can be external (e.g. small cracks, shatter cracks, skin break) or internal (stress cracks mostly due to temperature and moisture gradients).

Mechanical damage can reduce the germination of seeds. Bartsch et al. (1986) impacted two varieties of soybeans at velocities of 5, 10, and 15 m/s with five seed orientations. Tetrazolium viability tests were used to quantify the impact damage. They found that direct impact to the radicle of the soybean caused the largest reduction in seed germination and vigor. The embryo is the critical part of the seed. A badly cracked or split embryo has a very low or almost no chance of germination, because of the arrangements of the vulnerable parts of the seed embryo. Slagell-Gossen et al. (1998) studied the anatomical effects of mechanical damage on caryopses of cheat seed. They found that the germination and viability of cheat caryopses were decreased by mechanical damage induced by a roller mill and a hammer mill. Moreover, both losses of anatomical integrity and consequent attack by fungi and nematodes contributed to this decrease.

In the absence of standards to quantify the damage, different techniques have been used to evaluate mechanical injury to grains and vegetables. Chowdhury (1976) listed and described 25 methods for determining grain damage. He stated that whether a grain is considered as damaged or not, depended on its ultimate use. The techniques to assess mechanical damage include: visual observation, sieving, germination, water adsorption, carbon-dioxide production, light reflectance, colorimetric reflectance, or storability. Effectiveness of visual inspection can be improved by treating the seed with chemical stains. French et al. (1962) used a 0.1-percent indoxyl acetate solution in 25-percent ethanol to detect seed coat cracks in white beans and other legume seeds. Paulsen and Nave (1979) developed an improved indoxyl acetate test to detect seed coat cracks in soybeans. The test is more effective in finding seed coat cracks than the sodium hypoclorite solution and tetrazolium viability tests. Nikolenko and Alexeeva (1994) studied X-ray images of two groups of wheat grains (damaged and undamaged) and their germination capacity. Koper and Tryka (1989) found that the intensity of photo-induced luminescence emitted by rapeseeds was directly correlated to their degree of damage.

In contrast to indirect methods, germination tests directly measure both seed viability and seedling vigor. A disadvantage is that the results are not quickly obtained, because germination cannot be confirmed until the radicle has emerged from the seed, which can take several days.

Mechanical devices have been used to study seed resistance to impact damage. Mitchell and Rounthwhaite (1964) studied the resistance of two varieties of wheat to impact by striking the individual grain with a rotating hammer. As impact velocity increased, the breakage was higher for lower moisture grain, but germination was reduced in grain with higher moisture levels. Nikolenko and Alexeeva (1994) found that wheat germination decreased as load levels and crack sizes increased. They found that germination capacity was inversely dependent on mechanical damage.

Two devices used to crack or grind grains are the roller mill and the hammer mill. The roller mill was introduced in the USA from Europe in 1873 (Smith and Naylor, 1981). It consists of corrugated or smooth cylindrical rolls oriented horizontally in pairs. Grinding occurs between the rolls. The kernels are subjected to shear and compressive forces, caused respectively by the corrugations on the roll surface and pressure exerted by the rolls when pulling particles towards the nip (Haque, 1991). The hammer mill is composed of hammers mounted on a rotor and a screen. Kernels are struck by the hammers until they are small enough to go through the selected screen. The seeds are subjected to impact forces.

Yu and Brusewitz (1993) determined the change in physical properties of mustard seeds as affected by mill type (roller mill or hammer mill), gap between rolls of the roller mill, feed rate through the hammer mill, and seed temperature at the time of cracking. They found: (1) lower seed cracking temperature and narrower roll gap, and lower hammer mill feed rate produced lower bulk density and lower bulk compression force; and (2) hammer milling produced more fine particles. They noted that hammer milled particles are mostly short and straight while roller milled samples have many long, curved particles. Ahlgren et al. (1950) used a small swinging hammer mill to dehull seed of smooth brome (*Bromus inermis* L.) and found that more damage (25% of the seed was fragmented) was caused at the highest speed (1600 rpm), and germination was reduced at all speeds. Moreover, the decrease in germination was due to mechanical damage and not to the dehulling because hand-dehulled seed maintained a satisfactory germination.

OBJECTIVE

The objective of this investigation was to determine whether the roller mill and the hammer mill could be used to devitalize (produce non-viable) seed of cheat (*Bromus secalinus* L.) without grinding the seed.

MATERIALS AND METHODS

The cheat seeds used in these experiments were cleaned from combine harvested wheat during the summers of 1993 and 1994 in Oklahoma. The moisture content of the seeds was 12 % wet basis. The average length, intermediate and minor diameters were, 6.84 mm, 1.35 mm and 1.24 mm, respectively.

An H. C. Davis Model 50B roller mill (Bonner Springs, Kansas) and a Jay Bee Disintegrator hammer mill (Tyler, Texas) were used in this research. The Davis roller mill consisted of two 23- x 15-cm-diameter (9 in. x 6 in.) corrugated rolls turning in opposite directions, and powered by a 1.12 kW (1.5 hp) motor. The nominal operating speed was 500 rpm. The two rolls tested had 5 teeth/cm (5 cuts/cm) and 8 teeth/cm (8 cuts/cm) of circumference.

The gap between the rolls (roll gap) tested were 0.1, 0.2, 0.3, 0.4, 0.6, 0.9, and 1.1 mm. Samples of seeds (approximately 0.5 g) were dropped slowly into a vertical hopper. The control samples were untreated seed from the same seed lots.

The Jay Bee hammer mill was equipped with 64 hammers, a 4.58 mm (3/16 in.) screen and operated at 3600 rpm. For the hammer mill treatment, a 18000-cm^3 bag (18- x 30.5 - x 33-cm) full of cheat, chaff and straw was fed in 5 seconds into the hopper and milled. The processed material was then cleaned by an improved M-2B Clipper seed cleaner (Ferrell Ross, Saginaw, Michigan) using a 5.56 mm (14/64 in.) oval and 1.3 mm (1/20 in.) round hole screens.

Seeds for the germination tests were selected from the treated lots. Three types of germination tests were used: growth chamber germination, greenhouse pots germination, and germination in the field.

Growth chamber germination

Growth chamber test (warm germination) was performed on four 100-seed samples from each treatment in a water curtain germinator (Stults Scientific Engineering Corp., Springfield, Illinois). The seeds were put on wet paper tissue and prechilled at 5°C in a refrigerator for 5 days to break dormancy, then placed in a growth chamber at 20°C for 9 days. Germinated seeds were counted on the sixth and fourteenth days. Since no procedures existed for cheat, the procedure to determine germination conformed to the requirements for smooth brome established by the Association of Official Seed Analysts (AOSA, 1978). At the end of the germination period, seedlings presenting a growing primary root were considered as germinated. Seedlings with strong and long roots, and no mold were classified as vigorous[1]. Intact and hard caryopses were considered as dormant seeds. The advantages of this test are that the temperature and the humidity are controlled to optimize germination and results can be determined in a relatively shorttime period.

The treatments evaluated were: control (undamaged seeds), hammer milled seeds, seeds damaged by roller mill with 0.1 to 1.1 mm roll gap and with 5 teeth/cm and 8 teeth/cm rolls. The advantages of this test were that the temperature and the humidity were controlled to produce ideal germination, and results could be determined in the shortest time period. The test was usually easy to conduct. However, problems were encountered in distinguishing between vigorous and non-vigorous seedlings.

Greenhouse pots germination

The treated seeds were refrigerated at 4.44°C (40°F) for 21 days dormancy before the germination tests. Seed was germinated in greenhouse pots to determine the effect of soil impedance on seed emergence. Germination was performed on four 25-seed replicates in

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[1] Personal communication, Mrs. Val oyster, Registered Seed Technologist, Oklahoma Crop Improvement laboratory, Stillwater, Oklahoma, March 1995.

7.5 cm diameter greenhouse pots. The pots were filled with 200 g of Kirkland silt loam soil, the treated seeds were placed on top of the soil, and then covered with 50 g of soil. The approximate depth of planting was 10 mm. The pots were placed under continuous light for 14 days and watered as needed. After 14 days the plants were counted and emerged plants were classified as germinated.

Field germination

Two field experiments were conducted to evaluate seed germination: the packaged-seed experiment and the broadcast seed experiment. The goals of the field experiments were to determine the long-term viability of milled seed and to measure the response of the damaged seeds to natural flora, fauna, and environmental conditions. The tests were conducted in the summer and fall of 1995 and 1996.

The packaged-seed experiment was conducted by putting 25 treated seeds into nylon mesh packets, which were buried 50 mm deep in the field. The nylon mesh was folded to form 150-mm (6 in.) long and 140-mm (5.5 in.) wide rectangular packets. The six treatments were: control (undamaged seed), hammer milled seeds, seeds crimped with the roller mill at 0.1 and 0.4 mm roll gap with the 5 teeth/cm, and the 8 teeth/cm rolls at each roll gap. They were termed respectively: Undamaged Seed (control), 5R0.4, 5R0.1, 8R0.4, 8R0.1, and hammer mill. The packets were planted in July of each year. The experiment design was a 2x3 (two sites and three dates of excavation) factorial arrangement in a completely randomized design. The treatments were replicated four times. The packets were buried 0.66 m (2ft) apart to avoid disturbing adjacent packets during removal. The Agronomy Research Stations near Perkins and Stillwater, OK, in

1995, and Lahoma and Stillwater, OK, in 1996 were the sites of the different experiments. Four packets of each treatment were excavated in September, October, and December 1995 (for the first series of tests) and in November, December 1996, and January 1997 for the second series. The excavated packets were opened, seeds counted and the florets visually inspected. The seeds were classified as germinated, dormant, or non-vigorous (only palea or lemma recovered, or cheat seeds were mushy).

The second field experiment, the broadcast seed experiment, was conducted by hand planting 18 g of treated seeds on 2.3 m x 6.6 m plots. The seed bed was prepared twice with an S-tine harrow with double rolling baskets. The seeds were incorporated into the soil, from 0 to 25 mm deep with the same S-tine harrow. The test was conducted in 1995 in Stillwater and in 1996 in Stillwater and Lahoma. The seven treatments were: control (undamaged seeds), hammer milled seeds, seeds damaged at 0.1 or 0.4 mm roll gaps with the 5 teeth/cm and the 8 teeth/cm rolls, and a treatment with no cheat seed planted to measure the natural cheat infestation. Each treatment was replicated three times. Cheat stands were counted within four 0.125 m^2 quadrats randomly placed in each plot. The soil types were a Teller loam (fine-loamy, mixed, thermic Udic Argiustolls), a Kirkland silt loam (fine, mixed, thermic Udertic Paleustolls, and a Grant silt loam (Udic Argiustolls) at Perkins, Stillwater, and Lahoma, respectively. All sites were conventionally tilled cropland sites.

F-tests from the analysis of variance procedure were used to test for differences in means due to main effects associated with sites, date of excavation, and treatments, as well as, any interactions. Data were pooled across sites and date of excavation without interactions. Duncan's multiple range test was used to test for differences in germination means among different treatments. The equality of two proportions test (Steel and Torrie, 1980) was used to compare the combination of laboratory germination tests and rolls tooth densities to other. The normal approximation Z was calculated in each case and comparisons were made.

Model prediction of field germination

Equations were fitted to the data from greenhouse pots experiments and field experiments, and data from the growth chamber experiments and the field experiments. These models will be useful in predicting the response of the field germination when only growth chamber data or greenhouse pots data are available. Indeed, the field germination experiment is time consuming and depends on various factors such as temperature, sunlight, rainfall, microorganisms actions and many more. The laboratory experiments are easy to conduct and give germination results within a few weeks.

The original data were plotted and different equations were fitted to the data using the software Table Curve (Jandel Scientific, San Rafael, CA). The final equations were chosen based on the coefficient of determination (r^2) and the simplicity of the equation.

RESULTS AND DISCUSSION

Laboratory experiments

Cheat seed germination tests in growth chamber and greenhouse pots decreased with a decreasing roller mill roll gap (Fig. 1). The data were subjected to nonlinear regression

(Table curve, Jandel Scientific) using the equation: y=1/(a+b/x) where x is the gap between rolls in mm, and y is the germination percentage. The coefficient of determination (r^2) varied from 0.85 to 0.97 for the different experiments. Germination was directly proportional to roll gap for both roll tooth densities.

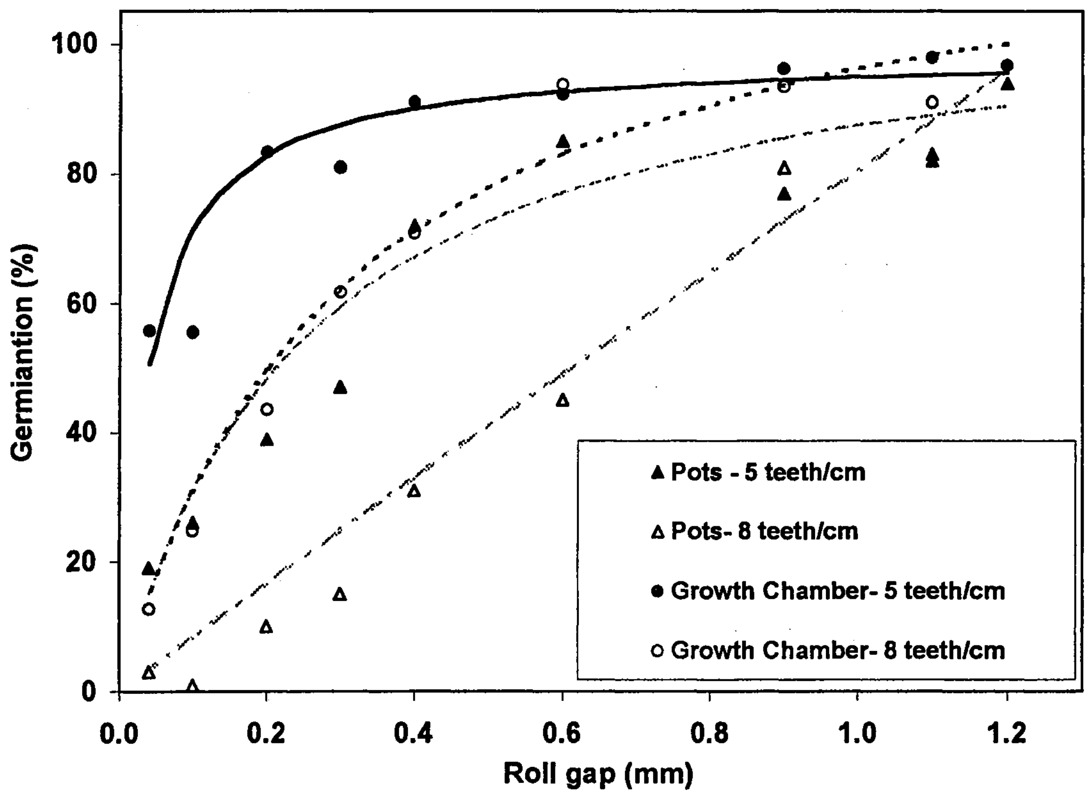


Figure 1 – Effect of roll gap on cheat seed germination.

Regression equation: y = 1/ (a+b/x) where:

Growth chamber 5 teeth/cm: a= 0.01014, b= 0.00038, $r^2 = 0.85$;

Growth chamber 8 teeth/cm: a= 0.00796, b= 0.00244, $r^2 = 0.97$;

Greenhouse pots 5 teeth/cm: a= 0.00912, b= 0.00232, $r^2 = 0.92$;

Greenhouse pots 8 teeth/cm: a= 0.00047, b= 0.001194, $r^2 = 0.97$;

However, roll gap had to be decreased to 0.4 mm to assure a statistically significant decrease in germination (Table 1, 2). The control (check) had 94% germination and was not statistically different from 1.1 mm with the 5 teeth/ cm rolls, and the 1.1 mm and 0.9 mm 5 teeth/cm rolls. Roller mill treatments with gaps greater than 0.4 mm had little or no effect on germination. However, with the 0.6 mm, 8 teeth/cm roll combination, the effect of more teeth/cm of circumference was apparent with germination significantly lower than control. As roll gap decreased, the number of injured seeds increased and the cracks on the seed coat were deeper (Fig. 2a,b,c,d,e,f). The greater the number of teeth on the roll, the greater the visible damage to the seeds. More physical damage to embryo, to scutellum (organ absorbing hydrolyzed enzymes from endosperm for utilization in embryo growth), and to endosperm in vicinity of embryo was observed with the narrow roll gap and high tooth density combination (Fig. 2d,f).

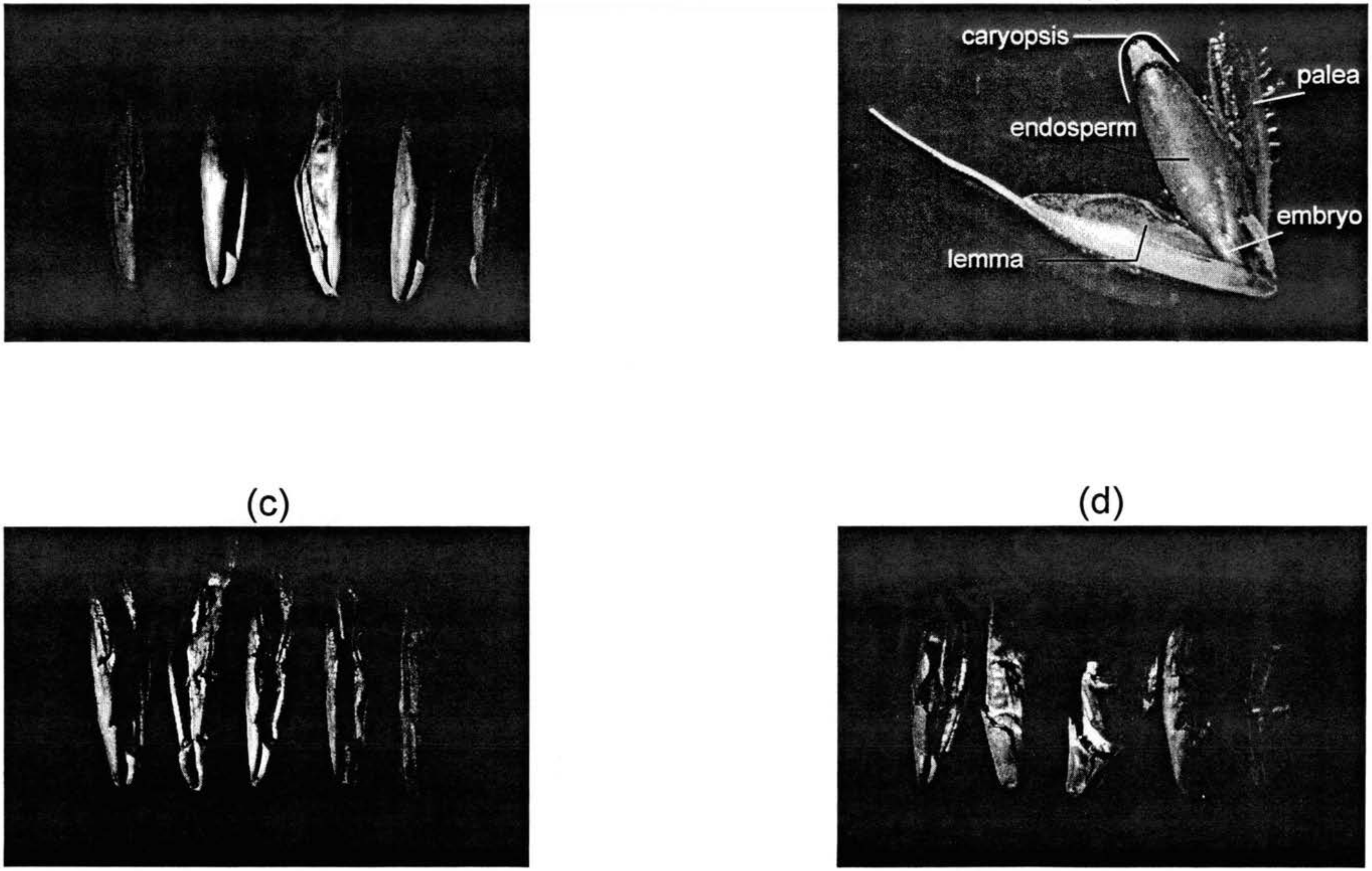
Table 1. Effect of roll gap and hammer mill treatment on cheat (*Bromus secalinus* L.) germination in the greenhouse pots.

Treatments	Mean germination (%)	
Roll gap (mm)	Roll 5 teeth/cm	Roll 8 teeth/cm
1.1	82a,b*	83a,b
0.9	77b	81a,b
0.6	85a,b	45c,d
0.4	72b	31d,e
0.3	47c	15f,g
0.2	39c,d,e	10g
0.1	26e,f	1g

*Means with the same letter are not significantly different at the 0.05 level using Duncan's Multiple Range Test.

(a)

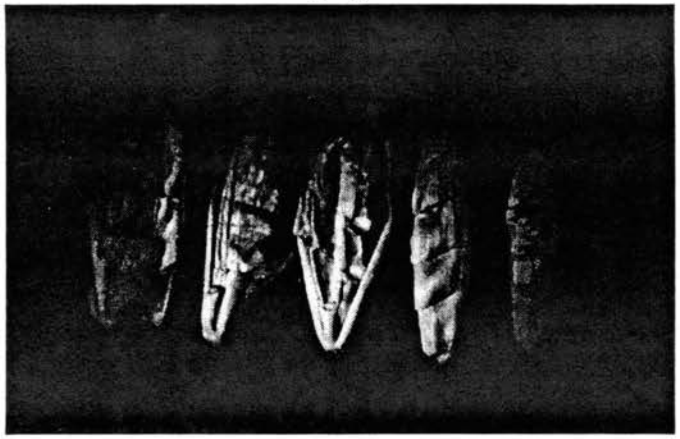
(b)



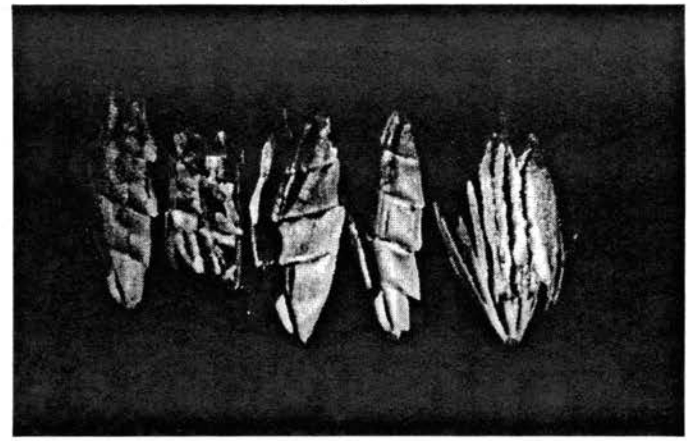
(c)

(d)

(e)



(f)



(g)

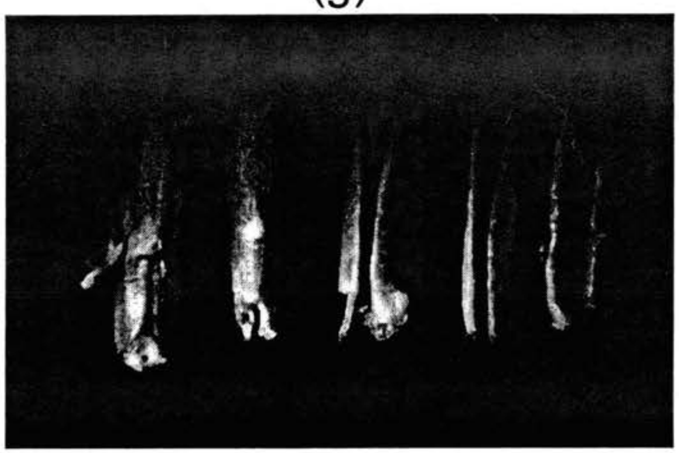


Figure 2-Treated seeds of cheat (*Bromus secalinus* L.): (a) Undamaged seed (control); (b) Opened floret; (c) Roller milled seed at 0.4 mm gap with 5 teeth/cm rolls (5R0.4 mm); (d) Roller milled seed at 0.1 mm gap with 5 teeth/cm rolls (5R0.1 mm); (e) Roller milled seed at 0.4 mm gap with 8 teeth/cm rolls (8R0.4 mm); (f) Roller milled seed at 0.1 mm gap with 8 teeth/cm rolls (8R0.1 mm); (g) Hammermilled seeds, embryos are broken and palea and lemma are missing.

Table 2. Effect of roll gap and hammer mill treatment on cheat (*Bromus secalinus* L.) germination in the growth chamber.

Treatments	Mean Germination (%)	
Rolls gap (mm)	Roll 5 teeth/cm	Roll 8 teeth/cm
1.1	98a*	91b,c
0.9	96a,b	94a,b
0.6	92a,b,c	94a,b
0.4	91a,b,c	71e
0.3	86c,d	62f
0.2	83d	44h
0.1	56g	25i

*Means with the same letter are not significantly different at the 0.05 level using Duncan's Multiple Range Test.

In general, germination in the growth chamber was greater than in the greenhouse pots, and germination with the 5 teeth/cm roll was higher than the 8 teeth/cm roll (Table 3). This difference was attributed to soil impedance reducing the emergence of non-vigorous seedlings. In the growth chamber, it was apparent that many of the germinated seeds from the roller mill treatment lacked vigor. With the roll gap of 0.4 mm or less, many germinated seeds were non- vigorous. As the gap decreased, the percentage of non-vigorous seedlings increase (Fig. 3, 4).

Table 3. Comparisons among the different laboratory germination tests using the equality of two proportions test*.

Y \ X	Pots *Roll 5 teeth/cm*	Growth Chamber *Roll 5 teeth/cm*	Growth Chamber *Roll 8 teeth/cm*
Pots *Roll 5 teeth/cm*	---	10.92 **	2.33 **
Pots *Roll 8 teeth/cm*	8.40 **	18.77 **	---
Growth Chamber *Roll 8 teeth/cm*	---	8.69 **	---

*This is a one way table. The numbers inside the table represent Z (normal approximation). The comparisons follow the pattern X versus Y and X>Y when Z is significant.
** highly significant $\alpha = 0.01$ level.

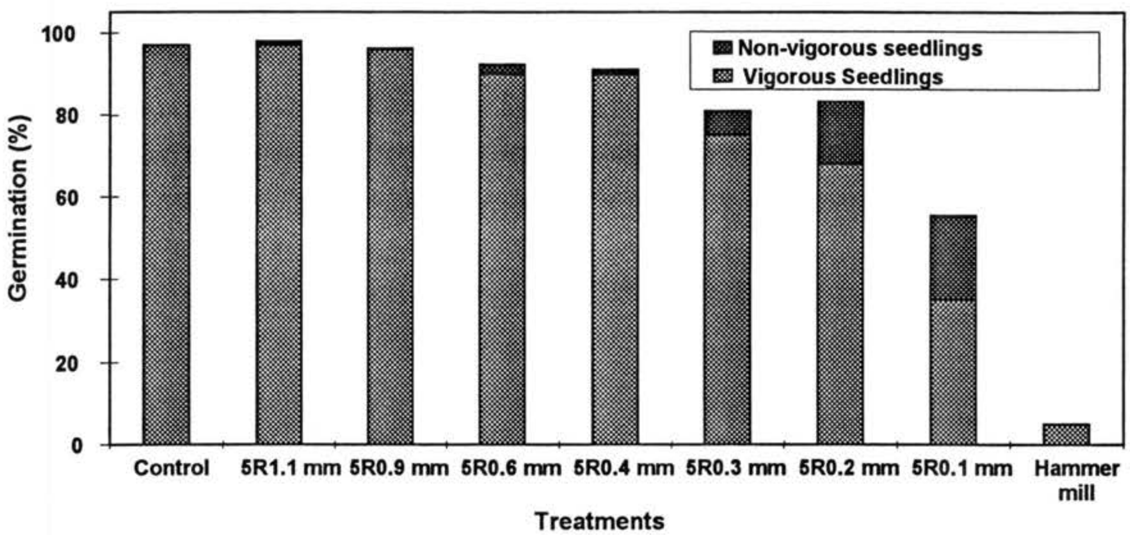


Figure 3- Growth chamber germination tests for hammer and roller milled seed with 5teeth/cm rolls. LSD (0.05) for total seedlings (vigorous + non-vigorous) = 5.10; LSD (0.05) for vigorous seedlings = 5.37

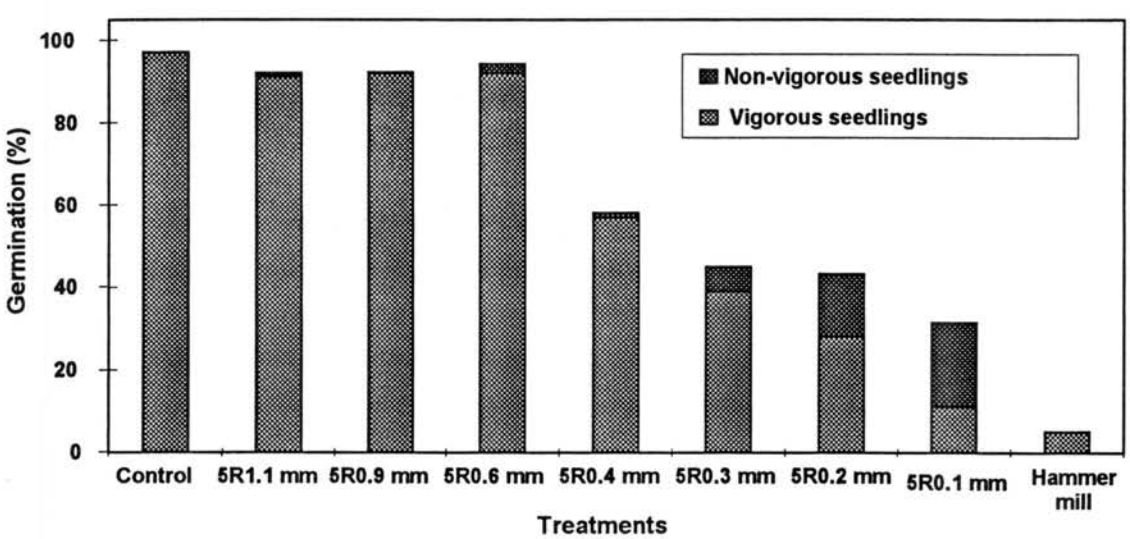


Figure 4- Growth chamber germination tests for hammer and roller milled seed with 8 teeth/cm rolls. LSD (0.05) for total seedlings (vigorous + non-vigorous) = 6.63; LSD (0.05) for vigorous seedlings = 6.17

Hammer milled cheat seed was dehulled and 92% of the embryos damaged (Fig. 2g). Germination of seed damaged by the hammer-mill was always grouped with narrower gaps roller milled treated seeds, and had 5% germination in pots and in the growth chamber compared to 94 % and 97 % for the control. Seeds with broken or missing embryos did not germinate. The hammer mill seed damage was greater than all of the roller mill treatments with roll gap greater than 0.1 mm. The hammer mill did relatively little damage to the endosperm. The roller mill, on the other hand, crimped the entire seed at regular intervals along the length of the seed. The greater the number of teeth, the closer were the cuts to the embryo (Fig. 2e,f). This explains why germination of the seed treated with the 8 teeth/cm rolls was lower than with the 5 teeth/cm roll (Table 3).

Field experiments

For both years, results from the packaged-seed experiment were similar to the laboratory experiments. Germination of control (intact) cheat seed increased from 21% in September to 52% in December in fall 1995 (Table 4). The data were pooled across the two locations (Perkins and Stillwater) because there was no interaction associated with the locations. For the fall of 1996, the data were pooled across locations and date of excavation because no interaction with the date of excavation was detected. This is due to the fact that the fall of 1996 was extremely dry and the seed did not germinate after the first week of October. For the same reason, germination in fall of 1996 was lower than germination of fall 1995. In general, germination decreased with decreasing roll gap and more roll teeth. In both years, four percent or less of the hammer milled seed germinated (Table 4).

Table 4. Effect of roll gap and tooth density, and hammer mill treatment on cheat (*Bromus secalinus* L.)germination; Packaged-seed experiments.

	Mean germination (%)			
	Fall 95*			Fall 96†
Treatments	September	October	December	Pooled data
Control	21a‡	41a	52a	25a
Hammer mill	4b	1c	4b,c	0.5c
8R0.1 mm	1b	3b,c	1c	1c
8R0.4 mm	2b	2c	4b,c	6b,c
5R0.1 mm	2b	8b,c	8b,c	3c
5R0.4 mm	2b	13b	14b	12b

* Data pooled across two locations (Stillwater and Perkins, OK)
† Data pooled across two locations (Stillwater, Lahoma, OK) and three dates of excavation.
‡ Means in the same column with the same letter are not significantly different at the0.05 level using Duncan's Multiple Range Test.

A Duncan's means comparison test showed no significant difference (0.05 level) between the hammer mill and the best roller mill treatments (Table 4). An average of 88% of the planted seed were recovered for the packaged-seed experiment. The missing seeds were likely consumed by wireworms (family Elateridae, probably *Aeolus sp*[1].) and other soil insects. Wireworms were found in the vicinity of three packets. A few seeds may have been lost while cleaning the soil from the seeds. The lower germination occurring in the field experiment can be explained by intervening natural causes. The variability of the available moisture in the soil, precipitation, presence of soil borne pathogens, insufficient light for optimal germination, and unsatisfactory temperatures are other possible causes of reduced germination (Bradbeer, 1988). The cracks on a seed allow the food reserve to be quickly leached from the seed and attract soil microorganisms. The fractured seed coat loses its ability to protect the seed and to regulate the water intake. The hammer milled seed do not have the hulls and can be rapidly eaten by microorganisms.

[1] Personal communication, Ronald Arnold , Entomologist, Noble Research Center; Oklahoma State University, Stillwater, Oklahoma, July 24, 1997.

Slagell-Gossen et al. (1998) sectioned and analyzed the treated seeds and found that roller milled seeds presented disrupted tissue organization of lemmas, paleas, and outer layers of the caryopses at the cuts. Hammer milled seeds not only lost their lemmas, paleas, and pericarp, but also exhibited severe damage to embryo. Nematodes and fungi were observed to penetrate the caryopses of the damaged seed and consume embryos and endosperm. No dormant seed were recovered after the third excavation. The seed had either germinated, were eaten by wireworms, or presented disrupted tissues.

Results of the broadcast experiments were similar to the laboratory tests and packaged-seed experiments. The control had the highest germination for all stand counts and at all sites. The control plot had cheat stands of 124 plants/m^2 in 1995 (Table 5). The stand count was lower in 1996, 45 and 41 plants/m^2 for the control, which was attributed to an infestation of weed species other than cheat and dry weather conditions. The germination decreased with decreasing roll gap and increasing number of roll teeth (Table 5). The combination wide roll gap and high tooth density (5R0.4 mm) treatment resulted in the least damage to the seed and was significantly different at the 0.05 level from the control (except for fall 96, Lahoma). It produced 45, 26, and 33 plants/ m^2 at the three sites (Table 5).

Table 5. Effect of roll gap and tooth density, and hammer mill treatment on cheat germination; Broadcast seed experiments.

	Cheat Stand Count per square meter		
Treatments	Stillwater, Fall 95	Stillwater, Fall 96	Lahoma, Fall 96
Control	124a*	45a	41a
Hammer Mill	7c,d	1d	1c
Natural Infestation	1d	1d	1c
8R0.1 mm	3c,d	7c,d	7c
8R0.4 mm	18c,d	18b,c	21b,c
5R0.1 mm	27b,c	14c	17b,c
5R0.4 mm	45b	26b	33a,b

*Means in the same column with the same letter are not significantly different at the 0.05 level using Duncan's Multiple Range Test.

In the broadcast experiments, the hammer mill, natural infestation, and 8R0.1 mm treatments resulted in the lowest germination level and were not significantly different at 0.05 level (Table 5) as was the case in all other types of germination tests. At the Stillwater 1995 and Lahoma 1996 sites, the 8R0.4 mm and 5R0.1 mm roller mill treatments were not significantly different from the hammer mill and gave similar, but not as consistent control as the hammer mill. At no site, did the 5R0.4 mm roller mill reduced cheat emergence as effectively as the hammer mill. The natural infestation treatment served as a check for residual cheat infestation. Cheat stand from these plots (1 plant/m^2), demonstrated that the previous cheat infestation was incidental. The same intervening causes observed with the packaged-seed experiment occurred with the broadcast experiment resulting in lower germination results in comparison to the pots and growth chamber experiments.

Model prediction of field germination

The equation that best predicted germination in the field from growth chamber data (Fig. 5) was:

$$y = \frac{1}{a + b\ x\ \ln(\ x)} \qquad (Eq\ .1)$$

where a= 0.189,

and b= - 0.00037

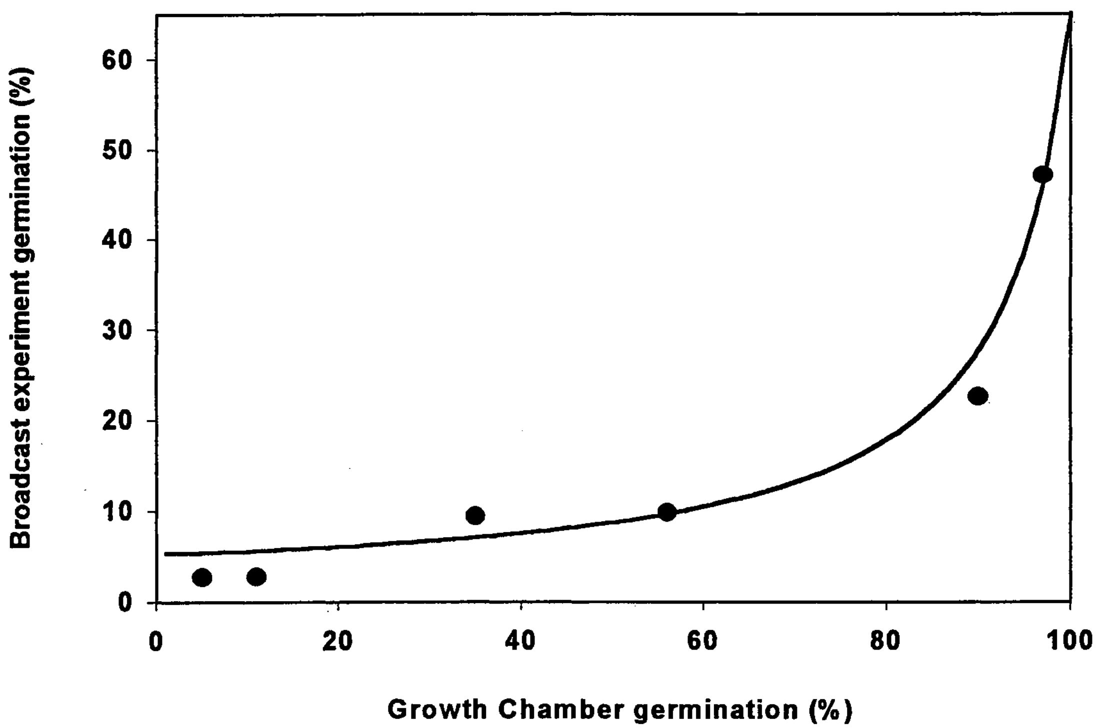


Figure 5- Growth chamber versus broadcast experiment germination of cheat seed

The germination in the field varied from 5% to 45% when the germination in the growth chamber varied from 5% to 95%. For germination percentage below 60% in the growth chamber, there was a very little increase in field germination for an increase in growth chamber germination percentage. The difference in germination was a consequence of the failure of the growth chamber to take into account the impedance of the soil. In the growth chamber, the seed has an ideal environment for germination.

For the greenhouse pot experiments, the data is best described (Fig. 6) by the equation:

$$y = a + be^{\frac{-x}{c}} \qquad (Eq.2)$$

where a= 1.485,

b= 2.515, and c = -32.57

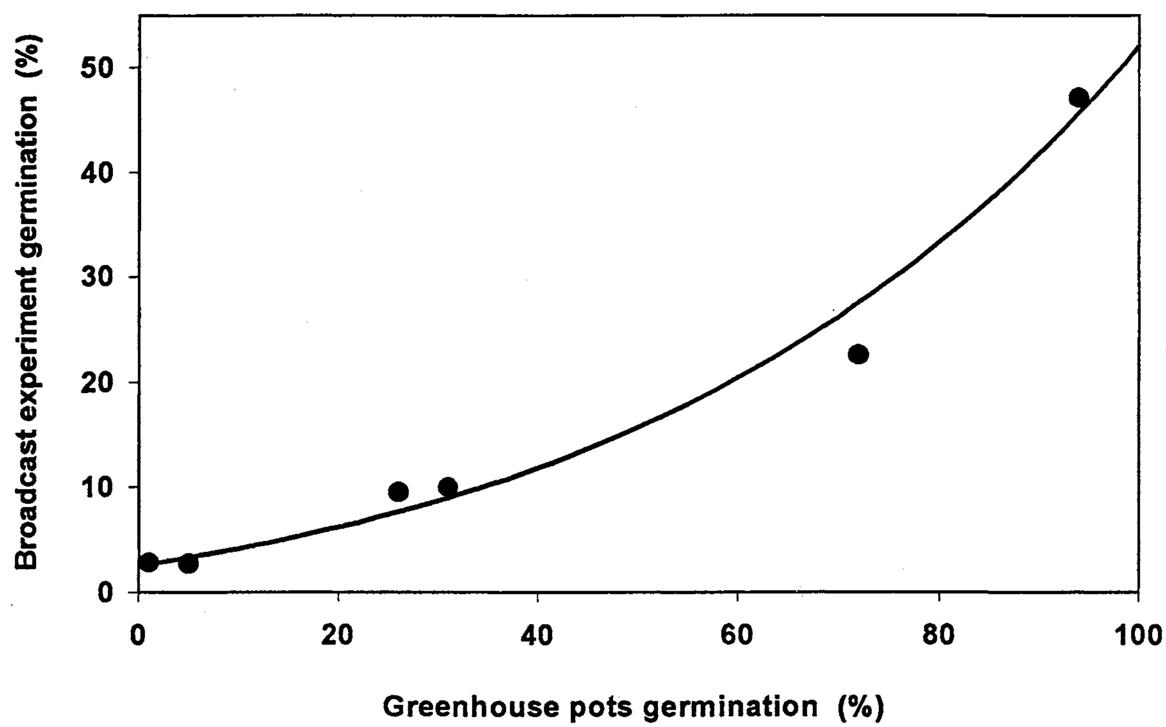


Figure 6- Greenhouse pots versus broadcast experiment germination of cheat seed

The germination in the field varied from 5% to 50% when the germination in the greenhouse varied from 5 to 95%. The change in field germination percentage for a change in greenhouse pots germination was different from the phenomenon observed with the growth chamber germination percentage. This can be explained by the fact that the pot and the field experiments both take into account the impedance of the soil. The seed must be vigorous enough to emerge from the soil and be counted as germinated.

Milling cheat seed could reduce its viability and germination. Germination tests were a good indicator of the viability and vigor of the seed. The same trend between degree of milling cheat seed and reduction in germination was observed with the laboratory and the field tests. The hammer mill treatment resulted in the lowest germination and most consistent response. The combination of narrowest roll gap and highest roll tooth density yielded germination reductions statistically equivalent to the hammer mill treatment, except in the growth chamber. However, the method of assessing the germination did have an effect on the results.

The germination in the growth chamber underestimated the effect of the roller mill treatments (Table 2). The tests in the greenhouse pots are a relatively rapid way to simulate the field conditions, but they overestimated the germination of 5R0.4 mm and 8R0.4 mm roller mill treatments. The field germination tests were influenced by intervening natural causes and generally produced reduced levels of germination. The choice of the type of test will depend on the amount of time available to conduct the tests. Nevertheless, the greenhouse pots and growth chamber can be used to predict ability of mechanical device to devitalize weed seeds.

CONCLUSIONS

The following conclusions may be drawn from this study:

1. The gap between the rolls and the density of the teeth on the rolls were correlated to the viability of the seeds. Germination decreased with decreasing roll gap and increasing number of roll teeth.
2. The hammer mill dehulled the seeds, fractured 92% of the seed embryos, and had the most consistent control of all germination tests.
3. The combination narrowest roll gap and highest tooth density yielded germination reduction statistically not different from the hammer mill treatment.
4. The field tests followed the same trend as growth chamber and greenhouse pots tests, but viability of seeds was lower because of additional intervening naturally factors. However, the ability of these mills and the other mechanical devices to devitalize seed can be predicted using either the greenhouse pots or growth chamber tests.
5. The hammer mill produced the lowest germination percentage in all the cases and is preferred over the roller mill.
6. Mechanically damaging cheat seed without complete grinding has considerable potential for weed control. The roller mill and the hammer mill can be used to mechanically injure cheat seed to reduce their capacity to germinate.

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CHAPTER IV

EFFECT OF HAMMER MILL SHAFT SPEED, SCREEN OPENING SIZE, FEED RATE, AND NUMBER OF HAMMERS ON CHEAT SEED GERMINATION

ABSTRACT

The improvement of the economic return and the enhancement of the sustainability of wheat production depend on weed control. Cheat, *Bromus secalinus L.*, is one of the most serious weeds infesting wheat fields. An alternative to herbicides for weed control is to devitalize cheat seed using a mechanical device such as the hammer mill. Tests were conducted to determine the effect of hammer mill shaft speed, screen opening sizes, feed rate, and number of hammers on cheat seed germination. Hammer mill shaft speeds were varied from 600 rpm to 3600 rpm. The two screen opening sizes evaluated were 3.2 mm (8/64 screen) and 4.0 mm (10/64 screen). Feed rates used were 50, 70, and 85 g/s. The two sets of hammers evaluated were 16 and 24 hammers. Seed viability was measured by the percentage of vigorous seedlings after growth chamber germination.

Germination percentage of identifiable hammer milled (whole, damaged, or partially broken) seed decreased as mill shaft speed or number of hammers increased, and screen opening size was reduced. Within the range of the experiments, the feed rate did not have a significant effect on cheat seed germination. The best hammer mill setting of 3600 rpm with the 8/64 screen, 24 hammers, and an average feed rate of 50 g/s resulted in 9% cheat seed germination compared to 99% for control and hand-harvested cheat samples. When all the material processed (small particles and identifiable seeds) was taken into account for germination percentage calculations, the germination was 3% at the same settings.

Keywords: Cheat, Hammer Mill, Weed Control, and Wheat.

INTRODUCTION

Hammer mills have historically been used in the feed milling industry. The hammer mill is composed of hammers mounted on a rotor which rotates within a peripheral screen. Seed is subjected to impact forces from the hammers until it is milled fine enough to go through the selected screen. Thus, screen opening size controls the fineness of the grind. However, parameters such as hammer tip speed, rotor volume, type and number of hammers, and feed rate also influence the performance of the hammer mill.

Researchers have investigated the effect of hammer mill operating parameters on milling parameters. Appel (1987) compared energy consumption and particle size of hammer milled and roller milled grain sorghum and corn. He found that: (1) the roller mill produced more surface area per unit of effective energy used than the hammer mill; (2) the energy required for grinding increased as the initial moisture content of the grain increased or screen size and roll gap were reduced. Yu and Brusewitz (1993) determined the change in physical properties of mustard seeds as affected by mill type (roller mill or hammer mill), gap between rolls of the roller mill, feed rate through the hammer mill, and seed temperature at the time of cracking. They found: (1) lower seed cracking temperature and narrower roll gap, and lower hammer mill feed rate induced lower bulk density and lower bulk compression force; and (2) hammer milling produced more fine particles than roller milling. They noted that hammer milled particles were mostly short and straight while roller milled samples had many long, curved particles. Ahlgren et al. (1950) used a small swinging hammer mill to dehull seed of smooth brome (*Bromus inermis* L.) and found that more damage was caused at the highest speed, and germination was reduced at all speeds. Moreover, the decrease in germination was due to mechanical damage and not to the dehulling. Bölöni (1997) studied the decimal efficiency (power required to create new surface area is considered as useful power output) of grinding using a hammer mill. He found that more than half of the total energy was absorbed by grains during impacts. Fang et al.(1997) compared energy efficiency between a roller mill and a hammer mill and tested the effect of the main operational parameters of both machines on mill performance. For hammer mill grinding, they observed that the screen opening size was the most significant parameter affecting mill performance, and feed rate effect was not a significant parameter.

As an alternative approach to weed control, Hauhouot et al. (1997) studied the feasibility of using a roller mill or a hammer mill to mechanically devitalize (produce non-viable seeds) seed of cheat (*B. secalinus* L.). Cheat seed was damaged by a hammer mill and germination tests were run to measure its viability. Based on the preliminary tests verifying the feasibility of using mechanical devices to devitalize cheat seed during harvest on a combine, it appeared that the hammer mill could be used for weed control as an alternative to herbicides. Experiments were needed to determine the effect of machine operating parameters such as shaft speed, feed rate, screen opening size, and number of hammers on cheat seed germination.

Objective

The objective of this research was to study the effect of hammer mill operating variables such as shaft speed, screen opening size, feed rate, and number of hammers on the viability of milled cheat seeds.

Materials and Methods

The cheat seeds used for the different tests were cleaned from 1997 combine-harvested wheat.

The laboratory type hammer mill (Model E-9506-TF BLISS Industries, Ponca City, Oklahoma) was powered by a pulse-width modulated 1.5kW electric motor. The shaft speed was controlled by fixing the local frequency on the variable frequency AC speed controller (ABB ACS 300, Orange, Connecticut). The maximum speed was 3600 rpm. The maximum number of hammers was 24. Hammer size was 6.4 mm x 2.5 mm x 60.3 mm. Hammer ends were machined square and mounted on four 152.4-mm rods oriented 90° apart and spaning the width of the mill. For the 16-hammers set, each rod had four hammers; two of the rods had 8 hammers for the 24-hammers set. The hammer-screen clearance was 13 mm. Two round-hole screens were used in these experiments: 3.2 mm (8/64 screen) and 4.0 mm (10/64 mm screen). Hammer mill specifications are summarized in Table 1.

Table 1- Hammer mill specifications

Chamber diameter (D_c)	mm	228.6
Chamber width	mm	152.4
Chamber volume	cm^3	6254.81
Rotor diameter (D_r)	mm	5.08
Rotor shaft speed	rpm	600 – 3600 rpm
Hammer tip speed	m/s	7.18-43.09
Number of hammers		16 or 24
Total screen area	cm^2	929.03
Hammer clearance from screens (e)	mm	12.7
Hammer size	mm	6.4 x 2.5 x 60.3
Screen opening sizes	mm	3.2, 4.0

For all tests, a known weight of cheat seed was fed through the hammer mill, and the processed seeds were collected in a vacuum cleaner (Fig. 1). At the conclusion of each test, seed remaining on the screens was vacuumed. The collected material was then passed through a laboratory seed cleaner (Seedburo Equipment Company, Chicago, IL) to remove dust, fine particles, and seed hulls. Germination tests were run in a growth chamber to determine the viability and germination percentage of the identifiable cheat seeds (whole, damaged, or partially broken seeds). Samples of unprocessed cheat seed and hand-harvested cheat seed were germinated as checks.

Shaft speed and screen opening size effect

An experiment was conducted to determine the effect of the mill rotor shaft speed (600 - 3600 rpm) and screen opening size (8/64 and 10/64 screens) on percentage of identifiable seeds (whole or partially damaged seeds) recovered after cleaning process. The experiment was a 2*6 factorial arrangement in a completely randomized design. The main factors were shaft speeds and screen opening size.

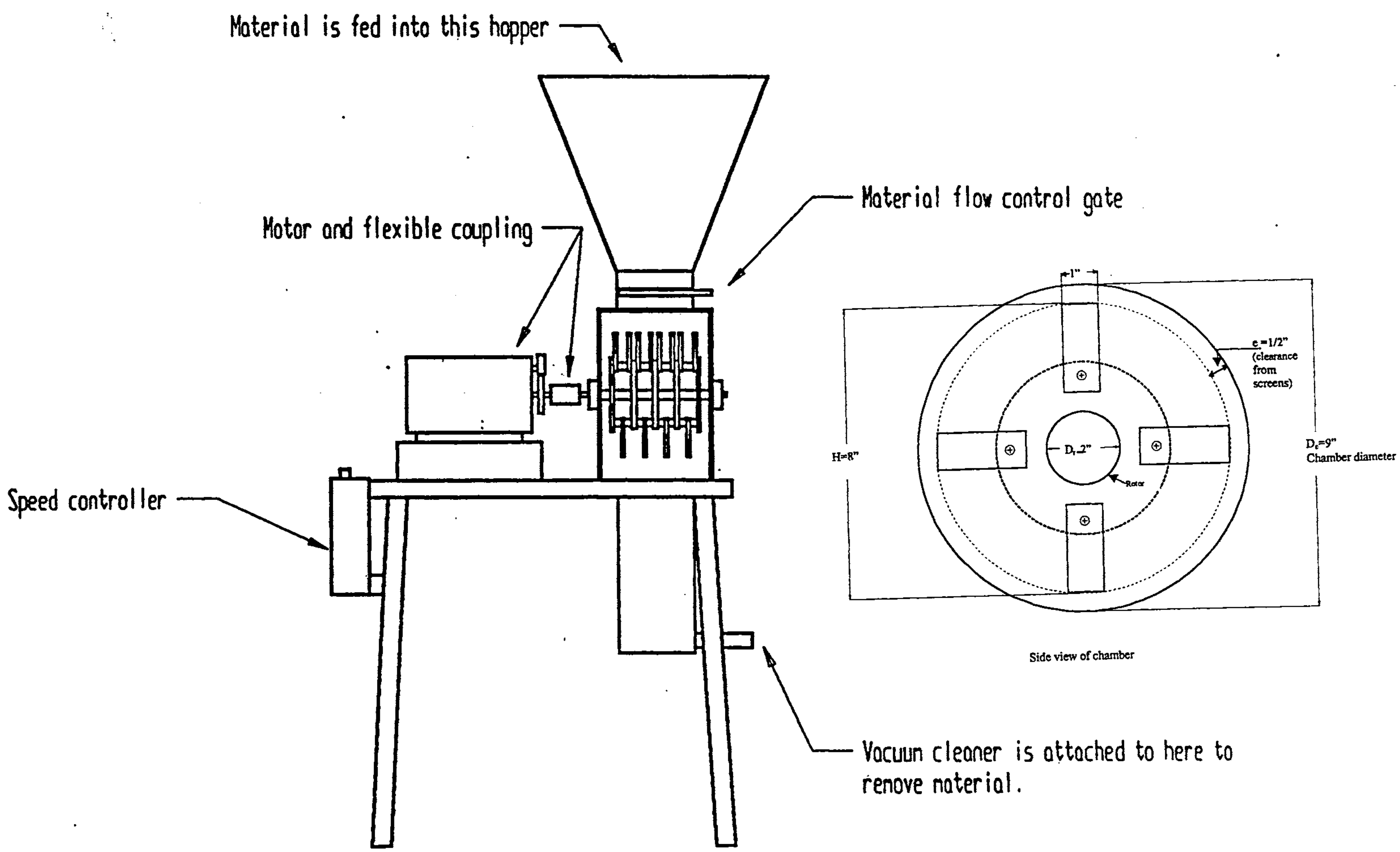

Figure 1- Hammer mill experiments setting

Another experiment was conducted to determine the effect of the mill rotor shaft and the screen opening size on cheat seed germination. The experiment design was a split-plot in a randomized block design with three replicates. Two screen sizes used were 8/64 and 10/64. Rotor shaft speeds were 600, 1200, 1800, 2400, 3000, and 3600 rpm. The hammer mill was equipped with 24 hammers set at 13 mm clearance from the screens. Approximately 210 g of cheat seed was weighed and manually fed in the machine in 3 seconds (70 g/s). The processed material was weighed and cleaned. After cleaning, the material was reweighed, and the percentage of identifiable seeds recovered was computed.

Shaft speed and feed rate effect

An experiment was conducted to determine the effect of the mill rotor shaft speed and feed rate on percentage of identifiable seeds (whole, damaged or partially broken seeds) recovered after cleaning process. The experiment was a 3*4 factorial arrangement in a completely randomized design. The main factors were shaft speeds and feed rate.

Another experiment was conducted to determine the effect of shaft speed and feed rate on cheat seed germination. The experiment design was a split-plot in a randomized block design with three replicates. Rotor shaft speeds were 1800, 2400, 3000, and 3600 rpm and three feed rates (50g/s, 70 g/s, and 85g/s) were used for both experiments. Approximately 150 g, 210 g, and 255 g of cheat seed was fed in the machine in 3 seconds to obtain 50g/s, 70 g/s, and 85 g/s. The hammer mill had 24 hammers set at 13 mm from the screens. The screen used was the 8/64. The processed material was weighed and cleaned. After cleaning, the material was reweighed, and the percentage of identifiable seeds recovered was computed.

Speed and number of hammers effect

An experiment was conducted to determine the effect of the mill rotor shaft speeds and number of hammers on percentage of identifiable seeds (whole, damaged or partially broken seeds) recovered after cleaning process. The experiment was a 2*4 factorial arrangement in a completely randomized design. The main factors were shaft speeds and number of hammers.

Another experiment was conducted to determine the effect of rotor shaft speed and the number of hammers on cheat germination. The experiment design was a split-plot in a randomized block design with three replicates. Rotor shaft speeds were 1800, 2400, 3000, and 3600 rpm and two sets of hammers (16, 24) were used for both experiments. The hammers were set at 13 mm clearance from the screens. The screen used was the 8/64. Approximately 210 g of cheat seed was fed in the machine in 3 seconds (70g/s). The processed material was weighed and cleaned. After cleaning, the material was reweighed, and the percentage of identifiable seeds recovered was computed.

Seed Germination

Growth chamber test (warm germination) was performed on four 100-seed samples from each treatment in a water curtain germinator (Stults Scientific Engineering Corp., Springfield, Illinois). The seeds were put on wet paper tissue and prechilled at 5°C in a refrigerator for five (5) days to break dormancy, then placed in a growth chamber at 20°C for nine (9) days. Germinated seeds were counted on the sixth and fourteenth days. Since no procedures existed for cheat, the procedure to determine germination conformed to the requirements for smooth brome established by the Association of Official Seed Analysts (1978). At the end of the germination period, seedlings presenting a growing primary root were considered as germinated. Seedlings with strong and long roots, and no mold were classified as vigorous. The advantages of this test are that the temperature and the humidity are controlled to optimize germination and results can be determined within a relatively short time period.

An analysis of variance (PROC ANOVA, SAS, 1987) was conducted on data obtained for each test for percentage of identifiable seeds recovered after cleaning process and for germination percentage of identifiable cheat seeds. The procedure MIXED (PROC MIXED, Littell et al., 1996) was used to compare germination mean percentages of each treatment to the others. A Fisher Least Significant Difference test was used to separate means of identifiable seeds recovered after cleaning process.

RESULTS AND DISCUSSION

The check samples composed of unprocessed cheat seed, and hand-harvested cheat seed had a mean germination percentage of 99%.

Shaft speed and screen size effect

Percentage of identifiable seeds recovered after cleaning decreased as speed increased for both screens (Fig. 2). An analysis of variance (ANOVA) showed that both rotor shaft speed and screen opening size had a significant effect on the percentage of identifiable seeds recovered after cleaning. It varied from 98% at 600 rpm to 39 % at 3600 rpm for the 8/64 screen, compared to 96 % to 55% for the 10/64 screen. With the 10/64 screen, a Fisher's Least Significant Difference (LSD) at the 0.05 level showed no significant difference for material recovered after cleaning between 600 rpm and 1200 rpm, between 1800 rpm and 2400 rpm, between 2400 rpm, and 3000 rpm. At 3600 rpm, the percentage of material recovered was the lowest (53%), and it was significantly different from all other rotor shaft speed treatments. As the speed increased, more seed was dehulled and/or broken and removed with the dust and very fine materials during the cleaning process. The 8/64 screen has smaller holes, which resulted in more small particles. All the percentages of material recovered after cleaning were significantly different from each other. The lowest percentage (39%) was obtained at 3600 rpm. In general, the 8/64 presented lower percentage of material collected after the cleaning process. Most of the identifiable seeds recovered after cleaning were missing seed coats (hulls) and embryos, or were partially broken. This was characteristic of hammer milled cheat seed.

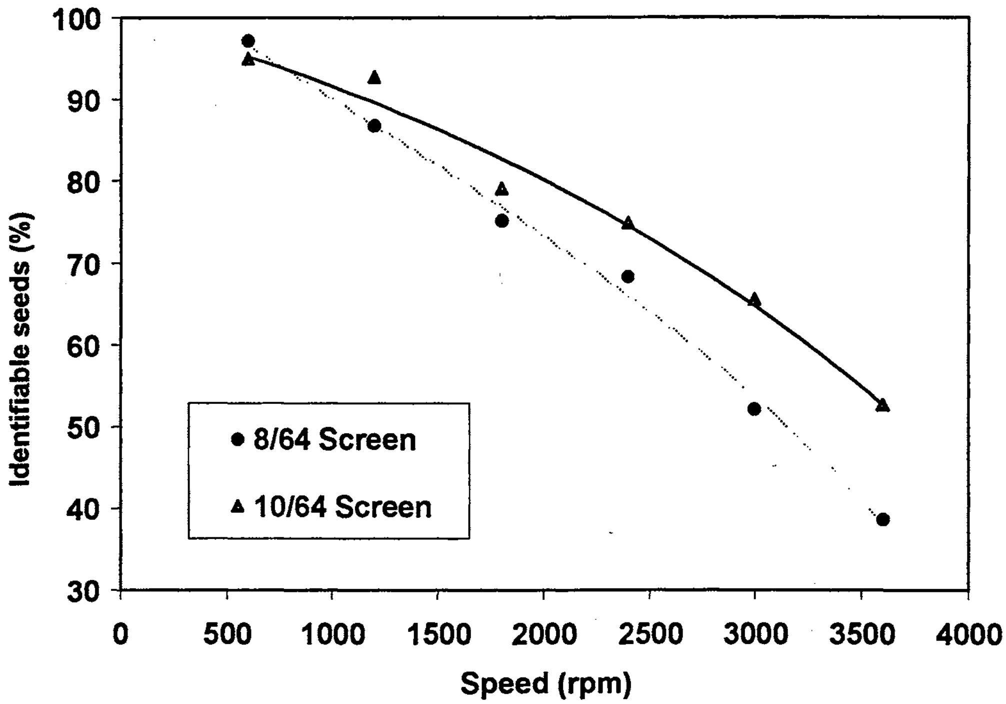

Figure 2- Effect of shaft speed and screen opening size on percentage of identifiable cheat seeds recovered after cleaning. 8/64 screen: LSD(0.05)=6.08; 10/64 screen: LSD (0.05)=11.18. Each point is the average of three points (replicates).

The equations that best fitted the data (Fig. 2) were the following:

$$8/64\ screen: \quad y = \sqrt{12646.7 - \frac{12.7x}{\ln(0.17x)}}$$

$$10/64\ screen: \quad y = \sqrt{9726.5 - 0.47x\ln(0.17x)}$$

where y is the percentage of material recovered after cleaning and x is the rotor shaft speed in rpm.

Both speed and screen size had a significant effect on cheat seed viability. Germination percentage was higher at low speeds i.e. 600, 1200, 1800 rpm (Fig. 3) and decreased as shaft speed increased. Germination of seeds processed with the 10/64 screen was higher than germination of seeds processed with the 8/64 screen. Germination decreased precipitously at 1200 rpm for the 8/64 compared to 1800 rpm for the 10/64 screen. There was no significant difference in germination percentage between 3000 rpm and 3600 rpm with the 8/64 screen (Table 2a). The lowest germination percentages were 11% and 10% obtained with seeds processed at 3000, and 3600 rpm with the 8/64 screen.

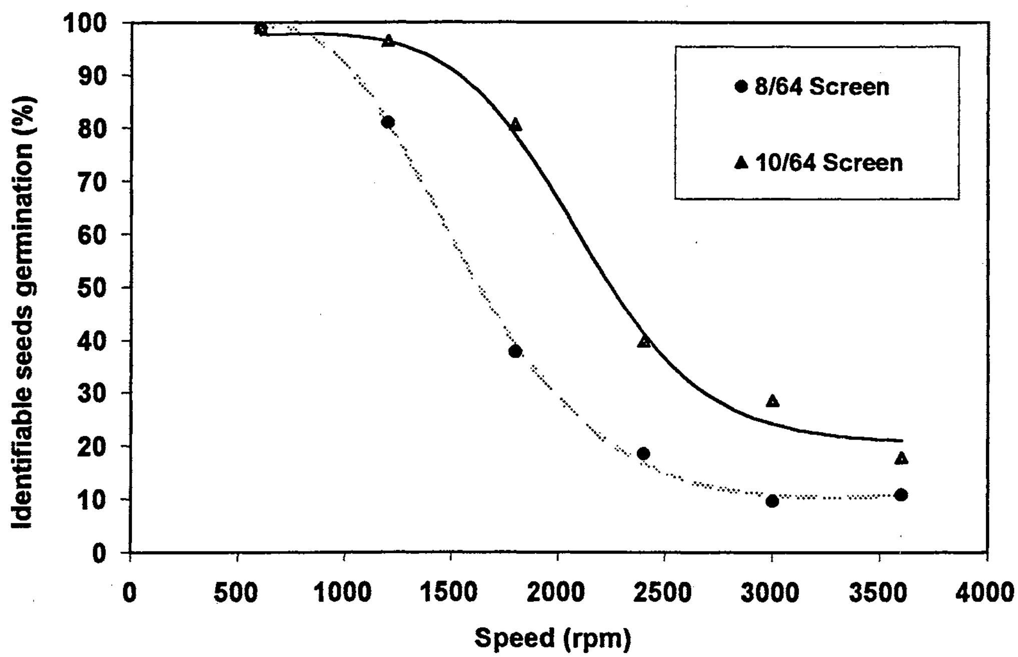

Figure 3- Effect of shaft speed and screen opening size on germination of identifiable cheat seeds recovered after cleaning.

Table-2a: Effect of speed and screen size opening on germination of identifiable cheat seeds recovered after cleaning

Speed (rpm)	Screen size opening 8/64 (%)	10/64 (%)
600	99 a*	99 a
1200	81 b	97 a
1800	38 c	81 b
2400	19 e	40 c
3000	11 f	29 d
3600	10 f	18 e

*Means with the same letter are not significantly different at the 0.05 level. (PROC MIXED, SAS).

Cheat seed the germination was lower when all seeds including seed ground during milling was accounted for. Table 2b. summarized effect of speed and screen opening size on cheat seed germination when all material processed was taken into account (identifiable seeds and ground seeds removed during cleaning). The germination response presented a similar trend to the response when only recovered material after processing was considered. The lowest germination percentage was 4% with the 8/64 screen at 3600 rpm compared to 10% when only the recovered processed material was considered.

Table-2b: Effect of speed and screen size opening on cheat seed germination for all material processed

Speed (rpm)	Screen size opening 8/64 " (%)	10/64 (%)
600	97 a*	94 a,b
1200	70 c	90 b
1800	28 e	63 d
2400	13 g	30 e
3000	5 h,i	19 f
3600	4 i	9 g,h

*Means with the same letter are not significantly different at the 0.05 level. (PROC MIXED, SAS)

Shaft speed and feed rate effect

Feed rate had no significant effect on the percentage of material recovered after cleaning. Consequently, data were pooled across feed rate and a Fisher's LSD at the 0.05 level was used to compare percentage means at different rotor shaft speeds. The percentage of material collected after cleaning decreased with the speed (Fig. 4). It varied from 70 % at 1800 rpm to 35% at 3600 rpm. The higher the speed, the more damage on the seed. Consequently, more seeds were broken and removed with dust and very fine materials during the cleaning process. There was no significant difference for material recovered after cleaning between 1800 rpm and 2400 rpm, between 2400 rpm and 3000 rpm, and between 3000 and 3600rpm. There was significant difference for percentage of material recovered after cleaning between 1800 rpm and 3600 rpm.

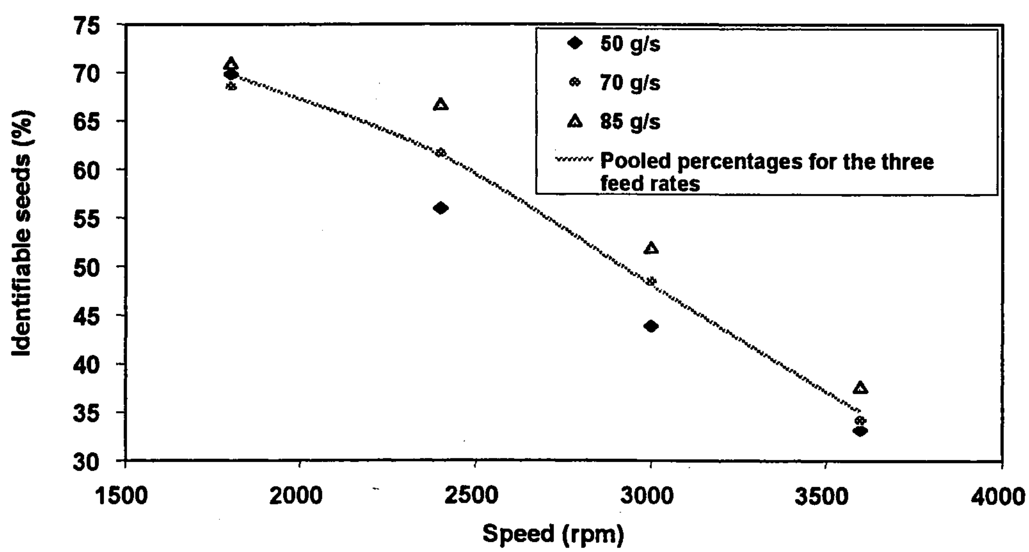

Figure 4- Effect of shaft speed and feed rate on percentage of identifiable cheat seeds recovered after cleaning. Pooled percentages for the three feed rates: LSD (0.05)=16.41.

Within the range of this investigation, there was no interaction between feed rate and speed on cheat seed germination. Speed had a significant effect on the viability of cheat seed, but feed rate appeared not to have a significant effect on the germination of cheat seed. Because the seed was hand fed into the mill, there was variation in the feed rate. However, feed rate would likely vary also with a hammer mill mounted on a combine to devitalize weed seed.

Germination decreased as the speed increased (Fig. 5), but there was no significant difference between germination percentage at the same speed for the feed rates (Table 3). The lowest germination percentages 9%, 12%, and 14% were obtained at shaft speeds of 3000 rpm and 3600 rpm and feed rate of 50, 70, and 85 g/s.

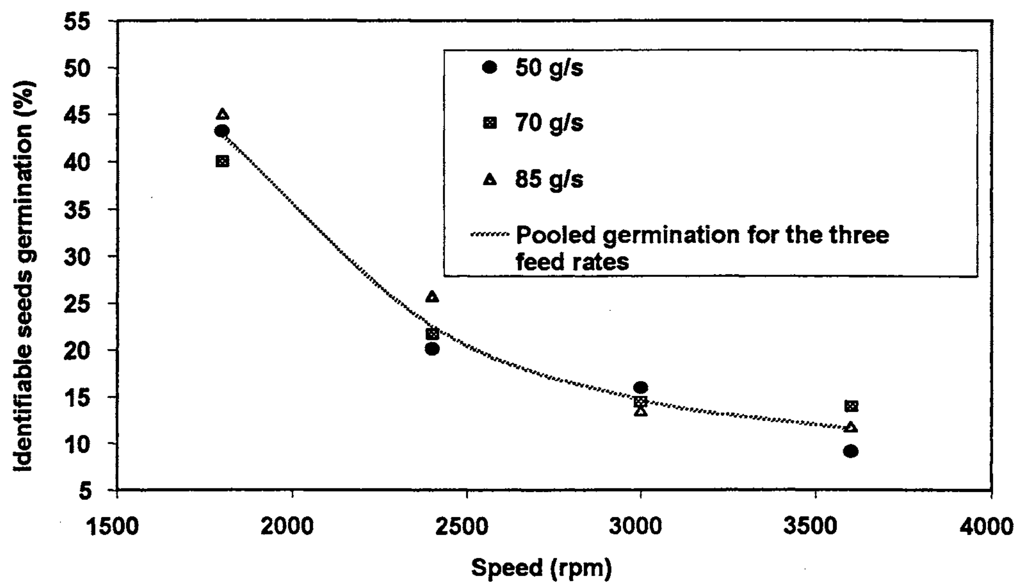

Figure 5- Effect of shaft speed and feed rate on germination of identifiable cheat seeds recovered after cleaning.

Table-3a: Effect of speed and feed rate on germination of identifiable cheat seeds recovered after cleaning

Speed (rpm)	Feed Rate 50 g/s (%)	70 g/s (%)	85 g/s (%)
1800	43 a*	40 a	45 a
2400	20 b,c	22 b,c	26 b
3000	16 c,d	15 d	14 d,e
3600	9 e	14 d,e	12 d,e

* Means with the same letter are not significantly different at the 0.05 level. (PROC MIXED, SAS).

When all material processed including ground seed was accounted for, germination was once again lower than when only the identifiable seeds recovered processed material was taken into account (Table 3b). The lowest germination percentage were 3%, and 5% at 3600 rpm with the three feed rates compared to 99% for unprocessed seeds.

Table-3b: Effect of speed and feed rate on cheat seed germination for all material processed

Speed (rpm)	Feed Rate 50 g/s (%)	70 g/s (%)	85 g/s (%)
1800	30 b*	27 b	34 a
2400	11 d	13 d	17 c
3000	7 e	7 e	7 e
3600	3 f	5 e,f	5 e,f

* Means with the same letter are not significantly different at the 0.05 level. (PROC MIXED, SAS)

Shaft speed and number of hammers effect

Both shaft speed and number of hammers had a significant effect on the percentage of material recovered after cleaning. Percentage of identifiable seeds recovered after cleaning increased with fewer hammers and a decreasing shaft speed (Fig. 6). Fewer hammers, the lower the probability of the seed being hit by the hammers. Consequently, fewer seeds were ground and were removed with the dust and the fine materials during the cleaning process. There was no significant difference for material recovered after cleaning between 1800 rpm and 2400 rpm for the 16 hammers set. There was significant difference for percentage of material recovered after cleaning between 1800 rpm and 3000 rpm, 1800 rpm and 3600, and between 3000 rpm and 3600 rpm. The lowest percentage of material recovered was 37% at 3600 rpm. With the 24 hammers set, the percentages of material recovered after cleaning were significantly different at all the rotor shaft speeds. The lowest percentage, 33%, was obtained at 3600 rpm.

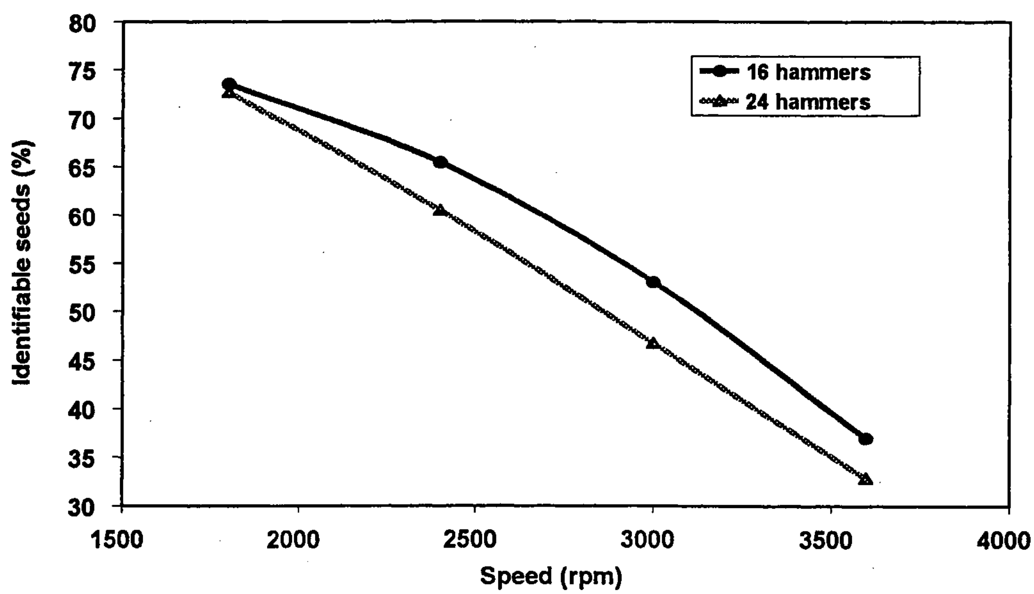

Figure 6- Effect of shaft speed and number of hammers on percentage of identifiable seeds recovered after cleaning. 16 hammers: LSD (0.05)=8.14; 24 hammers: LSD (0.05)=8.67.

Each point is the average of three points (replicates).

There was an interaction between number of hammers and speed. Shaft speed and number of hammers had a significant effect on the viability of cheat seed. At shaft speeds lower than 2700 rpm, germination increased with decreasing speed (Fig. 7), and 16-hammers mill yielded higher germination than 24-hammers mill. At 2700 rpm and higher shaft speeds, germination was the same for both hammer sets. Germination tended to decrease as the speed increased, but there was no significant difference between the germination percentage at 3000 rpm and 3600 rpm for both number of hammers (Table 4). The lowest germination percentages obtained were 12% and 11% at 3000 rpm and 3600 rpm for both 16 and 24-hammer sets.

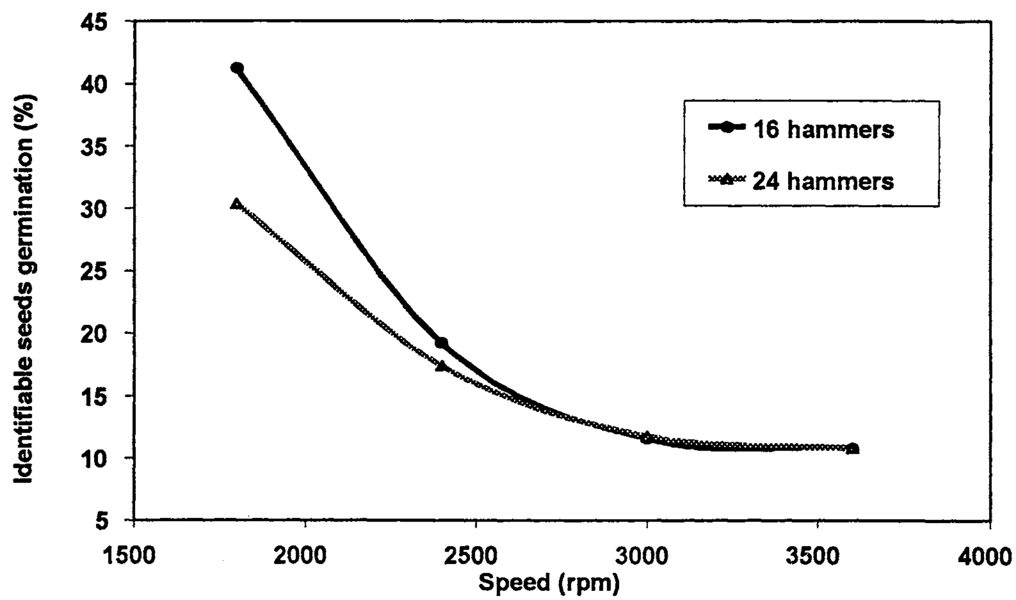

Figure 7- Effect of shaft speed and number of hammers on germination of identifiable cheat seeds recovered after cleaning.

Table-4a: Effect of shaft speed and number of hammers on germination of identifiable cheat seeds recovered after cleaning

Speed (rpm)	Number of hammers: 16 (%)	Number of hammers: 24 (%)
1800	41 a*	30 b
2400	19 c	17 c
3000	12 d	12 d
3600	11 d	11 d

* Means with the same letter are not significantly different at the 0.05 level. (PROC MIXED,SAS).

When all the material processed including ground seed was considered (Table 4b), germination was once again lower than when only the identifiable seeds recovered after cleaning was taken into account. The lowest germination percentage were 3%, and 6% at 3000 and 3600 rpm for the two sets of hammers compared to 99% for unprocessed seeds.

Table-4b: Effect of shaft speed and number of hammers on germination of cheat seed for all material processed

Speed (rpm)	Number of hammers: 16 (%)	Number of hammers: 24 (%)
1800	30 a*	22 b
2400	13 c	11 c
3000	6 d	6 d
3600	4 d	4 d

* Means with the same letter are not significantly different at the 0.05 level. (PROC MIXED, SAS)

CONCLUSIONS

The conclusions of this investigation were the following:

1. Germination percentage of cheat seed decreased with higher speed and large screen hole diameter, and more hammers.
2. Within the range of the experiments, the feed rate did not have a significant effect on cheat seed germination.
3. Cheat seed germination was lowest, 9%, at 3600 rpm shaft speed, with the 8/64 screen, 24 hammers, and an average feed rate of 50 g/s compared to 99% for the check and the hand-harvested samples.
4. Cheat seed germination was very low 3%, at 3600 rpm with the 8/64 screen, 24 hammers, and an average feed rate of 50 g/s when all amount of material processed was taken into account for the germination tests including the ground seeds.

These results indicate that the hammer mill has potential to sufficiently damage cheat seed to dramatically reduce its germination.

ACKNOWLEDGEMENTS

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CHAPTER V

EFFECT OF ROLLER MILL ROLL SPEED DIFFERENTIAL AND ROLL GAP ON GERMINATION OF MILLED CHEAT (*Bromus secalinus* L.) SEED

ABSTRACT

The improvement of the economic return and the enhancement of the sustainability of wheat production depend on weed control. Cheat, *Bromus secalinus* L., is one of the most serious weeds infesting wheat fields. After preliminary tests to verify the feasibility of using mechanical devices to devitalize cheat seeds during harvest on a combine, it appeared that the roller mill could be used for weed control as an alternative to herbicides. Further tests were conducted to determine the effect of roller mill speed differential and gap between the rolls on cheat seed germination. The three speed differential ratios tested were: 1:1, 1:1.1, 1:1.27, and the five gaps between the rolls between 0.1 to 0.9 mm. The viability of the seed was measured by the percentage of

vigorous seedlings after growth chamber germination. The roll speed differential had a significant effect on cheat seed germination, but roll gap was the most significant factor. Germination decreased with increasing roll gap and roll speed differential ratio. At the widest and narrowest roll gap (0.9 mm and 0.1 mm) there was no significant difference among the three speed ratios. The combination of the highest roll speed ratio (1:1.27) and the narrowest roll gap (0.1 mm) reduced the germination 95%.

Keywords. Cheat, Roller Mill, Speed Differential, Weed Control, and Wheat.

INTRODUCTION

The roller mill was introduced into the USA from Europe in 1873 (Smith and Naylor, 1981). It consists of rotating corrugated or smooth paired cylindrical rolls oriented horizontally. Grinding of feed particles occurs between the hard metal rolls. The kernels are subjected to shear and compressive forces caused respectively by the corrugations on the roll surface and pressure exerted by the rolls when pulling particles towards the nip (Haque, 1991).

Roller mill performance has been the subject of many investigations. Yu and Brusewitz (1993) determined the changes in physical properties of mustard seeds as affected by mill type (roller mill or hammer mill), gap between rolls of the roller mill, feed rate through the hammer mill, and seed temperature at the time of cracking. They found: (1) lower seed cracking temperature and narrower roll gap, and lower hammer mill feed rate induced lower bulk density and lower bulk compression force; and (2) hammer milling produced more fine particles than roller milling. They noted that hammer milled particles were mostly short and straight while roller milled samples had many long, curved particles.

Appel (1987) compared energy consumption and particle size of hammer milled and roller milled grain sorghum and corn. He found that: (1) the roller mill produced more surface area per unit of effective energy used than the hammer mill; (2) the energy required for grinding increased as the initial moisture content of the grain increased or screen size and roll gap were reduced. Fang et al. (1995) studied the energy requirements for size reduction of wheat using a roller mill with three roll speed differentials. They found that the feed rate had no effect on energy per unit mass and specific energy. On the other hand, the roll gap had a significant effect on roller mill grinding energy requirements. Fang et al. (1997) compared energy efficiency of a roller mill with a hammer mill and tested the effect of the main operational parameters of both machines on mill performance. They observed that the roll gap has the most significant effect on characteristics of the ground material and the energy requirement. However, they noticed that the roll speed differential also had significant effects on the geometric mean diameter and energy required per unit mass milled, but not on the specific surface area increase and the specific energy (energy required to create a new surface area). They observed that the feed rate had no significant effect on any of the variables described above.

Hauhouot et al. (1997) studied the feasibility of using a roller mill or a hammer mill to mechanically devitalize (produce non-viable seeds) seed of cheat (*B. secalinus* L.). Cheat seed was damaged by a roller mill and germination tests were run to verify its viability. After preliminary tests verifying the feasibility of using mechanical devices to devitalize cheat seed during harvest on a combine, it appeared that the roller mill could be used for weed control as an alternative to herbicides. Further experiments to determine the effect of roll speed differential on the seed were needed before implementation of this approach.

OBJECTIVE

The goal of this investigation was to analyze the effect of roller mill speed differential and roll gap on cheat seed germination.

MATERIALS AND METHODS

Roll speed differential

A H. C. Davis Model 50B roller mill (Bonner Springs, Kansas) was used in this research. The roller mill had two 23- x 15-cm-diameter corrugated rolls turning in opposite directions, and powered by a 1.1 kW motor. The nominal operating speed was 500 rpm. The rolls tested had 8 teeth/cm (8 cuts/cm) of circumference.

For all tests, samples of 100 g of cheat seed were hand fed at a low rate so that they did not pile up between the rolls. The processed seeds were collected in a pan and weighed. The weighed material was then sieved through a laboratory seed cleaner (Seedburo Equipment Company, Chicago, IL) to remove dust, fine particles, and seed hulls. After cleaning, the material was reweighed, and the percentage of identifiable seeds (whole, damaged, or partially broken seeds) recovered was computed. Germination tests were run in a growth chamber to determine the viability and germination percentage of identifiable cheat (whole, damaged, or partially broken seeds) seeds. Samples of unprocessed and hand-harvested cheat seeds were germinated as checks.

The experiment to determine the effect of roll gap and roll speed differential on percentage of identifiable seeds recovered after cleaning was a 3*5 factorial arrangement in a completely randomized design. The second experiment to determine the effect of the roll speed differential ratio and the roll gap on germination of identifiable cheat seeds was a split-plot in a randomized block design with three replicates. The variables included gap between the rolls (roll gap) i.e. 0.1, 0.2, 0.4, 0.6, and 0.9 mm and roll speed differential ratios i.e. 1:1, 1:1.1, 1.27. The roll gaps were set by means a feeler gauge. The roll speed differential ratios 1:1.1 and 1:1.27 were obtained by changing the size of the driven pulley (pulley 2 in Fig. 1). The driven roll was turned at a lower speed than the other roll.

Seed Germination

Growth chamber test (warm germination) was performed on four 100-seed samples from each treatment in a water curtain germinator (Stults Scientific Engineering Corp., Springfield, Illinois). The seeds were put on wet paper tissue and prechilled at 5°C in a refrigerator for 5 days to break dormancy, then placed in a growth chamber at 20°C for 9 days. Samples of unprocessed cheat seed and hand-harvested cheat seed were germinated as check. Germinated seeds were counted on the sixth and the fourteenth days. Since no procedures existed for determining cheat germination the procedure used conformed to the requirements for smooth brome established by the Association of Official Seed Analysts (1978). At the end of the germination period, seedlings presenting a growing primary root were classified as germinated. Seedlings with strong and long roots, and no mold were classified as vigorous. The advantages of this test are that the temperature and the humidity are controlled to optimize germination and results can be determined in a relatively short time period.

An analysis of variance (PROC ANOVA, SAS, 1987) was conducted on data obtained for each test for percentage of identifiable seeds recovered after cleaning process and for germination percentage of identifiable cheat seeds processed material. The procedure MIXED (PROC MIXED, Littell al., 1996) was used to compare germination means percentage of each treatment to the others. A Fisher's Least Significant Difference test

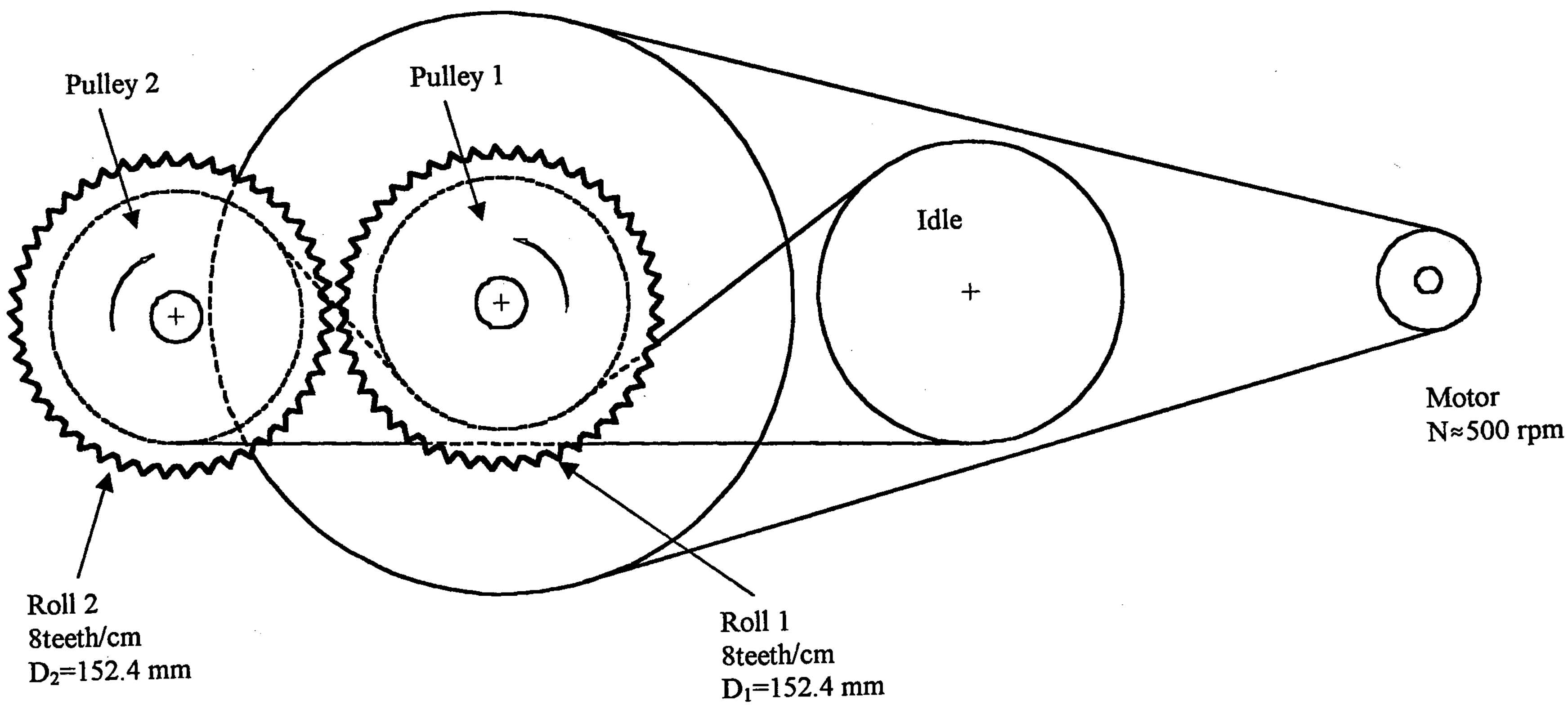

Figure 1- Schematic of the roller mill

was used to separate means of percentages of identifiable seeds recovered after cleaning process.

RESULTS AND DISCUSSION

Cleaning

The percentage of identifiable seeds recovered after cleaning decreased as the roll gap decreased (Fig. 2).

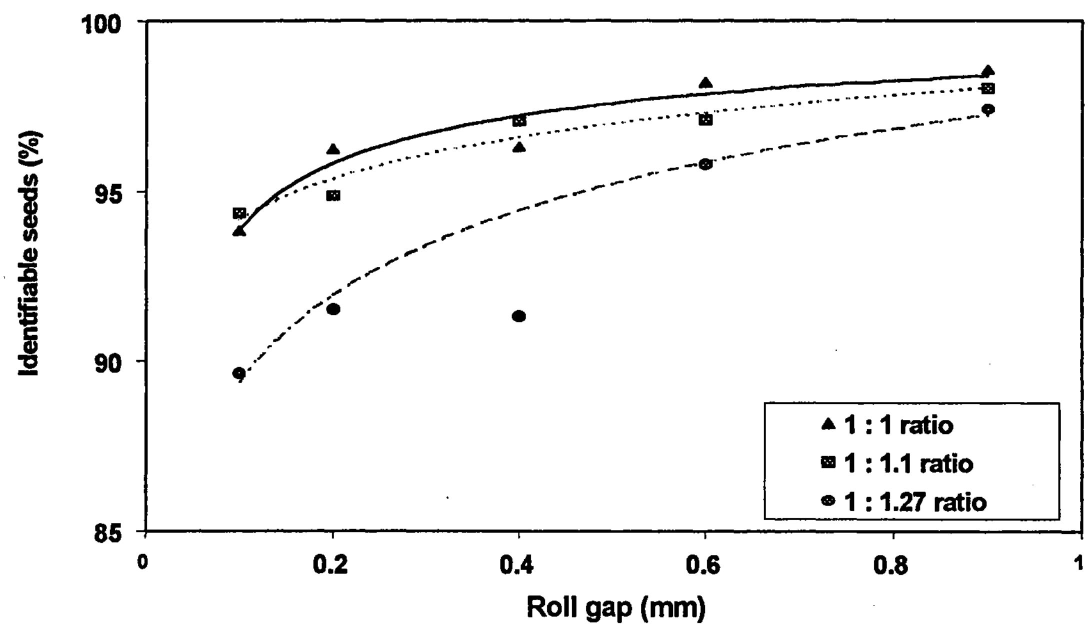

Figure 2- Effect of roll speed differential and roll gap on percentage of identifiable cheat seeds recovered after cleaning.

The curves that best fitted the data were the following:

significant different mean percentage of material recovered after cleaning. There was no significant difference among the other roll gaps (Table 2).

Table 1- Effect of roll gap and roll speed differential on percentage of material recovered after cleaning process

Roll gap (mm)	Material recovered after cleaning (%) — Roll speed differential ratios 1:1	1:1.1	1:1.27
0.9	99a	98a	94a
0.6	98a,b	97a,b	96a,b
0.4	96b	97a,b	92a,b
0.2	96b	95a,b	91a,b
0.1	94c	94b	90b

*Means with the same letter in each column are not significantly different at the 0.05 level. 1:1 ratio LSD (0.05)=2.25; 1: 1.1 ratio LSD (0.05)=3.60; 1:1.27 (LSD (0.05)=6.47

Germination

The check samples composed of unprocessed, and hand-harvested cheat seed had a mean germination percentage of 99%. The roll speed differential ratios and roll gap significantly affected cheat seed germination. The analysis of variance (Table 2) also showed an interaction between the two factors.

Table 2- Analysis of variance (ANOVA) for roll speed differential and roll gap effect on cheat seed germination

Source	MSS*	F value	Pr > F
Speed ratios	6760	37	0.0027
Roll gap	46847	1132	0.0001
Speed ratios* Roll gap	1830.83	44.22	0.0001

*MSS: Mean sum of square

$$1:1\ ratio; \qquad y = \frac{1}{0.00992 + \frac{0.00023}{\sqrt{x}}}$$

$$1:1.1\ ratio; \qquad y = e^{(4.58729 + 0.01835\ln(x))}$$

$$1:1.27\ ratio; \quad y = \sqrt{9529.96 + 669.47\ln(x)}$$

where y was the percentage of material recovered after cleaning and x the gap between the rolls in mm.

There was no interaction between roll gap and roll speed differential ratio, but roll gap and roll speed differential ratio had significant effect on the percentage of material recovered after cleaning. For roll speed differential ratios of 1:1 and 1:1.1, material recovered after cleaning varied from 91% at 0.1 mm to 99% at 0.9 mm gap. With the 1:1.27 speed ratio the percentage of material recovered varied from 81% at 0.1 mm to 98% at 0.9 mm. Production of more small particles at 0.1 mm gap was likely caused by increased shear effect on the seed. The seeds were sheared as well as crimped by the differential operation of the rolls. The greater the roll speed differential, the greater the shear effect. At 0.1 mm, the shearing and crimping actions were greater on the seeds producing more fine particles. These fine particles were removed during the cleaning process, causing a decrease in the amount of identifiable seeds recovered.

With the 1:1 roll speed differential, there was no significant difference at the 0.05 level between the 0.9mm and 0.6 mm gap, and among the 0.6 mm, 0.4 mm, and 0.2 mm gaps. At 0.1 mm the material recovered after cleaning was the lowest caused by more fines particles produced during the milling process (Table 1). With the 1:1.1 and 1:1.27 roll speed differential ratios, only the 0.9 mm and 0.1 mm roll gap settings presented a

Germination decreased as roll gap decreased and roll speed differential increased (Fig. 3).

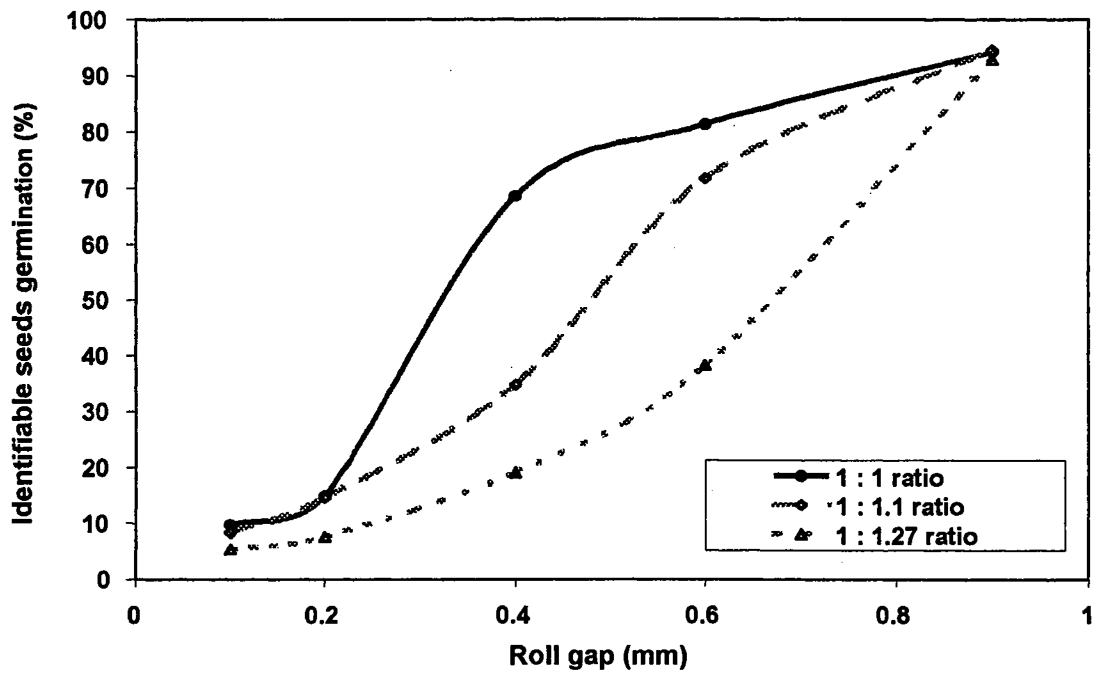

Figure 3- Effect of roll speed differential and roll gap on germination of identifiable cheat seeds recovered after cleaning

With the 1:1 roll speed ratio, the germination decreased from 95% to 10% as the roll gap decreased from 0.9 mm to 0.1 mm. With the 1:1.1 roll speed ratio, the germination decreased from 95% to 8% as the roll gap decreased from 0.9 mm to 0.1 mm. With the 1:1.27 roll speed ratio, the germination decreased from 93% to 5% as the roll gap decreased from 0.9 mm to 0.1 mm. There was no significant difference between the 0.2 mm and the 0.1 mm roll gap for any of the roll speed differential ratios (Table 3). At the extreme roll gaps (0.1, 0.2, 0.9 mm) there no significant difference between different speed differential ratios, while at intermediate gaps (0.4 and 0.6 mm) there was significant difference between speed ratios.

The lowest germination percentages were 5% and 8% at 0.1 mm and 0.2 mm gap with the 1:1.27 roll speed differential ratio, 8% at 0.1 mm gap with the 1:1.1 roll speed differential ratio, and 10% at 0.1 mm gap with 1:1 roll speed differential ratio. The shearing effect induced by the roll speed differential on the seed increased the damage and consequently reduced the germination. This could explain the important decrease in germination from 95% at 0.9 mm to 38% at 0.6 mm roll gap. For the other two roll speed differential ratios, this decrease was smaller (Table 3). However, the shearing effect was not noticed at wide roll gap (no difference among the three speed differential ratios at 0.9 mm). The 1:1 and 1:1.1 speed differential ratios induced a germination percentage smaller than 20% at roll gaps narrower than 0.4 mm compared to 0.6 mm for the 1:1.27 speed differential ratio (Table 3). More internal damage was likely induced with the introduction of the speed differential which combined shearing action with crimping action.

Table 3- Effect of roll gap and roll speed differential on cheat seed germination for identifiable cheat seeds recovered after cleaning

Roll gaps (mm)	Mean germination %		
	Roll speed differential ratios		
	1:1	1:1.1	1:1.27
0.9	95 a*	95 a	93 a
0.6	81 b	72 c	38 d
0.4	69 c	35 d	19 e
0.2	15 e,f	15 e,f	8 f,g
0.1	10 f,g	8 f,g	5 g

*Means with the same letter are not significantly different at the 0.05 level. (PROC MIXED, SAS).

When all material processed including ground seeds was accounted for, germination did not vary (Table 4). Indeed, roller milling cheat seeds at the gaps tested did not produced a large amount of fine particles. For all the treatments, 90% or more of the initial amount of material is recovered after cleaning.

Table 4- Effect of roll gap and roll speed differential on cheat seed germination for all material processed

	Mean germination %		
	Roll speed ratios		
Roll gaps	1:1	1:1.1	1:1.27
0.9 mm	93 a*	93 a	91 a
0.6 mm	80 b	71 c	37 d
0.4 mm	66 c	34 d	18 e
0.2 mm	14 e,f	14 e,f	7 f,g
0.1 mm	9 f,g	8 f,g	5 g

*Means with the same letter are not significantly different at the 0.05 level. (PROC MIXED, SAS)

CONCLUSIONS

The roll speed differential ratios (1:1, 1:1.1, and 1:1.27) had a significant effect on cheat seed germination. Germination percentage of cheat seed decreased with increasing roll speed differential and narrower roll gaps. The greater the roll speed differential, the greater the shear effect on the seed at narrow roll gaps and the lower the germination. The roller mill setting producing the lowest cheat seed germination, 5%, was at 1:1.27 roll speed ratio and 0.1 mm roll gap. The results indicated that the roller mill has potential for damaging cheat seed sufficiently to reduce its germination.

ACKNOWLEDGEMENTS

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CHAPTER VI

DAMAGE EVALUATION OF HAMMER AND ROLLER MILLED CHEAT (*Bromus secalinus* L.) SEED

ABSTRACT

Measurement of mechanical damage on grain has always been a major concern for farmers, grain graders and the grain industry. Cheat seeds (*Bromus secalinus* L.) was mechanically devitalized by a roller mill at three roll speed differentials, and a hammer mill at four and six shaft speeds, two screen opening sizes, three feed rates, and two sets of hammers. In order to evaluate the mechanical damage on the treated cheat seed, seeds were stained with a FCF fast green solution and graded into different classes according to the type and level of damage. Germination tests were conducted to measure the viability of the seed in each class and a damage index class was created from 1 - 100. Hammer milled seed embryos were broken and missing. A damage index varied from 1.5 to 87 when the hammer mill shaft speed increased from 600 rpm to 3600 rpm. Roller milled seed was cracked, and a damage index varying from varying from 71 to 84 for the three

roll speed differentials at the roll gap investigated. The hammer mill produced a non-continuous damage scale while roller mill damage followed a continuous scale. The visual damage classification and the damage index predicted the viability for hammer milled seed. Some potential internal damage occurred in roller milled seed that was not detected by the visual classification or reflected in the damage index.

Keywords: Cheat, Weed Control, Damage Classification, Roller Mill, and Hammer Mill

INTRODUCTION

Hauhouot et al. (1997) investigated the possibility of hammer and roller milling to devitalize seed of *Bromus secalinus* L. Germination decreased with decreasing roll gap and increasing number of roll teeth. At 0.1 mm roll gap and 8 teeth/cm, germination was 1% in greenhouse pots and 25% in the growth chamber. The hammer mill dehulled and fractured 92% of the seed embryos. These results demonstrated the feasibility of substituting mechanically devitalizing seeds to control weeds in wheat. Other experiments were conducted to analyze the effect of roller mill and hammer mill machine parameters on the viability of cheat seed. Parameters evaluated included: rotor shaft speed (600 rpm – 3600 rpm), screen opening size (3.2 mm and 4.0 mm), feed rate (50, 70, and 85 g/s) and number of hammers (16 and 24). Roll mill speed differential effect on cheat seed germination was measured. Germination tests were run to determine the viability of the damaged seed. A major limitation in current procedure to determine seed germination after mechanical devitalization is the time delay between treatment and assessment of damage. Germination tests must be run 7-14 days before germination could be determined. A method that could predict germination immediately after treatment was needed if these machine variables were to be optimized in a reasonable period of time. It appeared from all the tests that a method to quantify and qualify the damage done unto the seeds by the different devices is needed.

Measurement of mechanical damage on grain has always been a big concern for farmers, grain graders, and the grain industry. However, the method of qualifying mechanical damage depended on the intended use. No standard method has been widely used to evaluate mechanical damage.

LITERATURE REVIEW

Mechanical damage to seeds and vegetables can affect their milling quality, lower germination, and inhibit the seedling development. The causes of mechanical damage and the methods to evaluate the damage have been studied by many researchers. Grunda (1994) defined mechanical damage "as a state of disturbance of the natural continuity of particular cells and tissues of the kernels, resulting from the destructive effect of external forces (harvest, transport) and/or internal strength, which may be caused by gradient of moisture in the process of dry grain wetting or drying wet ones." The damage can be external (small cracks, shatter cracks, or skin break) or internal (stress cracks mostly due to temperature and moisture gradients). In the absence of standards to quantify the damage, numerous techniques have been used to evaluate mechanical injury to grains and vegetables. Chowdhury (1976) listed and described 25 methods for determining grain damage. He stated that whether a grain is considered as damaged or not, depended on its ultimate use. Techniques to assess mechanical damage included: visual observation, sieving, germination, water adsorption, carbon-oxide production, light reflectance, colorimetric reflectance, X-ray technique, or storability. Effectiveness of visual inspection can be improved by treating the seeds with some stains. French et al. (1962) used a 0.1 percent indoxyl acetate in 25-percent ethanol to detect seed coat cracks in white beans and some others light colored leguminous seed. They found that the indoxyl acetate procedure facilitated visual examination by marking the cracked seeds with blue dye and removed the necessity for magnification. Paulsen and Nave (1979) developed an improved indoxyl acetate test to rapidly detect seed coat cracks in soybeans. The test was more effective in finding seed coats cracks than hypochlorite and tetrazolium tests, and had no detrimental effect on warm germination of undamaged soybeans. Rodda et al. (1973) soaked damaged and undamaged soybeans in a solution of sodium hypochlorite and determined the damage by the swelling of the grain. Chowdhury and Buchele (1974) developed a numerical damage index for critical evaluation of mechanical damage of corn. They used a 0.1 percent of Fast Green FCF dye to stain damaged corn seed and classified the damaged kernels according to the severity of the damage. They found that the damage index represented both quantity (percentage) and quality (severity) of the damaged kernels.

Germination tests (standard, cold, or acid germination) are a reliable way to test the effect of mechanical damage on seed germination, because they directly measure both seed viability and the seed vigor. Paulsen et al. (1981) used warm and cold germination tests to evaluate the seed quality of soybean seed damaged with a centrifugal impactor. Mitchell et al. (1964) used an acid germination test to determine the mechanical damage realized by a rotating hammer on two varieties of wheat. A disadvantage of these tests is that the results are not quickly available, because germination counts cannot be made until the radicle has emerged from the seed, and this process can take several days.

OBJECTIVES

The objectives of this investigation were to classify into categories the physical damage realized by the hammer mill and roller mill on cheat seed, create a damage index for the damaged seed, and assess usefulness of this index to predict germination.

MATERIALS AND METHODS

Visual classification

Material: The cheat seeds used for the different tests were cleaned from wheat combine harvested during the summer of 1997 in Oklahoma.

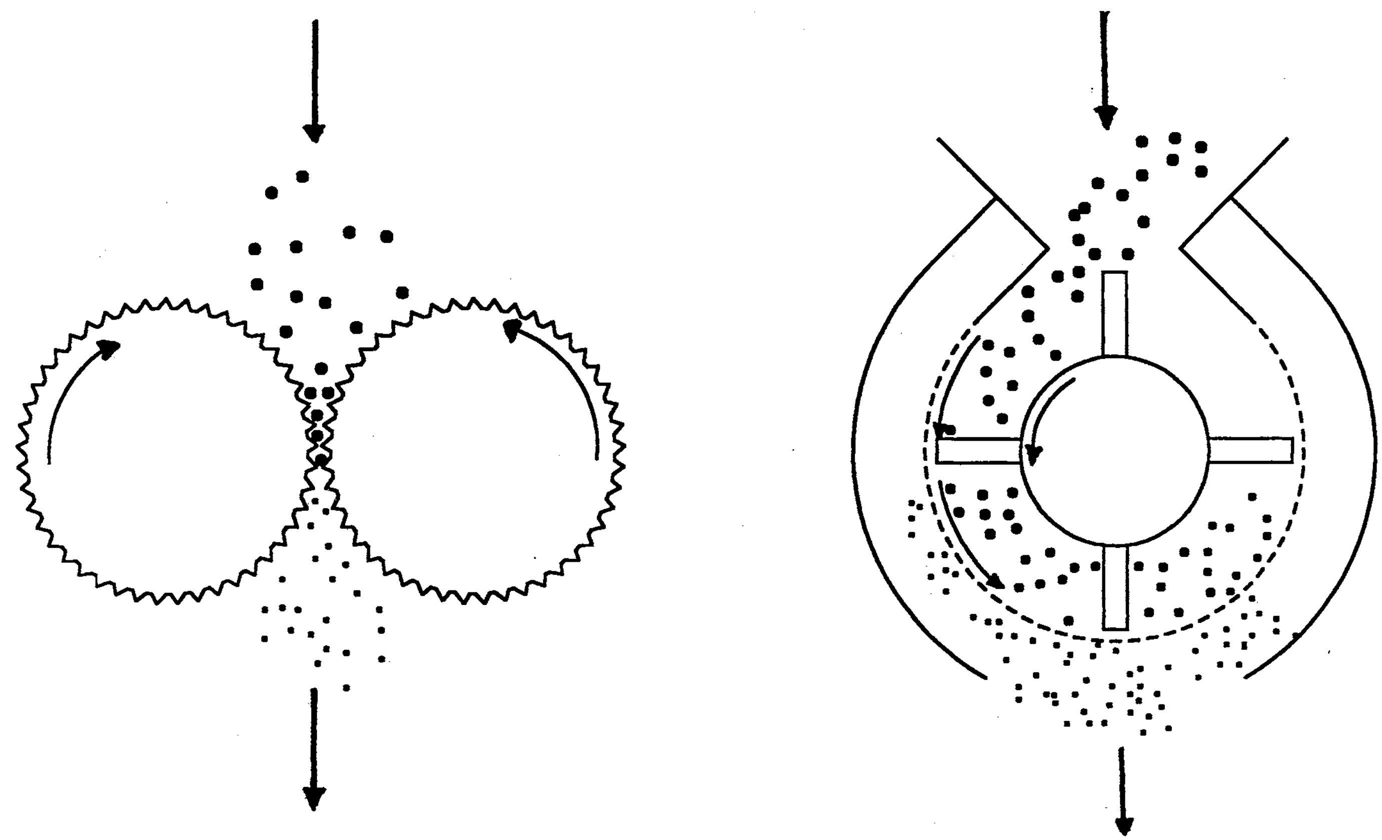
An H. C. Davis Model 50B roller mill (Bonner Springs, Kansas) and a Bliss (Ponca City, Oklahoma) laboratory hammer mill Model E-9506-TF were used to process the seeds. The laboratory hammer mill was powered by a pulse width modulated 1.5kW electric motor. Shaft speed was controlled by a ACS 300 (ABB, Orange Connecticut) speed controller.

Hammer milled seeds were obtained from three tests conducted to evaluate shaft speed, screen hole size, shaft speed and feed rate effect, number of hammers on cheat seed germination. The shaft speeds tested were 600, 1200, 1800, 2400, 3000, and 3600 rpm. The mill was equipped with 16 or 24 hammers. The hammer size was 6.3 mm x 2.54mm x 60.3 mm. The hammer ends were machined square and mounted on four rods at 90° each. The hammers could be set at either 13 mm away from the screens. The two screen opening sizes tested were 3.2 mm (8/64 screen) and 4.0mm (10/64 screen) and the screens were mounted in pairs. The screen opening sizes were noted as 8/64 and 10/64. The hammer mill damaged the seed by impact. The seed was struck by the hammers until it was small enough to go through the selected screen opening (Fig. 1).

The Davis roller mill consisted of two 23- x 15-cm-diameter corrugated rolls turning in opposite directions, and powered by a 1.1kW motor. The nominal operating speed was 500 rpm. The rolls tested had 8 teeth/cm (8 cuts/cm) of circumference. Roller mill seed was obtained by processing the seed at three roll speed differentials (1:1, 1:1.1, 1:1.27) and two roll gaps (0.1and 0.4 mm) but only the 0.1 mm and 0.4 mm gap treated seed were classified. The roller mill crimps and crushes the seed between its rotating corrugated rolls (Fig. 1).

Staining method: Approximately 5 g of seed from each treatment were soaked in 0.1 percent Fast Green FCF (SIGMA Chemical Company, St. Louis, Missouri) dye for 4 min. and placed on a strainer. Excess dye was washed away with running tap water. Dyed samples were spread on paper towels to dry for 24 hours before being visually inspected under a magnifying lamp. The dye stained cracked, broken or chipped kernels and made the visual inspection easier.

The samples were visually sorted in damage classes according to the type impact or crimping and degree of seed damage.



Roller mill process: the seeds are crimped and crushed between the rolls

Hammer mill process: the seeds are struck by the hammers until they are small enough to pass through the screen holes

Figure 1- Schematic of hammer mill and roller mill

Damage classes. Preliminary tests, identified four classes to describe seed damage induced by the hammer mill (Fig. 2).

1. BRS: Broken seed; seed that was broken during milling. The broken part will be easily stained. The seed coat was typically missing.
2. BRE: Seed with a broken or missing embryo. This seed was dehulled and the dye stained the broken area.
3. WPD: Whole or partially dehulled seed with embryo still present. The seed in this class had the seed coat or part of it but had the embryo present.
4. NAD: Seed with no apparent damage. This type of seed presented no stained areas and the seed appeared intact.

Five classes were identified to describe the damage induced by the roller mill (Fig. 3).

1. BRS: broken seed. This seed was broken but had part of the seed coat still attached to the endosperm.
2. DPCK: Seed with deep cracks. The roll teeth cut the seed coat and penetrated the endosperm. The dye deeply stained the cracked areas.
3. SHCK: Seed with shallow cracks. The shallow cracks were barely stained.
4. THMK: Seed with minor tooth marks. The crimping action was not hard enough to leave cracks in the seed, but the tooth imprint could be observed.
5. NAD: Seed with no apparent damage. The seed looked intact.

The cracks and tooth marks are formed by the crushing and shearing effect of the roll corrugations (teeth) in the seed.

For each treatment, the number of seeds in each class was determined after visual classification, and percentages were computed. Growth chamber germination tests were

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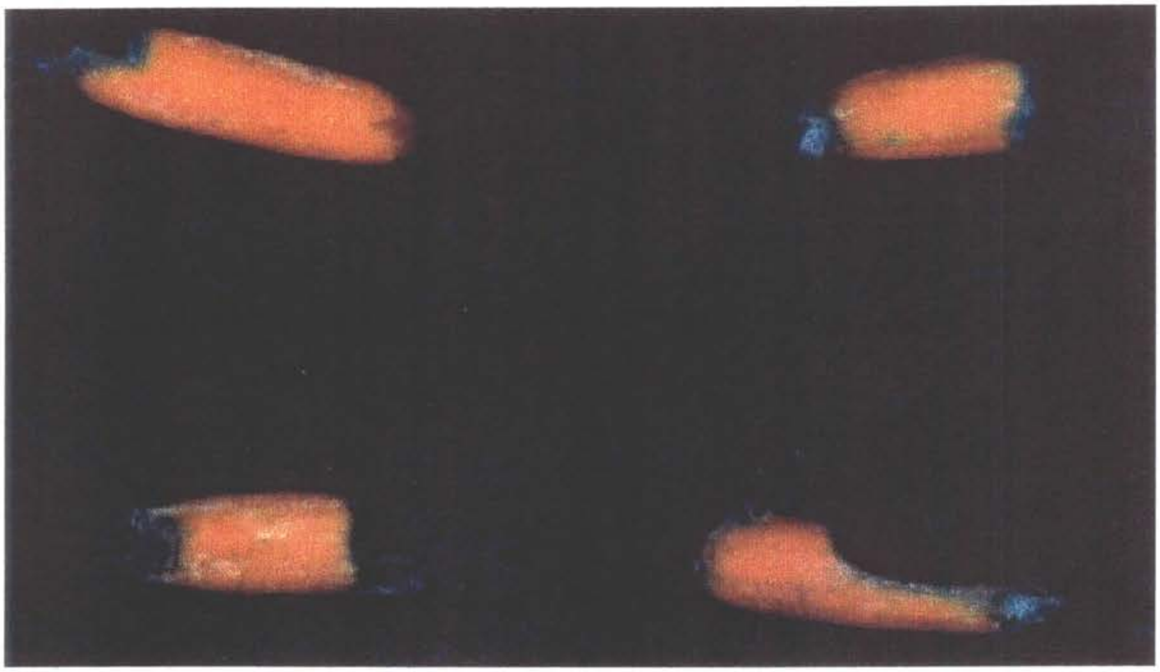

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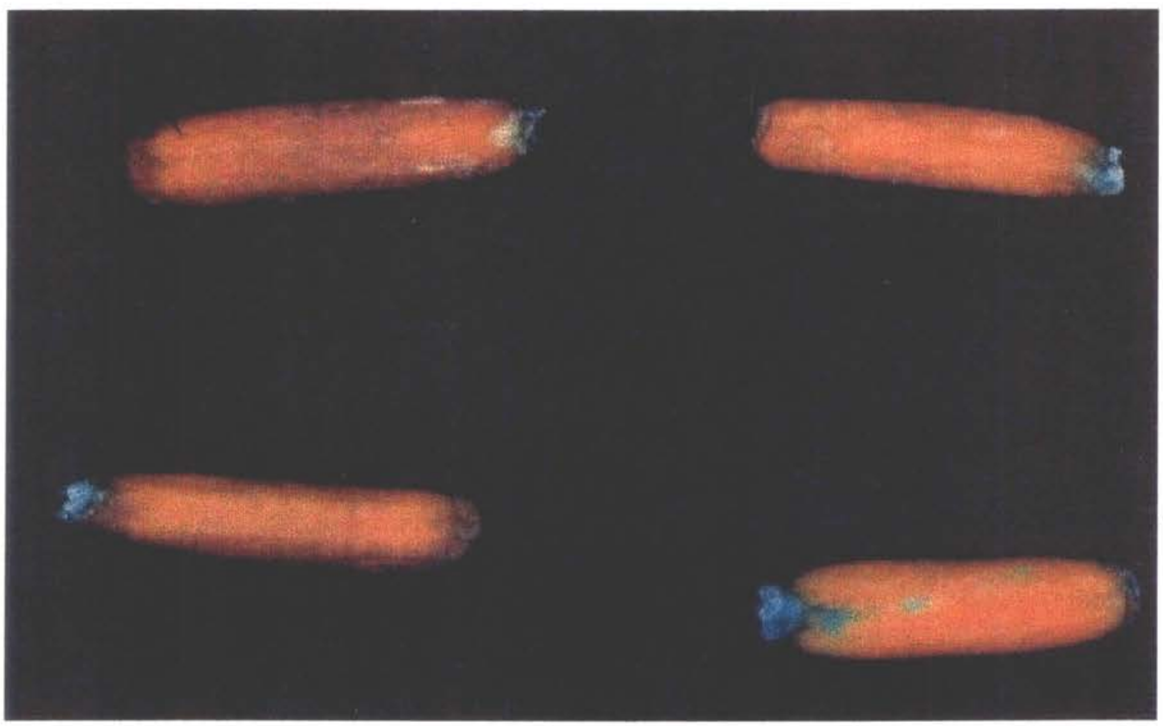

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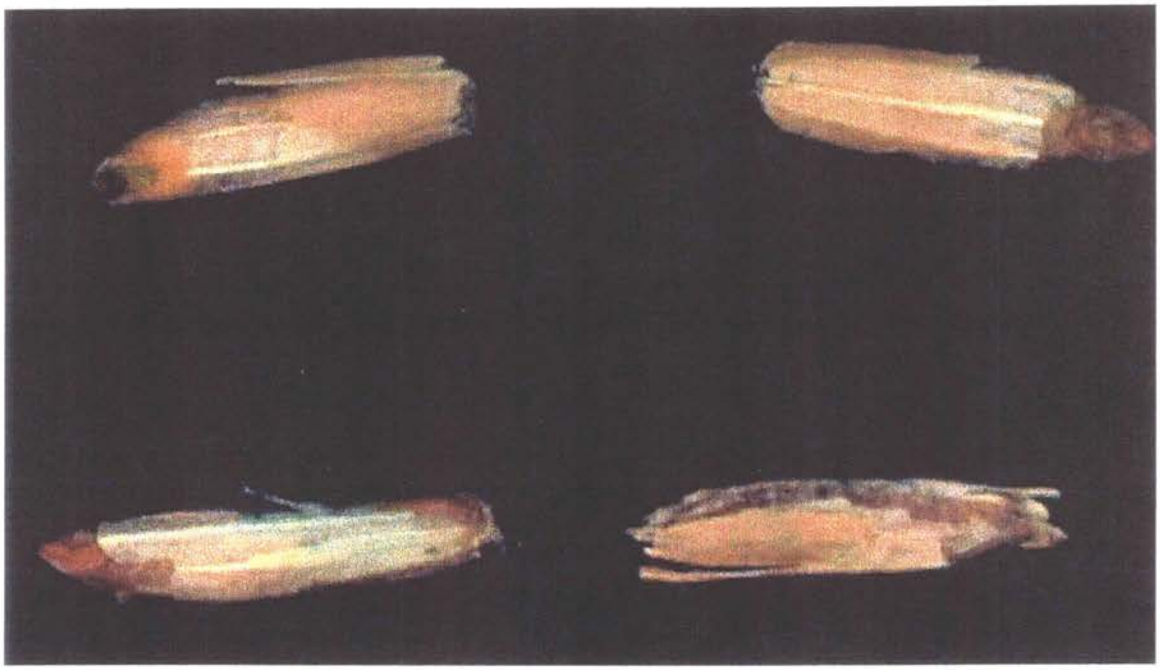

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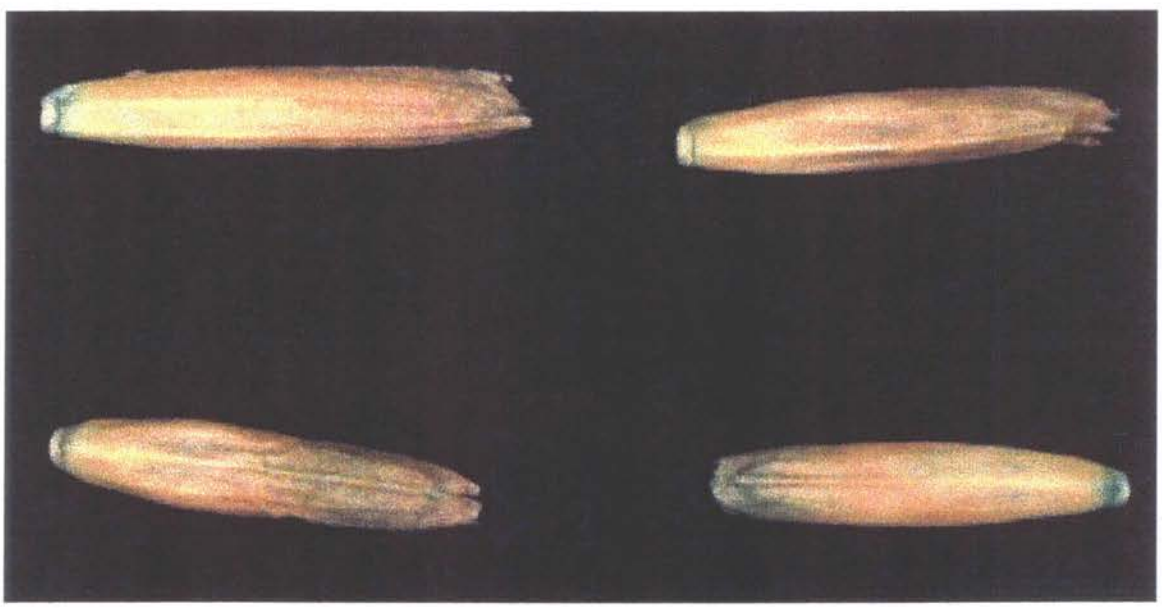
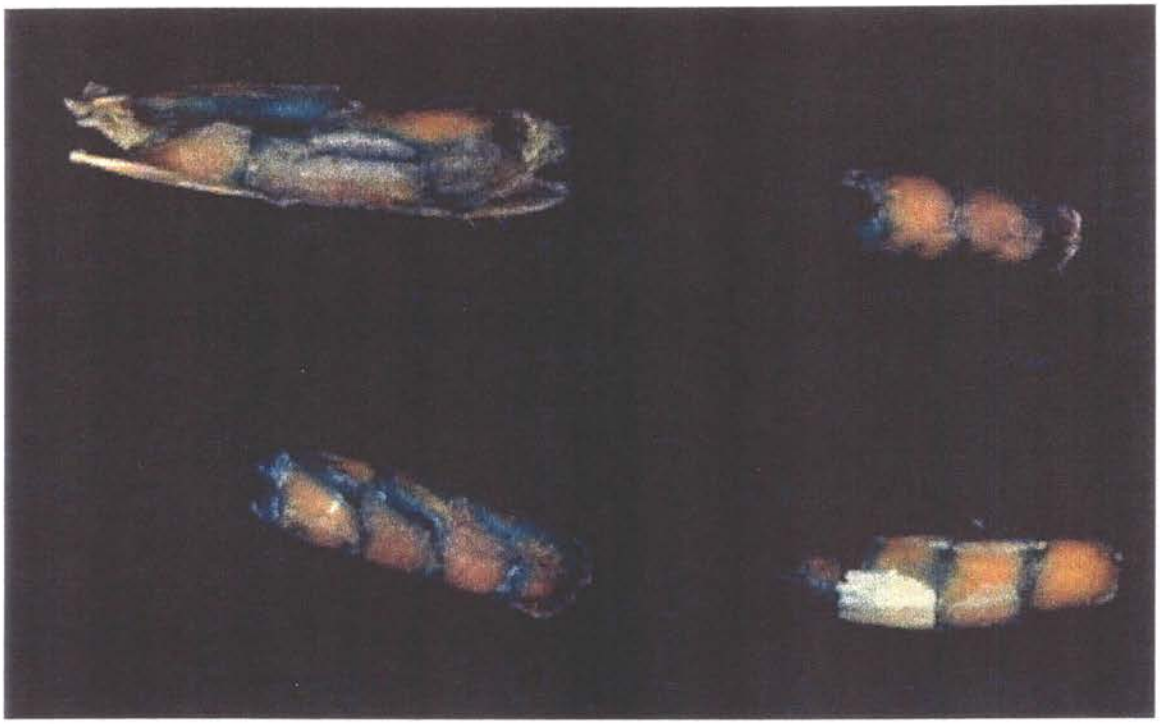


Figure 2- Damaged cheat (*Bromus secalinus* L.) seeds: hammer mill damage classes. (a) BRS: broken seed; (b) BRE: seed with broken or missing embryo; (c) WPD: whole or partially dehulled seed with embryo present; (d) NAD: seed with no apparent damage.

(a)



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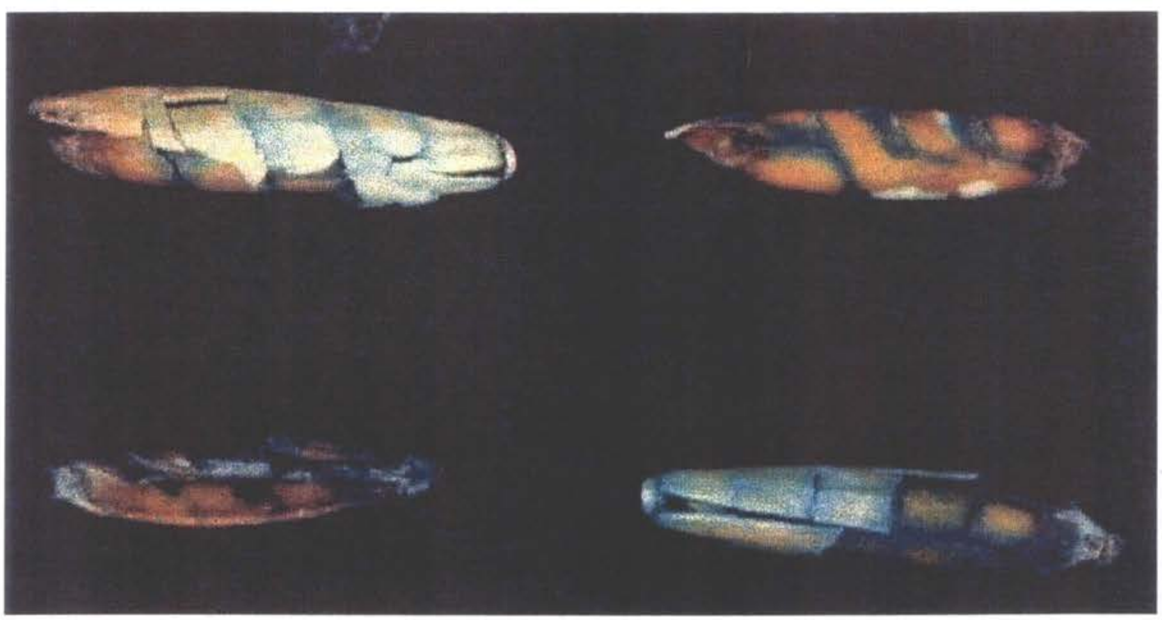

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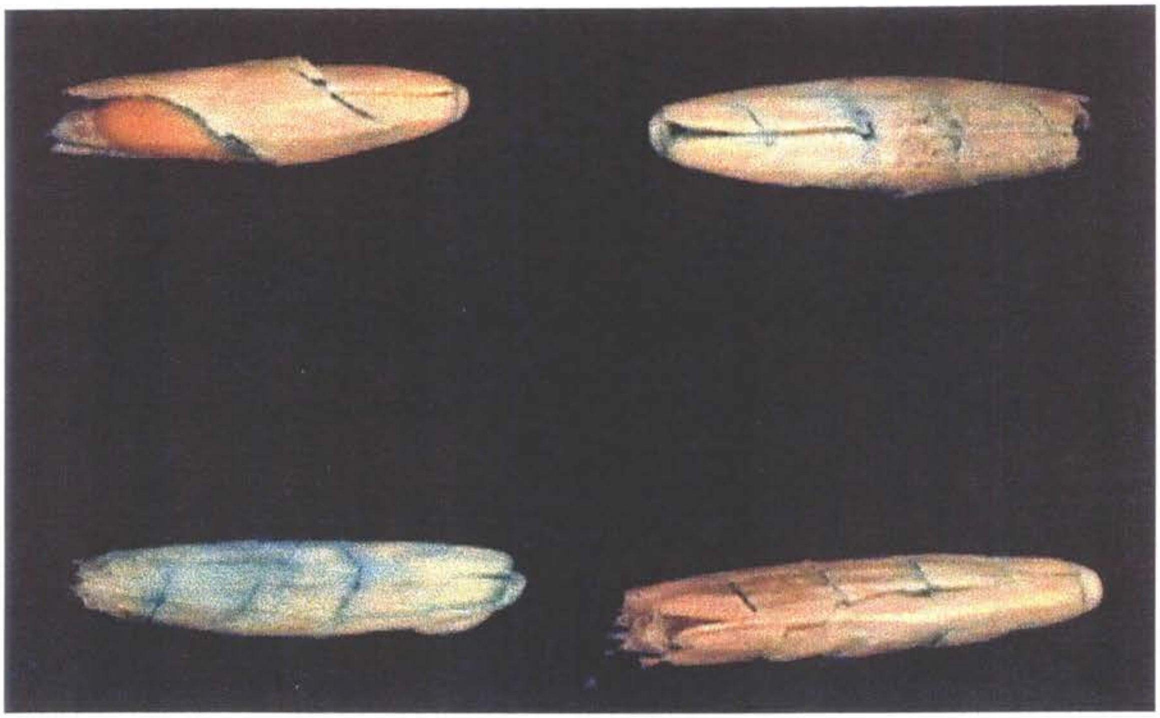

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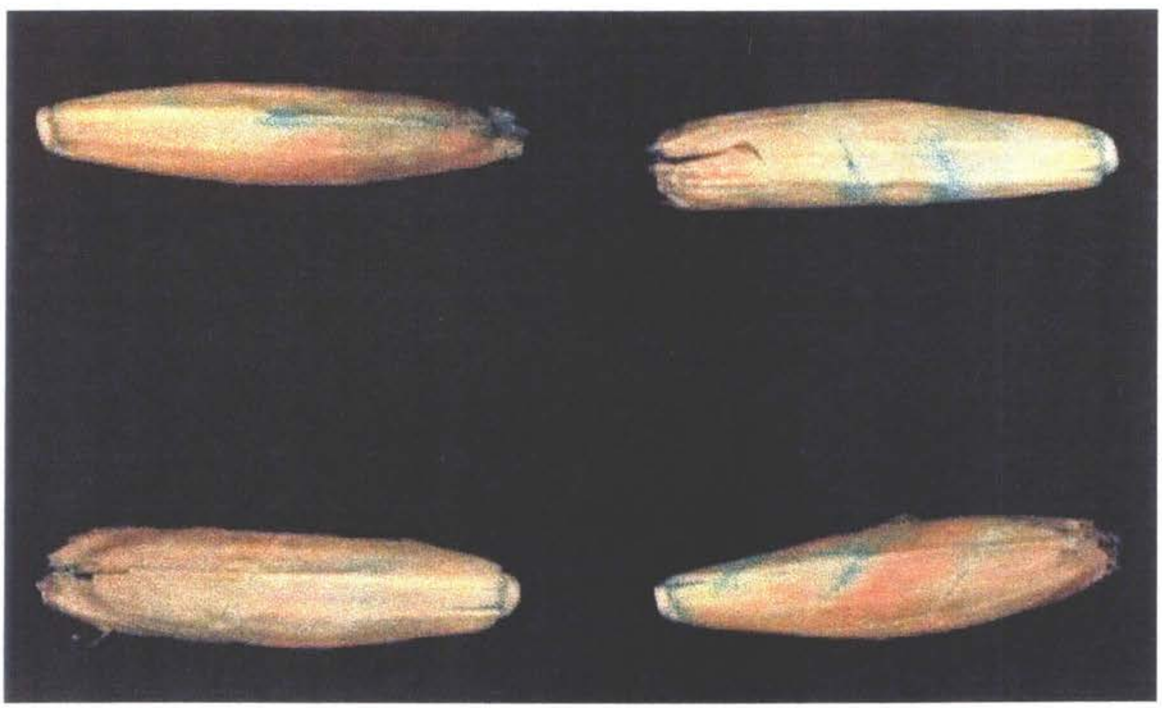

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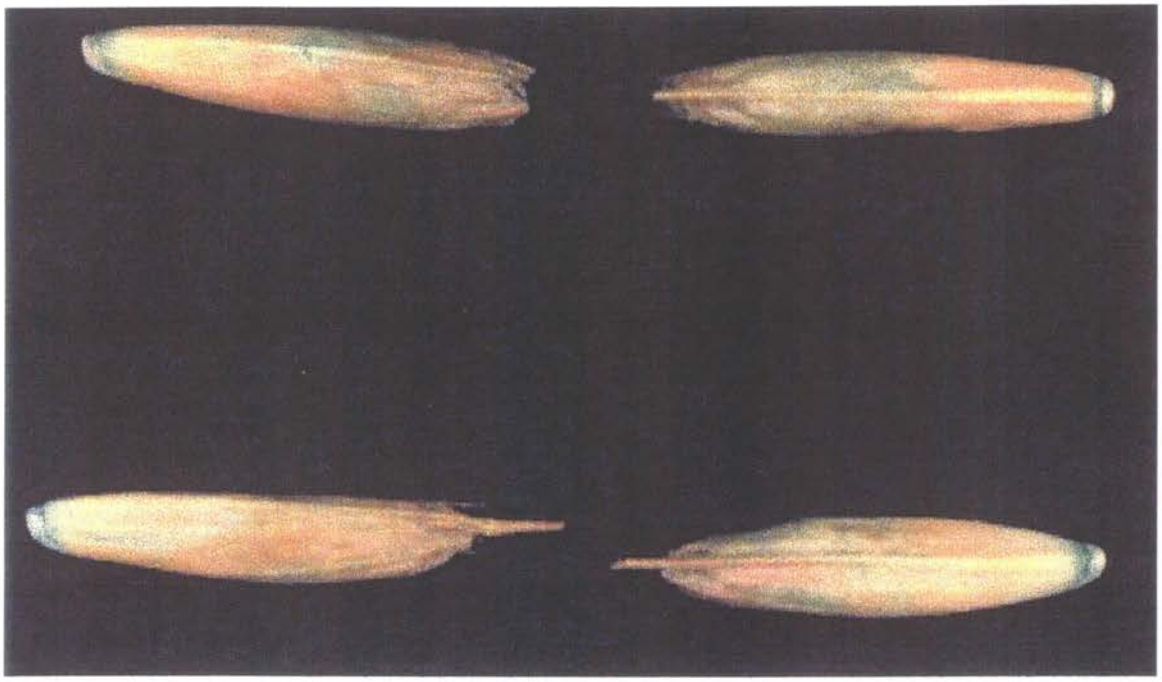


Figure 3- Damaged cheat (*Bromus secalinus* L.) seeds: roller mill damage classes. (a) BRS: broken seed; (b) DPCK: seed with deep cracks; (c) SHCK: seed with shallow cracks; (d) TMRK: seed with minor tooth marks; (e) NAD: seed with no apparent damage.

performed on 10 to 15 samples from each class to determine the viability of cheat seed in each class. A viability index (VIF) factor was calculated for each class by dividing the germination percentage of that class by 10 and rounding the number. The damage index factor (DIF) was calculated as follow:

$$DIF = 10 - VIF \qquad (Eq.\ 1)$$

A damage index (DI) was created from the seed classification and the germination results of each damage class.

hammer mill: (Eq.2)

$$DI = \frac{DIF_{BRS} * x_{BRS} + DIF_{BRE} * x_{BRE} + DIF_{WPD} * x_{WPD} + DIF_{NAD} * x_{NAD}}{10}$$

roller mill: (Eq. 3)

$$DI = \frac{DIF_{BRS} * x_{BRS} + DIF_{DPCK} * x_{DPCK} + DIF_{SHCK} * x_{SHCK} + DIF_{TMRK} * x_{TMRK} + DIF_{NAD} * x_{NAD}}{10}$$

Where DIF_i was the damage index factor in the i^th^ class and x_i, was the percentage of seed in the i^th^ damage class.

Germination for each treatment was predicted from the percentage of material in each class and the germination percentage of seed from each damage class. The calculated germination was the sum of the products of the damage class percentage by the germination percentage of the corresponding class (Eq.4).

Calculated germination (%) = $100^* (g_{BRS} * x_{BRS} + g_{BRE} * x_{BRE} + \ldots)$ (Eq. 4)

where g_i is the germination percentage of the i^{th} damage class.

Seed Germination

The growth chamber test (warm germination) was performed on 10-15 samples for each damage class in a water curtain germinator (Stults Scientific Engineering Corp., Springfield, Illinois). The seeds were planted on wet paper tissue and prechilled at 5°C in a refrigerator for 5 days to break dormancy. They were transferred in a growth chamber maintained at 20°C for 9 days. Germinated seeds were counted on the sixth and fourteenth days. This procedure conformed to the requirements for testing smooth brome germination established by the Association of Official Seed Analysts (1978), because no official procedures have been established for cheat. At the end of the germination period, seedlings presenting a growing primary root were considered as germinated. Seedlings with strong and long roots and no mold were classified as vigorous[1].

RESULTS AND DISCUSSION

Hammer mill

Sound (unprocessed) cheat seeds (Fig. 4) presented a caryopsis tightly enclosed within the palea and lemma. The awn and the rachilla were present. After being processed by the hammer mill or the roller mill, the seed exhibited different features.

[1] Personal communication, Mrs.Val Oyster , Registered Seed Technologist, Oklahoma Crop Improvement Laboratory, Stillwater, Oklahoma, March 1995.

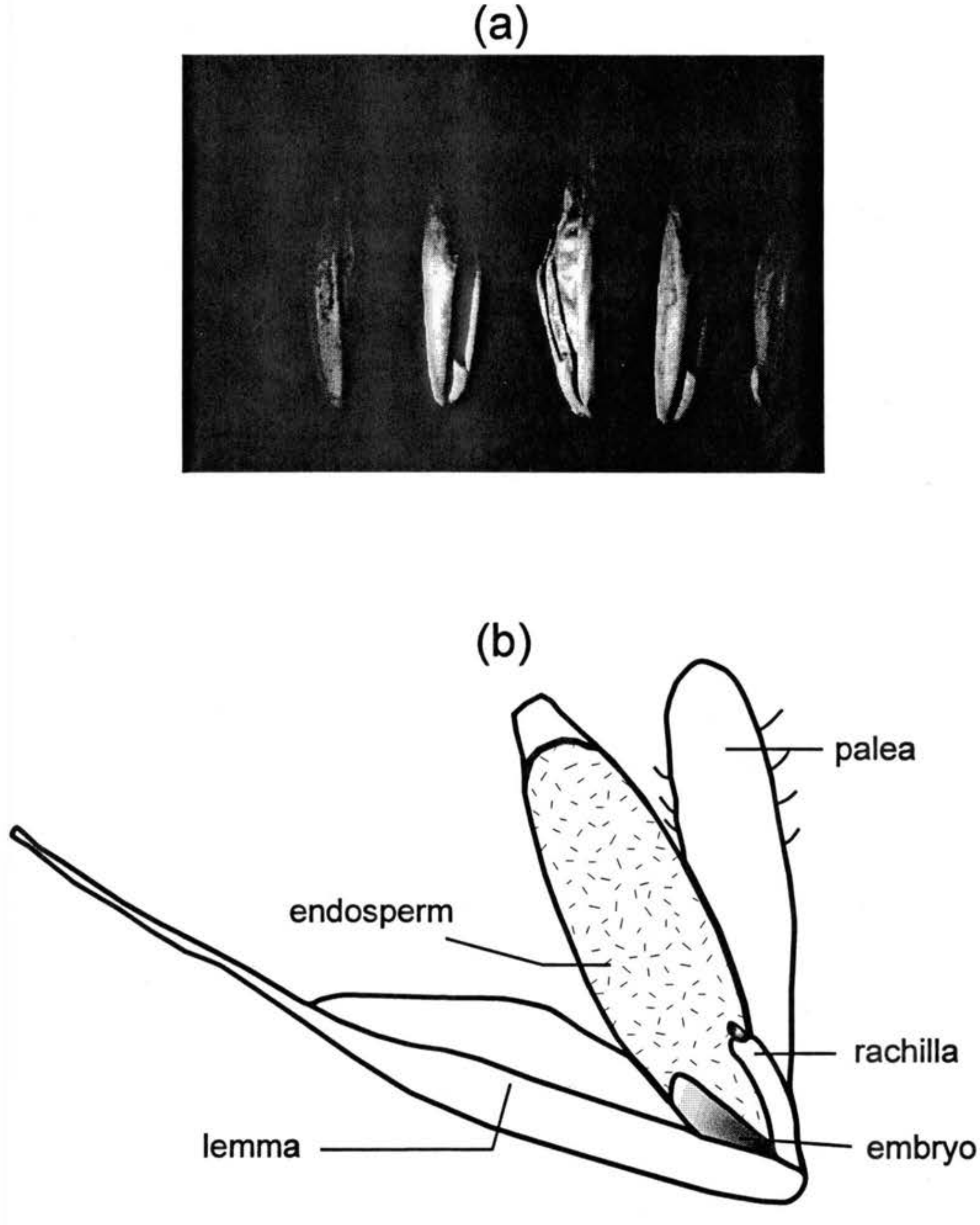
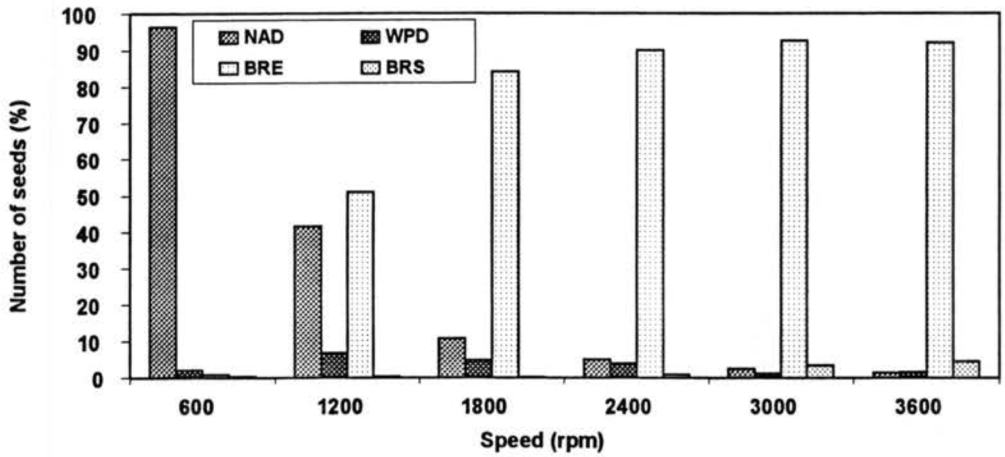


Figure 4 - Undamaged cheat (*Bromus secalinus* L.) seeds
(a) : Intact (control) seeds; (b) : Opened floret

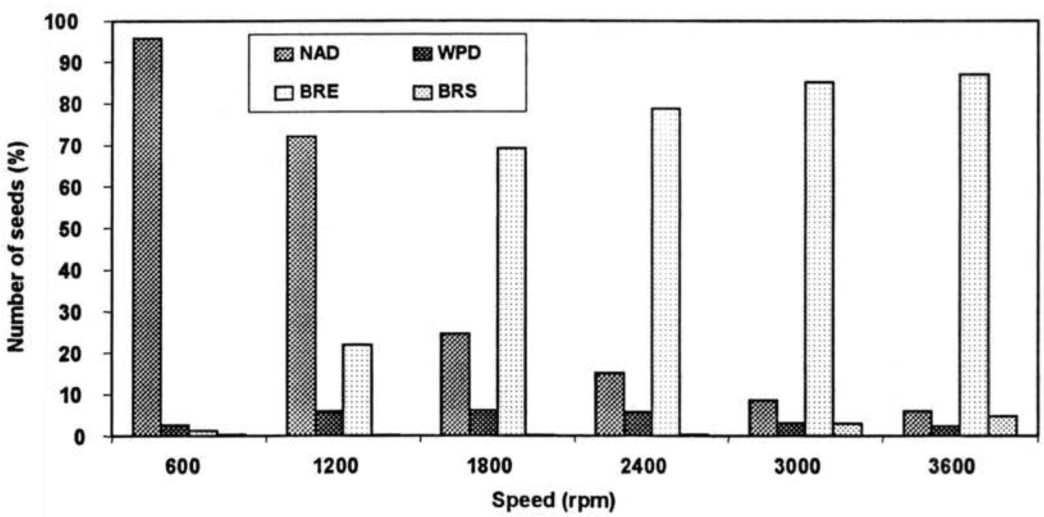
Damage classes: Most of the seeds damaged by the hammer mill were broken, had the seed coat missing, and embryos were broken or removed. A very small percentage of the seeds were whole or partially dehulled with the embryo present, and some presented no apparent damage.

Shaft speed and screen opening size effect.

The number of broken or missing embryos (BRE) increased with the hammer shaft speed (Fig.5a-b). BRE increased from 1% at 600 rpm to 92% at 3600 rpm for the 8/64 screen, and from 1.2% to 87% for the 10/64 screen. The increase was greater with the 8/64 than the 10/64 screen. Indeed, at 1200 rpm more than 50% of the seed presented broken or missing embryos with the 8/64 compared to 22% with the 10/64 screen. With the smaller screen size, the seed stayed longer in the hammer mill increasing its probability of being hit by the hammer. Conversely, the number of seed with no apparent damage (NAD) decreased with increased hammer shaft speed. The percentage of NAD varied form 96% at 600 rpm to 1.5 % at 3600 rpm with the 8/64 screen, and from 96% to 6% with 10/64 screen. More damage was done to the seed at higher shaft speed and smaller screen opening size. The percentage of whole or partially dehulled seed (WPD) and broken seed (BRS) was not different for both screen opening sizes. The highest percentage of BRS seeds (5%) was obtained at 3600 rpm. At higher shaft speeds and smaller screen opening sizes, the hammer mill generally dehulled and broke the embryos of cheat seed.



(a)



(b)

Figure 5- Effect of hammer mill shaft speed and screen opening size on percentage of seed in different damage class. (a) 8/64 screen; (b) 10/64 screen.

Shaft speed and feed rate effect

There was not much difference in the percentage of seed in each class for the different feed rates investigated (Fig 6a-c). The damage increased as the shaft speed increased.

The percentage of NAD decreased from 18% to 3%, the WPD from 9% to 2%, the BRE increased from 71% to 90%, and BRS increased from 0.3% to 5% when the shaft speed increased from 1800 to 3600 rpm. The BRE damage class contained the highest number of seeds. This confirmed the description of the hammer mill damage. The greatest damage was at 3600 rpm for the three feed rates.

Shaft speed and number of hammers effect

The degree of damage slightly increased with an increase of the number of hammers (Fig7a-b). With more hammers the percentage of seed in NAD and WPD classes decreased, and the percentage of number of seed in BRS and BRE increased. The more hammers present the more seeds were struck and presented broken or missing embryos. The percentage of WPD seed was lower with the 24-hammers set than with the 16-hammers set.

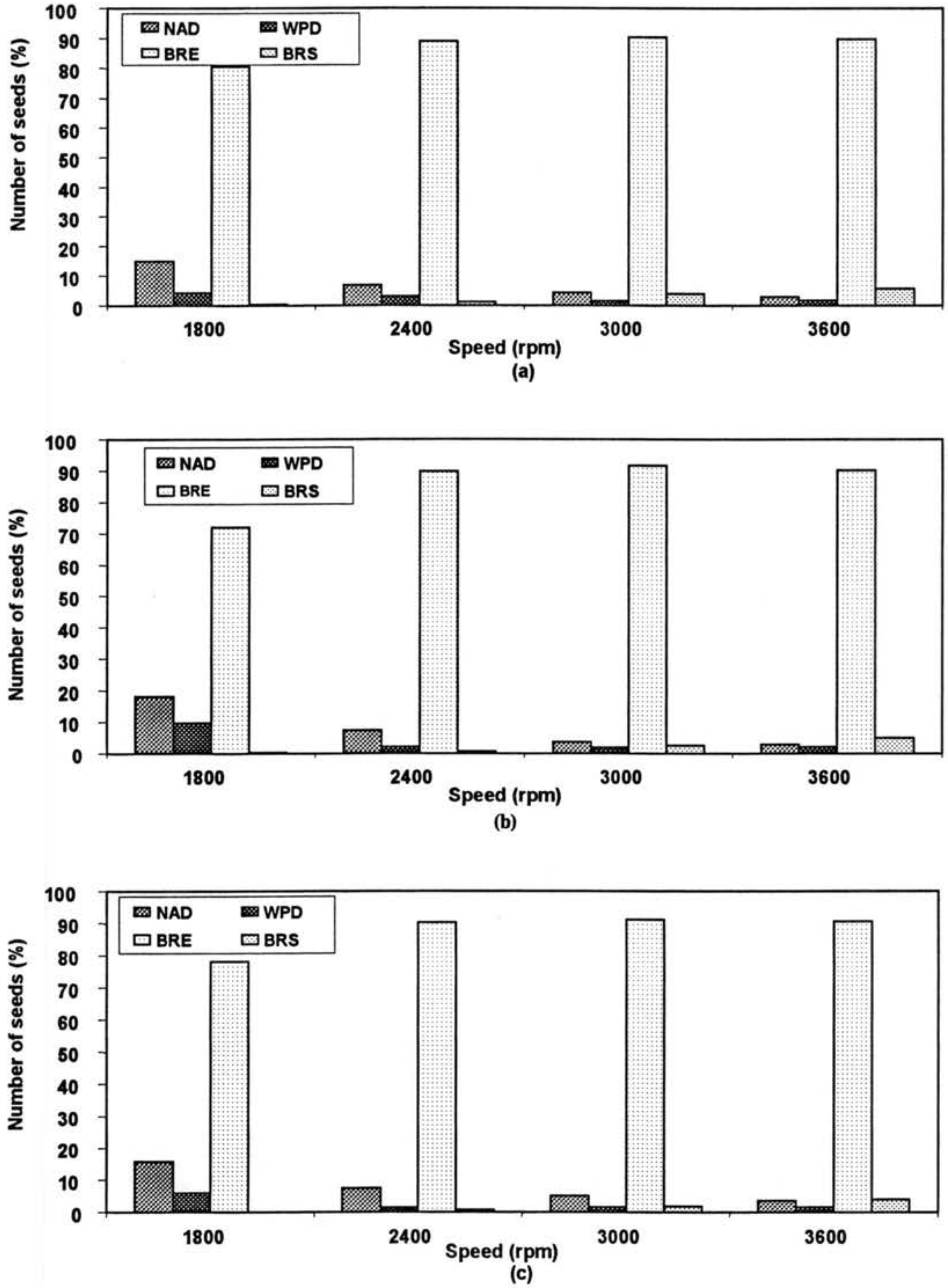


Figure 6- Effect of hammer mill shaft speed and feed rate on percentage of seed in different damage class. (a) 50 g/s; (b) 70 g/s; (c) 85 g/s.

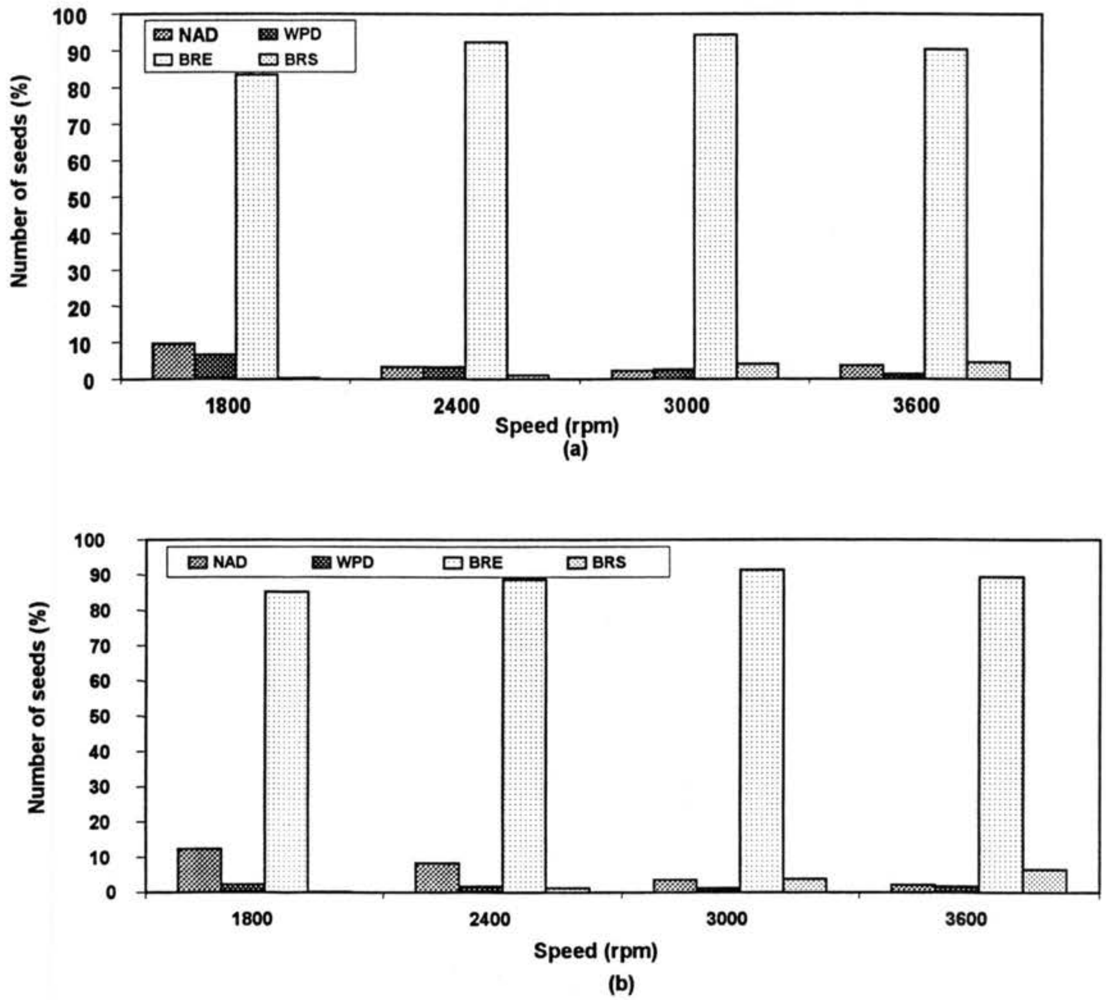


Figure 7- Effect of hammer mill shaft speed and number of hammers on percentage of seed in different damage class. (a) 16 hammers; (b) 24 hammers.

When samples of damaged seed from each of the four hammer mill damage class were germinated, the germination percentage varied from 0.2 % for the worst damage class BRS (broken seed) to 99% to the least damage class NAD (Fig. 8) compared to 100% for the check (control sample of undamaged seed). The germination decreased as the level of damage increased. The BRS class presented the lowest germination 0.3%. In that class, part of the seed was missing and the seed tissue was disrupted. The percentage germination from the NAD class (99%) implied that the hammer mill imposed almost no injury to the seed in this class. It appeared that the degree of hammer mill seed damage did not vary continuously. WPD had 91% germination, NAD 99%, BRS 0.3%, and BRE 8%. The seed was either damaged and would not germinate or was not damaged and would germinate. The hammer mill broke most of the embryos and thus greatly reduced the viability of the cheat seed.

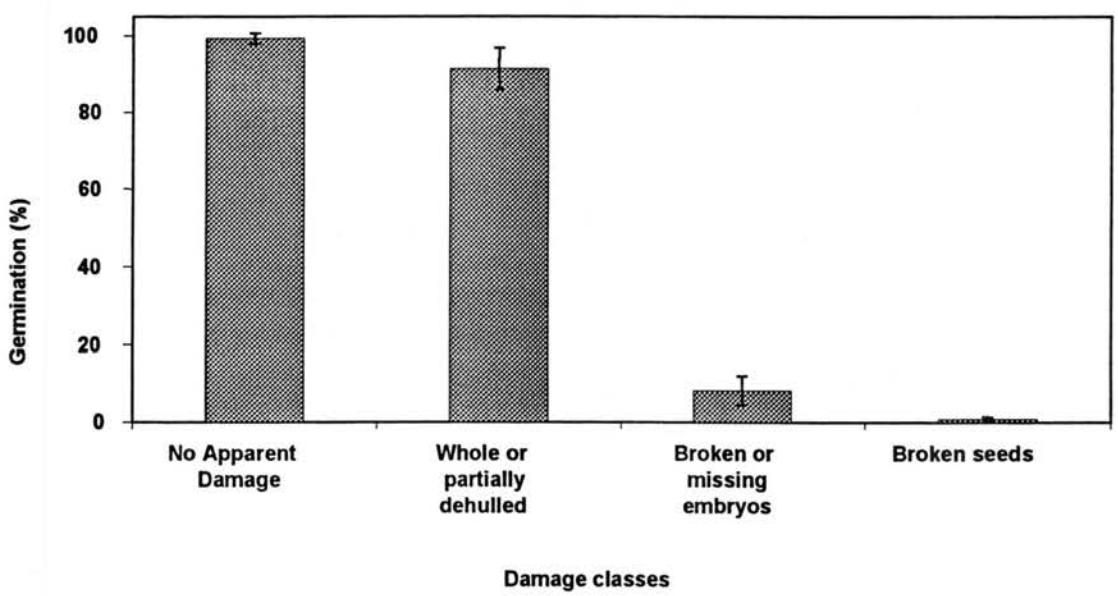


Figure 8- Mean germination percentage for damage classes of hammer milled seed

Damage index: From the germination tests of each damage class viability (VIF) and damage index factors (DIF) were computed. (Table 1) from Eq. 1.

Table 1- Viability and damage index factors of hammer milled cheat seed

Damage classes	Germination (%)	Viability index factor	Damage index factor
BRS	0.2	0	10
BRE	8	1	9
WPD	91	9	1
NAD	99	10	0

The damage index factor was 10 for the class (BRS) with the greatest damage and 0 for the class (NAD) with the least damage. If no seeds had been damaged by the hammer mill, the damage index (DI) of the sample would be equal to zero (Eq. 2), and if all seeds were broken DI would be equal to 100.

To evaluate the utility of the damage index, measured germination was compared to germination calculated using damage classification. The measured and calculated germination data were subjected to a linear regression and the coefficient of determination (r^2) was calculated for each test to determine the correlation between the data.

Shaft speed and screen opening size effect

The measured and the calculated germination were similar at all speeds but 1200 rpm and 1800 rpm for both screen sizes (Table 2). At those two speeds the viability of the cheat seed was underestimated. A possible cause was the difficulty in classifying the seed into the proper damage class at those speeds. More seeds might have been classified BRE when their embryo was still present. The DI increased from 1 to 88 when the speed increased from 600 rpm to 3600 rpm for the 8/64 screen and varied from 2 to 83 for the 10/64. DI values with the 10/64 screen size were lower than the 8/64 screen DI values (except at 600 rpm). This confirmed that damage to the seed was greater with the smaller screen hole size. In general, DI values reflected the same differences that were found in the germination. The DI could be a good indicator of the seed vigor for hammer milled seed if classification at 1800 rpm and 2400 rpm could be improved.

Table 2- Comparison between measured germination, calculated germination percentages, and damage index for hammer milled seed at different shaft speeds and screen opening sizes

Shaft Speed (rpm)	Screen size (in)	DI	Measured germination (%)	Calculated germination (%)
600	8/64	1	99	98
1200	8/64	47	83	52
1800	8/64	76	39	22
2400	8/64	82	19	16
3000	8/64	87	10	11
3600	8/64	88	11	10
600*	10/64	2	99	98
1200	10/64	20	97	79
1800	10/64	63	82	37
2400	10/64	72	38	27
3000	10/64	80	28	19
3600	10/64	83	19	15

For this test the coefficient of determination (r^2) between the measured and calculated germination percentage was 0.85.

Shaft speed and feed rate effect

For feed rate tests, the calculated germination percentage was similar to the measured germination except at 1800 rpm (Table 3). The damage classification predicted the viability of the seed very well at high shaft speeds. The damage at those speeds was easily detected by the staining and visual inspection. The DI was higher (80%) at 2400 rpm and above, and practically the same for the three feed rates. This confirmed the conclusion that the feed rate did not have an effect on cheat seed germination. The DI was a good indicator of the viability of hammer milled seed.

Table 3- Comparison between measured germination, calculated germination percentage, and damage index for hammer milled seed at different speeds and feed rates

Shaft Speed (rpm)	Feed rate (g/s)	DI	Measured germination (%)	Calculated germination (%)
1800	50	73	43	25
2400	50	81	20	17
3000	50	85	16	13
3600	50	87	9	12
1800	70	66	40	33
2400	70	82	22	17
3000	70	85	15	13
3600	70	86	14	12
1800	85	71	45	28
2400	85	82	26	16
3000	85	84	14	14
3600	85	86	12	13

For this test the coefficient of determination (r^2) between the measured and calculated germination percentage was 0.88.

Shaft speed and number of hammers effect

Once again, the calculated germination was closer to the measured values at speeds of 2400 rpm and higher (Table 4). The damage classification method predicted the germination better at higher shaft speeds. DI was lower at 1800 rpm for both sets of hammers indicating less damage at that speed, and higher at speed of 2400 rpm and higher indicating more seed damage. The visual damage classification and the DI were good indicators of hammer mill effect on cheat seed. They could both be used to predict the viability of the damaged seed.

Table 4- Comparison between measured germination, calculated germination percentage, and damage index for hammer milled seed at different speeds and number of hammers

Shaft speed (rpm)	Number of hammers	DI	Measured germination (%)	Calculated germination (%)
1800	16	76	41	23
2400	16	85	18	14
3000	16	89	12	12
3600	16	86	11	12
1800	24	77	29	21
2400	24	81	20	17
3000	24	86	11	12
3600	24	87	11	11

For this test the coefficient of determination (r^2) between the measured and calculated germination percentage was 0.91.

Roller mill

Damage classes: A shear effect was added to the crimping effect by the roll speed differential. Seed damaged by the roller mill usually presented cracks in the seed coat and the endosperm at very narrow roll gaps. Some seeds were broken and a very few exhibited no apparent damage. The narrower the gap, the deeper the cracks. (Hauhouot et al. 1997). Figure 4 illustrates damage classes for roller milled seeds. From Figure 9a-c, it appeared that the damage was greater at the combination 1:1.27 roll speed differential ratio and 0.1 mm roll gap. This roller mill setting presented the highest number of broken seed and had more than 70% of the seed in BRS and DPCK classes. When the roll speed differential ratio decreased to 1:1 (Fig 9a), more seeds were found in NAD and THMK classes. In all the cases, DPCK class had the highest percentage of seed (from 47% to 64%).

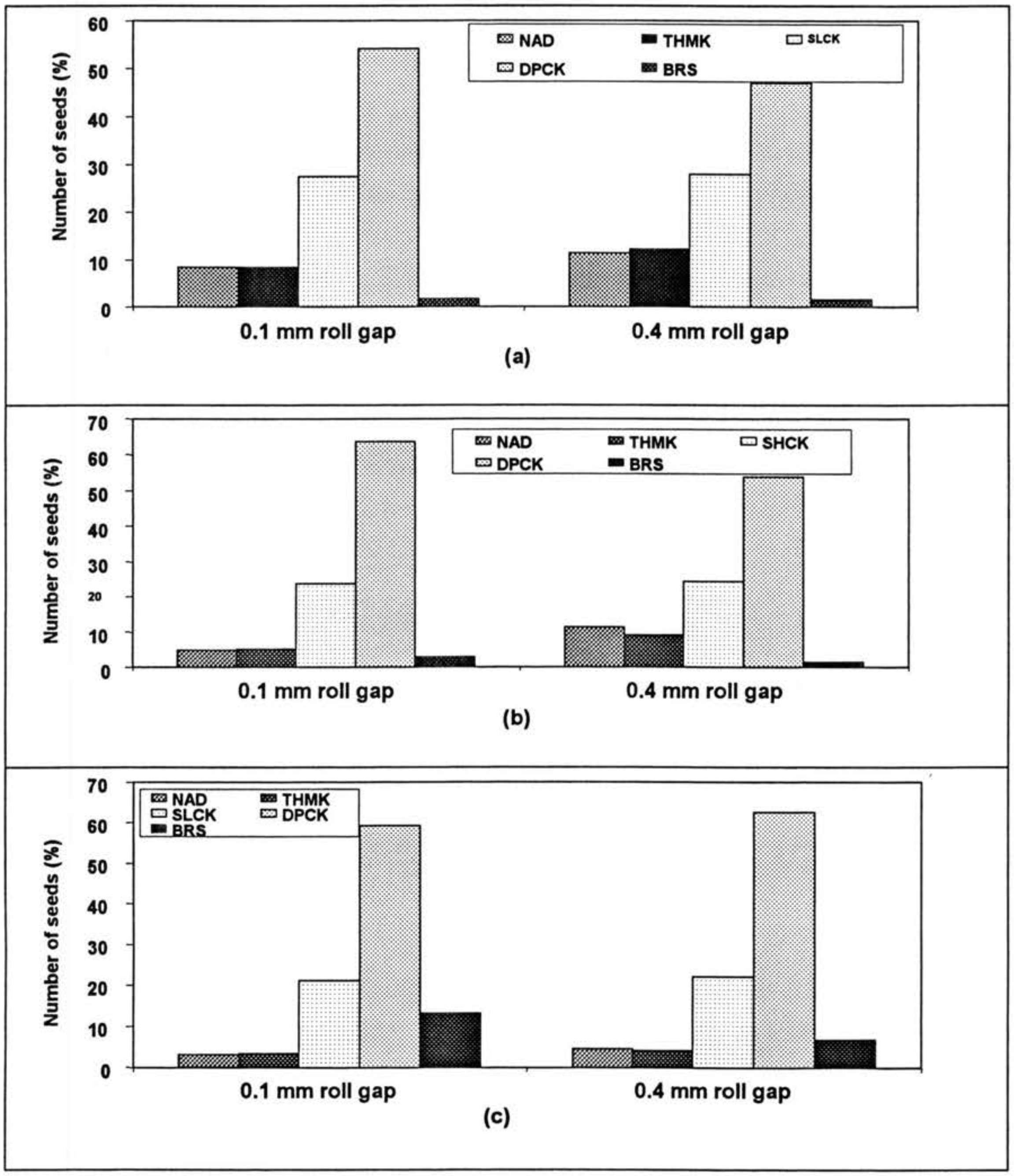


Figure 9- Effect of roll speed differential and roll gap on percentage of seed in different damage classes. (a) 1:1 ratio; (b) 1:1.1 ratio; (c) 1:1.27 ratio.

Seed germination varied from 0.3 % for the worst damage class BRS (broken seed) class to 72% to the least damage NAD (Fig. 10) compared to 100% for the check (control sample of undamaged seed). The germination decreased as the level of damage increased. The BRS class presented the lowest germination 0.3%. In that class, part of the seed was missing and the seed tissue was disrupted. Germination from the NAD class (72%) implied that the roller mill induced internal damage (approximately 18 %) that was not identifiable by visual inspection of stained seed

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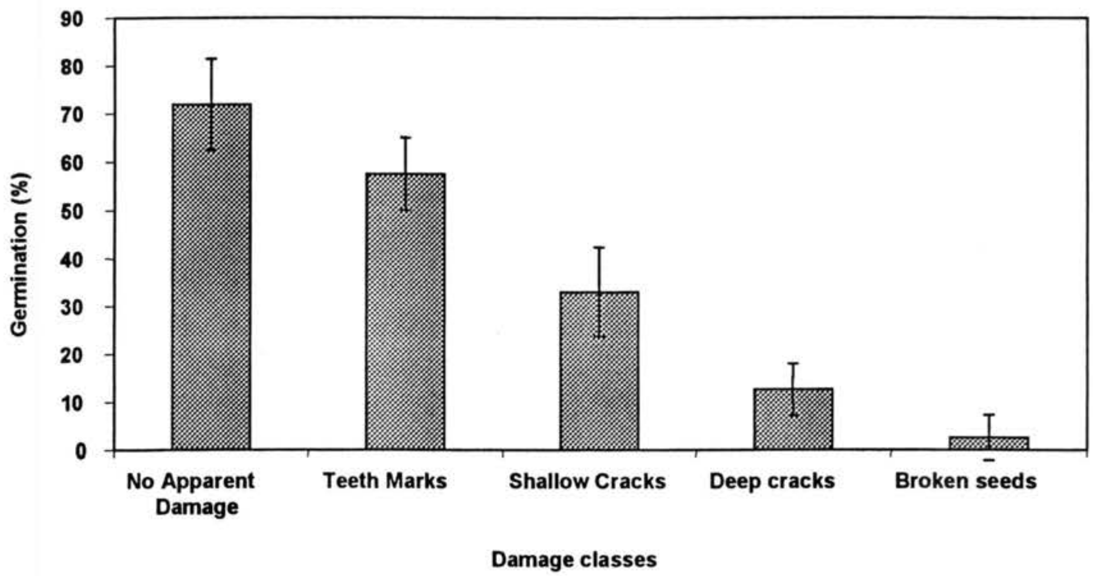

Figure 10 – Mean Germination percentage for damage classes of roller milled seed

Damage index: From the germination tests, viability and damage index factors (VIF and DIF) were calculated for roller milled seed (Table 5).

Table 5- Viability and damage index factors of roller milled cheat seed

Damage classes	Germination (%)	Viability index factor	Damage index factor
BRS	0.3	0.03	10
DPCK	12	1	9
SHCK	33	3	7
TMRK	57	6	4
NAD	72	7	3

A summary of comparisons of measured germination and the germination calculated using the damage classification as well as the damage index is presented in Table 6. The calculated germination was obtained by multiplying the percentage of seed in each class by the germination percentage from that class and adding the number for each treatment. The measured and the calculated germination were only 10% different except for the 1:1.27 roll speed differential ratio at 0.4 mm roll gap and the 1:1.1 roll speed differential ratio at 0.4 mm gap. This result implied the existence of internal damage that was not detected by the staining and visual inspection. The DI showed that the damage level (severity) and the quantity of damaged seeds was almost the same for the three roll speed differential ratios at the investigated roll gap.

Table 6-Comparison between measured germination and calculated germination percentage for roller milled seed at different speed differential and roll gaps.

Treatments	DI	Measured germination (%)	Calculated germination (%)
1RM0.4 mm	76	69	30
1RM0.1 mm	72	10	27
1.1RM0.4 mm	80	35	28
1.1RM0.1 mm	74	8	22
1.27RM0.4 mm	84	19	21
1.27RM0.1 mm	82	5	19

*1RM0.4 mm: Roller mill test with the 1:1 roll speed differential at 0.4 mm gap between the rolls; 1.1RM0.1mm: roller mill test with the 1:1.1 roll speed differential ratio at 0.1 mm gap between the rolls; etc.

For this test the coefficient of determination (r^2) between the measured and calculated germination percentage was 0.61 which was considerably lower than those obtained from classifying hammer milled cheat seed damage ($0.80 \leq r^2 \leq 0.88$).

CONCLUSIONS

From the results of the different test the following conclusions could be drawn:

1. Visual classification of damaged seed was easier for hammer milled seed than for roller milled seed.
2. Hammer milled seed could be classified into four damage classes: NAD, WPD, BRE and BRS. The NAD (99% germinated) was the class with least damage and the BRS (0.2% germinated) was the class with the worst damage.
3. At 3000 rpm and higher, 90 % of the hammer milled seed presented broken or missing embryos.
4. The hammer mill seemed to have a non continuous scale of damage. The percentage germination for the different classes was either above 90% or below 10%.
5. The visual damage classification predicted better the viability of seed at speeds of 2400 rpm and higher. The damage index (DI) described the same response as the germination test and could be used to describe cheat seed viability.
6. The roller mill seemed to damage the seed on a continuous scale. The roller milled seed could be classified in five damage classes NAD, TMRK, SHCK, DPCK, and BRS. The germination percentage in each class was 72%, 57%, 33%, 12%, and 0.3% respectively.
7. The visual damage classification was not an efficient way to evaluate the roller mill damage on cheat seed because it did not reveal potential internal damage in the seed. Consequently, the DI was not an efficient method to predict the viability of the roller mill seed.

ACKNOWLEDGMENTS

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CHAPTER VII

SUMMARY AND CONCLUSIONS

Bromus secalinus L., a winter grass known under the common name of cheat, badly infests wheat fields. More than 150 *Bromus* species are found in northern temperate regions, temperate South America, and a few on the mountains of the tropics. In the Great Plains of the USA, many hectares of wheat fields are infested by these species. In Oklahoma, more than 1,000,000 hectares have been infested in certain years and the yield reduced by as much as 50%. Many solutions have been suggested or tried to overcome these weeds. Annual application of herbicides, moldboard plowing to bury the seeds, burning the wheat stubble, and rotation to summer crops were used as weed control, but they all have potential adverse environment effects. Consequently, new approaches were considered.

Mechanically damaging cheat seed to reduce its germination or emergence (devitalize) was investigated as an alternative to weed control. The feasibility of using a hammer mill and a roller mill to intentionally damage cheat was examined. The process to devitalize cheat could consist of the following steps: (1) weed seed would have to be separated from the wheat in the combine, (2) weed seed would be fed to a mechanical device capable of inducing enough damage to the seed to reduce its viability, would be advantageous if the mechanical processing of the cheat seed would be a combine-mounted operation, so cheat seed would be devitalized immediately after harvest and left on the ground or collected for animal feed.

The physical characteristics and aerodynamic properties necessary to implement the separation process were measured, and compared to those of wheat. Cheat seeds were 6.85 mm long, 1.35 mm wide, and 1.24 mm thick whereas wheat seeds were 6.02 mm long, 2.79 mm wide, and 2.54 mm thick. The average weight of 1000 cheat seeds was 5 g compared to 40 g for wheat. The bulk density of cheat was 210 kg/m^3 compared to 772 kg/m^3 for wheat. These physical characteristics are important in selecting design variables for machines to devitalize cheat. The gap between the rolls of the roller mill and the screen opening size of the hammer mill can be selected from knowing the physical characteristics of cheat seed. Cheat seeds had an average terminal velocity of 3.14 m/s compared to an average of 7.84 m/s for wheat; leading to drag coefficients of 1.05 and 0.74 respectively. There was a considerable difference between terminal velocities of cheat and wheat seed, which suggested that aerodynamic separation of cheat, and wheat was possible.

Preliminary tests were conducted with a hammer mill and a roller mill to damage cheat seed to prevent germination or emergence. Milling effects on cheat germination were evaluated in greenhouse pots, in a laboratory growth chamber, and in the field. Roller mill variables tested were gap between the rolls (from 0.1 mm to 1.1 mm) and density of the teeth on the rolls (5, and 8 teeth/cm). The gap between the rolls and the density of the teeth on the rolls were correlated to the viability of the seeds. Germination decreased with decreasing roll gap and increasing number of roll teeth. The hammer mill dehulled the seed and fractured 92% of the seed embryos. Hammer milled seed had lower germination than most roller milled seed treatments. With the roller mill, the combination of narrow roll gap and high tooth density reduced germination as much as the hammer mill treatment. Field tests results were similar to the laboratory tests, but seedling emergence in the field was lower because of additional natural factors.

Tests were conducted to determine the effect of hammer mill speed, screen opening sizes, feed rate, and number of hammers on cheat seed germination. The hammer mill speeds were varied from 600 rpm to 3600 rpm. The two screen opening sizes evaluated were 3.2 mm and 4.0 mm. The feed rates used were 50, 70, and 85 g/sec. The machine was equipped with 16 or 24 hammers. The viability of the seed was measured by the percentage of vigorous seedlings after growth chamber germination. Shaft speed, screen opening size, and the number of hammers had a significant effect on cheat seed germination. Germination percentage decreased with increasing shaft speed, and number of hammers, and decreasing screen opening sizes. Within the range of the experiments, feed rate did not have a significant effect on cheat seed germination. Germination was lowest (9%) at 3600 rpm with the 8/64 screen, 24 hammers, and an average feed rate of 50 g/s. These results indicated that the hammer mill has potential to sufficiently damage cheat seed to dramatically reduce its germination.

Additional tests were conducted to determine the effect of roller mill speed differential and gap between the rolls on cheat seed germination. The speed differential ratios tested were: 1:1, 1:1.1, 1:1.27, and the five gaps between the rolls between 0.1 to 0.9 mm. The viability of the seed was measured by the percentage of vigorous seedlings after growth chamber germination. The speed differential had a significant effect on cheat seed germination, but the roll gap was the most significant factor. Germination decreased with increasing roll gap and roll speed differential ratio. The greater the speed differential, the greater the shear effect on the seed, and the lower the germination. At the widest and narrowest roll gap (0.9 mm and 0.1 mm), there was no significant difference among the three speed differential ratios. The combination of the widest speed differential ratio (1:1.27) and the narrowest roll gap (0.1 mm) resulted in a low germination (5%) compared to 99% for hand-harvested cheat samples.

In order to better evaluate the mechanical damage on the hammer milled and roller milled cheat seed, the seeds were stained with a FCF fast green solution and classified into different classed according to the type and level of damage. Germination tests were run to check the viability of the seed in each class and create a damage index class. The hammer mill and the roller mill presented different types of damage. The visual classification was easier for hammer milled seed than for roller milled seed. Hammer milled seed was classified into four damage classes: NAD (no apparent damage), WPD (whole or partially dehulled), BRE (broken or missing embryos) and BRS (broken seed). The NAD (99 % germinated) was the class with least damage and the BRS (0.20% germinated) was the class with the greatest damage. At 3000 rpm and higher, 90 % of the hammer milled seed presented a broken or missing embryos. The hammer mill seemed to have a non-continuous scale of damage. The percentage germination for the different class was either above 90% or below 10%. The visual damage classification could better predict the viability of seed damaged at speeds of 2400 rpm and higher. The damage index (DI) varied from 1 to 87 when the hammer mill shaft speed increased form

600 rpm to 3600 rpm. The higher index., the greater the damage, and the lower the germination percentage. The damage index predicted the same response as the germination tests and could be used to assess cheat seed viability.

The degree of damage by the roller mill could be described on a continuous scale. The roller milled seed could be classified in five damage classes NAD, TMRK (teeth marks), SHCK (shallow cracks), DPCK (deep cracks), and BRS. The mean germination percentage in each class was 72%, 57%, 33%, 12%, and 0.3% respectively. The visual damage classification could only partially predict roller mill damage to cheat seed because visual inspection could not detect internal seed damage. Consequently, the damage index could not precisely predict the viability of the roller mill seed.

In conclusion, mechanically devitalizing seed of *Bromus secalinus* L. is an alternative to weed control with potential. The hammer mill and the roller mill were two devices capable of inducing enough damage to cheat seed to reduce its viability. Changing the operating parameters of the two machines can increase the damage to the seed. Shaft speed and the screen opening size are critical for the hammer mill; gap between rolls and roll speed differential affected damage by roller mill damage. The reduction in cheat germination effect on cheat seed germination. Damaged hammer milled seed can easily be evaluated by visual inspection and a damage index can be related to the viability of the seed. Roller mill seed had internal damage that can not be detected by visual classification.

The hammer mill is the best equipment to devitalize cheat seed because viability of hammer milled seed could be easily predicted. At shaft speed higher than 2400 rpm, 90% or more of the hammer milled seeds had a broken or missing embryo. From the different tests, cheat germination was in average 10% at 3600 rpm with the 3.18 mm screen opening size, 24 hammers sets, and 50-85 g/s feed rate. That percentage goes down to 3% when the initial material processed is considered instead of the material recovered after cleaning. Variations in feed rate seemed not to have an effect on the damage of the seed and this will simplify equipment design since feed rate would likely not be constant on the combine.

Suggestions for future research

The following research subjects could be investigated:

1. Improve separation process of cheat from wheat seed on the combine.
2. Design power requirement of the hammer mill for combine-mounted operations.
3. Design experiments to verify the validity of this new method of weed control with the mechanical device mounted on a combine harvester.
4. Investigate efficiency of mechanically devitalizing cheat seed compared to current practices.
5. Investigate the mill performance with an increase of the load.
6. Evaluate the population dynamics of cheat to see how much of the damaged seed will germinate and produce viable plants.
7. Investigate the effect of moisture content of the seed on the performance of the mill.

APPENDIX A

DATA FOR MEASUREMENTS OF PHYSICAL CHARACTERISTICS AND AERODYNAMIC PROPERTIES OF CHEAT SEED

APPENDIX A-1

DATA FOR LENGTH, WIDTH, AND THICKNESS MEASUREMENTS OF CHEAT SEED

Major Diameter (mm)					
7.08	7.48	6.71	7.42	6.95	7.28
7.69	7.54	6.83	7.10	6.93	7.48
6.16	6.32	6.83	6.73	6.56	7.53
7.14	6.84	6.56	7.11	6.67	8.05
6.59	7.34	6.72	7.15	6.60	6.55
7.07	6.84	7.24	7.26	6.57	6.39
6.60	7.37	6.89	7.56	6.87	6.64
7.62	6.51	7.48	7.34	6.61	7.19
7.05	7.77	7.09	6.48	6.99	6.45
6.60	6.27	6.41	7.02	7.22	7.01
6.45	7.36	6.34	6.64	7.01	6.64
7.48	7.04	6.86	7.16	6.87	6.26
7.45	7.16	6.31	6.92	7.06	7.51
7.30	7.06	7.37	6.31	6.91	6.39
6.72	6.29	6.60	7.59	6.20	7.56
6.30	7.51	7.46	7.49	6.58	6.58
6.76	7.51	6.34	6.46	7.82	7.10
7.19	7.19	6.74	6.16	6.08	6.88
6.97	5.95	6.43	6.90	7.07	7.29
6.76	6.64	6.22	6.33	6.71	6.67
6.71	5.96	6.35	7.35	6.95	7.42
6.66	6.56	6.61	6.59	7.36	6.36
6.55	6.88	6.60	6.52	6.88	6.34
6.22	7.71	6.64	6.73	6.46	7.08
6.86	6.63	7.12	6.25	7.58	6.98
6.55	6.76	7.59	6.95	6.53	6.50

APPENDIX A-1 (Cont'd)

Major Diameter. Cont'd (mm)		Intermediate Diameter (mm)		Minor Diameter (mm)	
6.45	6.79	1.28	1.49	1.36	1.27
6.89	6.40	1.35	1.38	1.24	1.27
6.33	6.58	1.38	1.19	1.10	1.36
7.23	7.03	1.42	1.32	1.25	1.33
6.83	7.05	1.41	1.31	1.15	1.30
6.71	6.79	1.39	1.25	1.40	1.18
6.76	7.10	1.15	1.43	1.26	1.12
6.74	6.33	1.40	1.26	1.20	1.36
7.37	7.15	1.35	1.24	1.06	1.18
7.35	6.48	1.28	1.24	0.97	1.18
6.72	6.98	1.18	1.07	1.06	0.95
6.46	7.54	1.71	1.21	1.14	1.21
6.52	6.12	1.39	1.30	1.38	1.33
7.18	6.85	1.39	1.40	1.25	1.28
7.36	6.03	1.39	1.31	1.15	1.26
7.61	7.60	1.48	1.33	1.31	1.23
7.47	6.32	1.15	1.35	1.27	1.11
6.77	7.07	1.26	1.43	1.25	1.17
6.25		1.52	1.45	1.28	1.18
6.65		1.58	1.34	1.21	1.56
6.36		1.36	1.52	1.31	1.31
7.20		1.38	1.33	1.15	1.20
7.08		1.34	1.36	1.34	1.26
6.45		1.27	1.40	1.46	1.27
6.25		1.18			
5.70		1.57			

Major Dia. = Length
Intermediate Dia. = Width
Minor Dia. = Thickness

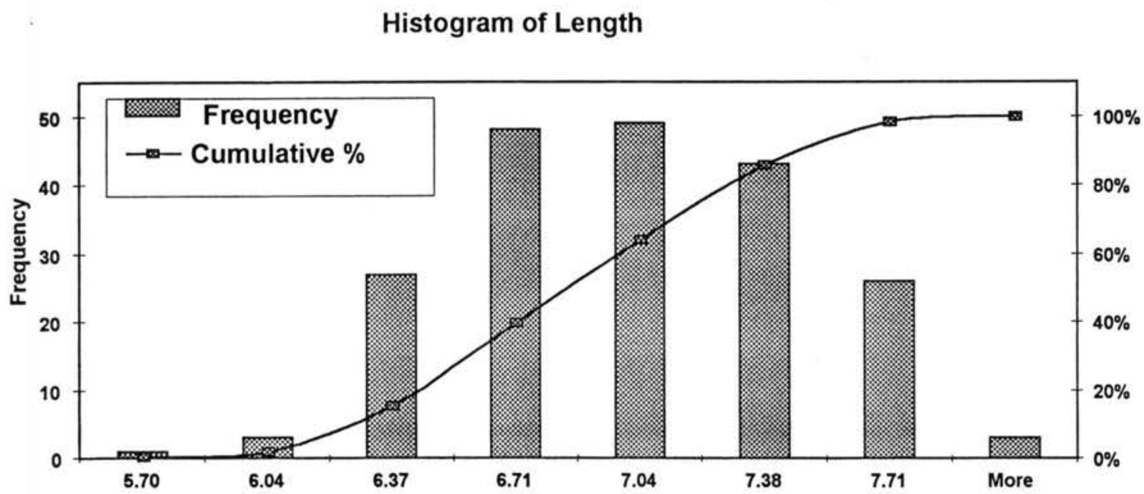
APPENDIX A-2

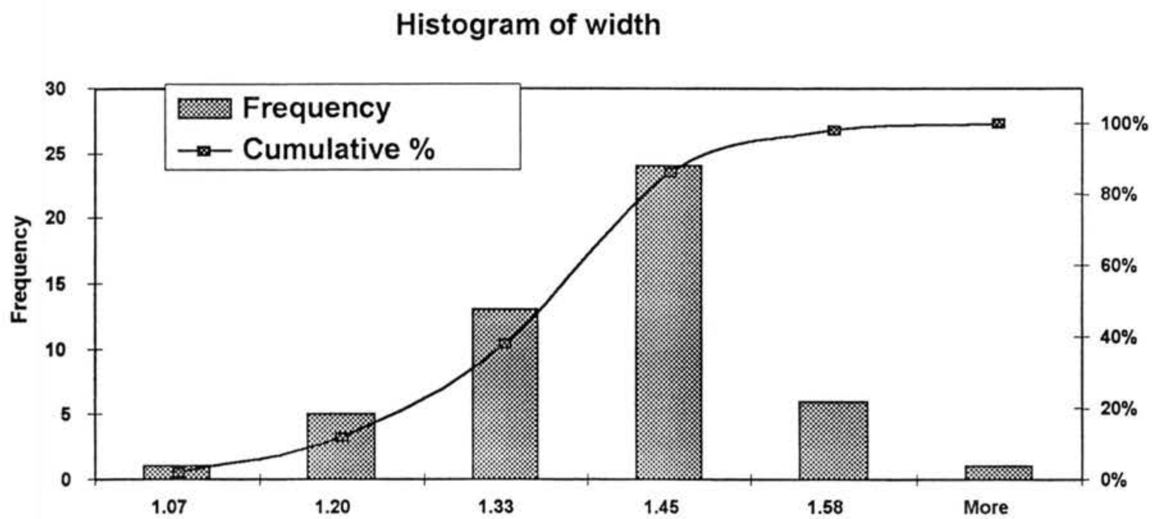
STATISTICS OF LENGTH, WIDTH, AND THICKNESS MEASUREMENTS OF CHEAT SEED

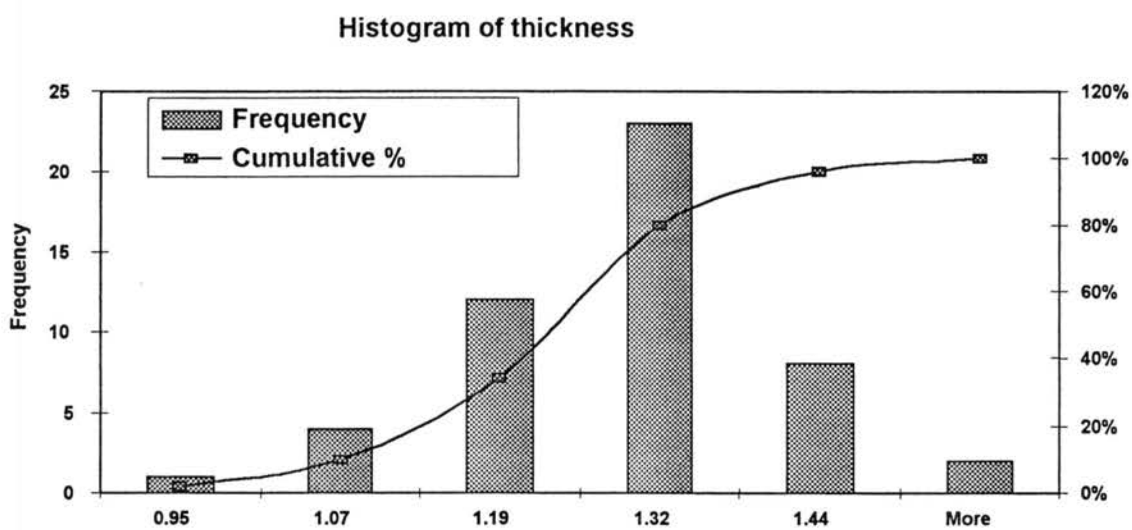
Major Diameter (mm)		*Intermediate Diameter (mm)*		*Minor Diameter (mm)*	
Mean	6.86	Mean	1.35	Mean	1.24
Standard Error	0.03	Standard Error	0.02	Standard Error	0.02
Median	6.84	Median	1.35	Median	1.25
Mode	6.60	Mode	1.39	Mode	1.31
Standard Deviation	0.44	Standard Deviation	0.12	Standard Deviation	0.12
Sample Variance	0.20	Sample Variance	0.01	Sample Variance	0.01
Kurtosis	-0.62	Kurtosis	0.92	Kurtosis	0.83
Skewness	0.15	Skewness	0.34	Skewness	0.21
Range	2.35	Range	0.64	Range	0.61
Minimum	5.70	Minimum	1.07	Minimum	0.95
Maximum	8.05	Maximum	1.71	Maximum	1.56
Count	200	Count	50	Count	50
Confidence Level(95%)	0.06	Confidence Level(95%)	0.03	Confidence Level(95%)	0.03

Major diameter = length
Intermediate diameter = width
Minor diameter = thickness

APPENDIX A-3
HISTOGRAMS OF FREQUENCIES







APPENDIX A-4

DATA AND STATISTICS FOR WEIGHT MEASUREMENT OF CHEAT SEED

Weight (g)	Number of seeds	Weight of 1000 seeds (g)	*Statistics for Data on Weight of 1000 seeds*	
0.500	105	4.762		
0.510	96	5.313	Mean	4.951
0.510	100	5.100	Standard Error	0.041
0.540	106	5.094	Median	5.000
0.510	109	4.679	Mode	5.000
0.500	100	5.000	Standard Deviation	0.182
0.500	99	5.051	Sample Variance	0.033
0.530	115	4.609	Kurtosis	-0.462
0.500	96	5.208	Skewness	-0.082
0.510	101	5.050	Range	0.704
0.503	102	4.931	Minimum	4.609
0.502	104	4.827	Maximum	5.313
0.500	98	5.102	Count	20.000
0.501	103	4.864		
0.504	100	5.040		
0.503	104	4.837		
0.501	106	4.726		
0.500	100	5.000		
0.502	100	5.020		
0.501	104	4.817		

APPENDIX A-5

DATA AND STATISTICS ON BULK DENSITY MEASUREMENTS OF CHEAT SEED.

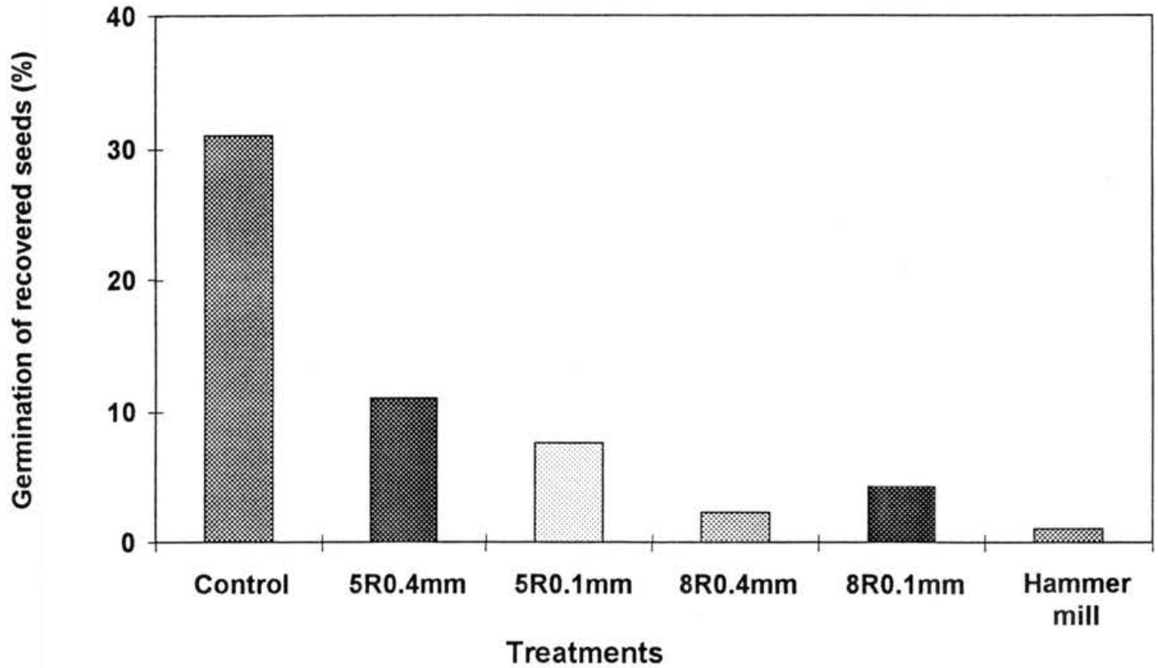
D_i (cm)	Area Can (cm^2)	Depth can (cm)	Volume can (cm^3)	Weight cheat (g)	Bulk density (kg/m^3)
7.19	40.60	10.82	439.46	93.56	210
7.24	41.19	10.58	435.83	95.73	220
7.21	40.77	10.89	444.07	89.30	200
7.24	41.12	10.89	447.74	88.05	200
7.20	40.66	10.93	444.34	98.56	220
7.21	40.84	10.92	445.83	93.32	210
7.23	41.02	10.87	445.97	89.33	200
7.22	40.92	10.87	444.82	94.59	210
7.26	41.38	10.87	449.68	93.98	210
7.23	41.07	10.83	444.65	92.01	210

D_i: Interior Diameter

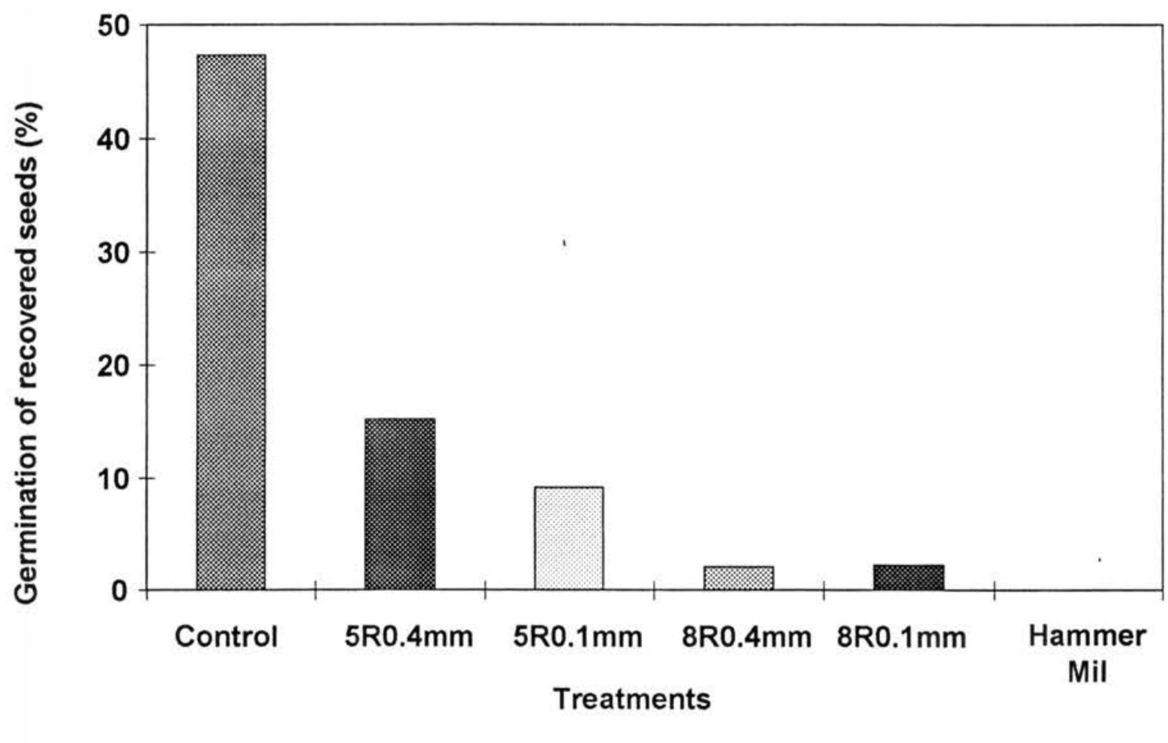
APPENDIX B

DATA FOR ROLLER MILL AND HAMMER MILL PRELIMINARY TESTS TO DEVITALIZE CHEAT SEED.

APPENDIX B-1
GERMINATION OF CHEAT FOR PACKAGED-SEED EXPERIMENTS



Oct 18, 1995. Perkins, OK.



Oct 18, 1995. Stillwater, OK.

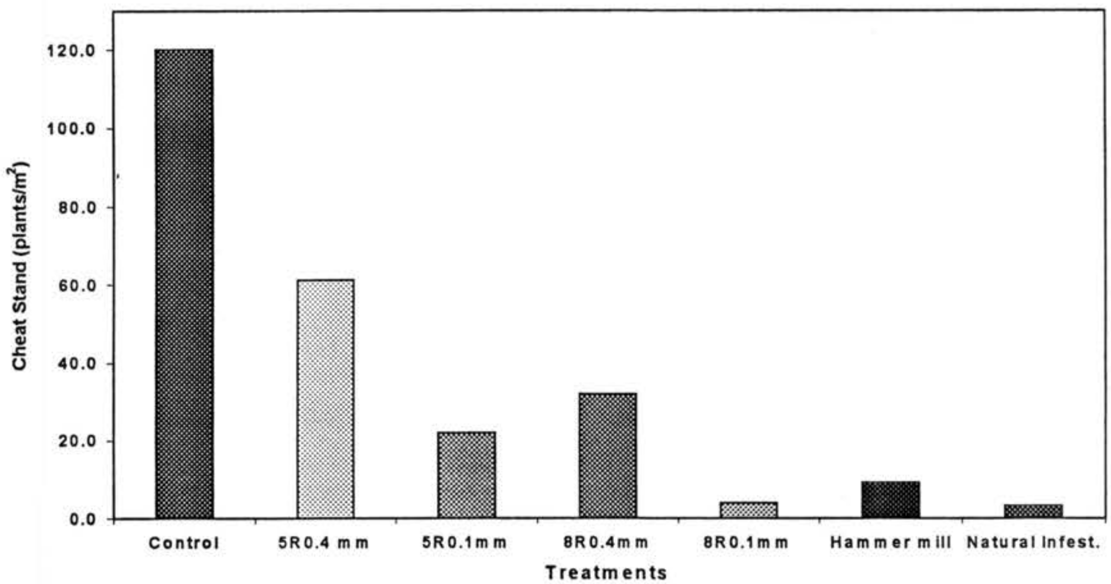
APPENDIX B-2
SUMMARY DATA FOR GERMINATION OF PACKAGED-SEED EXPERIMENTS IN THE FALL OF 1995

Perkins		Early removal: September 18, 1995			
Treatments	Germinated	Dormant seeds	"Non-vigorous" seeds	Total seeds recovered	Recovered germinated seedlings (%)
Control	18	21	40	79	22.78
5R0.4mm	2	21	55	78	2.56
5R0.1mm	2	3	72	77	2.60
8R0.4mm	2	1	93	96	2.08
8R0.1mm	0	1	92	93	0.00
Hammer Mill	4	2	77	83	4.82
Stillwater					
Control	18	55	19	92	19.57
5R0.4mm	1	8	72	81	1.23
5R0.1mm	2	7	85	94	2.13
8R0.4mm	2	0	95	97	2.06
8R0.1mm	1	5	85	91	1.10
Hammer Mill	3	0	88	91	3.30
Perkins		Normal removal: October 18, 1995			
Control	26	2	56	84	30.95
5R0.4mm	10	2	79	91	10.99
5R0.1mm	7	1	85	93	7.53
8R0.4mm	2	0	88	90	2.22
8R0.1mm	4	0	89	93	4.30
Hammer Mill	1	0	90	91	1.10
		Stillwater			
Control	36	2	38	76	47.37
5R0.4mm	13	1	71	85	15.29
5R0.1mm	8	2	78	88	9.09
8R0.4mm	2	0	94	96	2.08
8R0.1mm	2	0	92	94	2.13
Hammer Mill	0	0	91	91	0.00
Perkins		Late removal: December 18, 1995			
Control	30	49	79	21	37.97
Control	1	85	86	14	1.16
5R0.4mm	6	78	84	16	7.14
5R0.1mm	4	83	87	13	4.60
8R0.4mm	1	91	92	8	1.09
8R0.1mm	5	83	88	12	5.68
Hammer Mill					
Stillwater					
Control	50	25	75	25	66.67
5R0.4mm	26	69	95	5	27.37
5R0.1mm	8	76	84	16	9.52
8R0.4mm	2	89	91	9	2.20
8R0.1mm	1	84	85	15	1.18
Hammer Mill	2	87	89	11	2.25

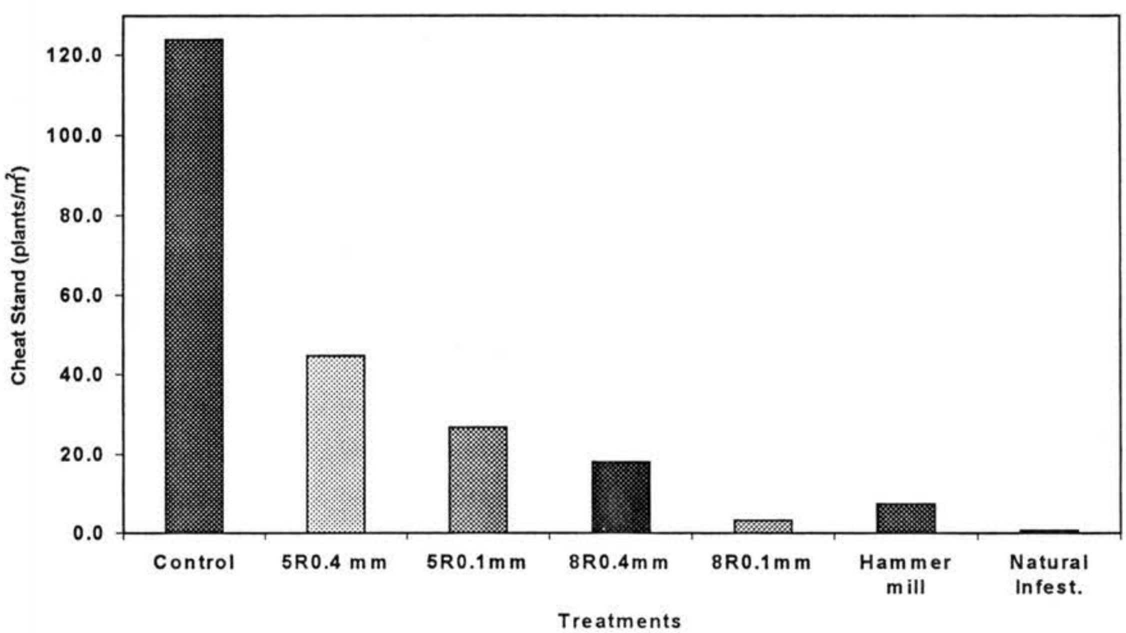
APPENDIX B-3

GERMINATION OF CHEAT FOR THE BROADCAST EXPERIMENT IN THE FALL OF 1995

First Count:



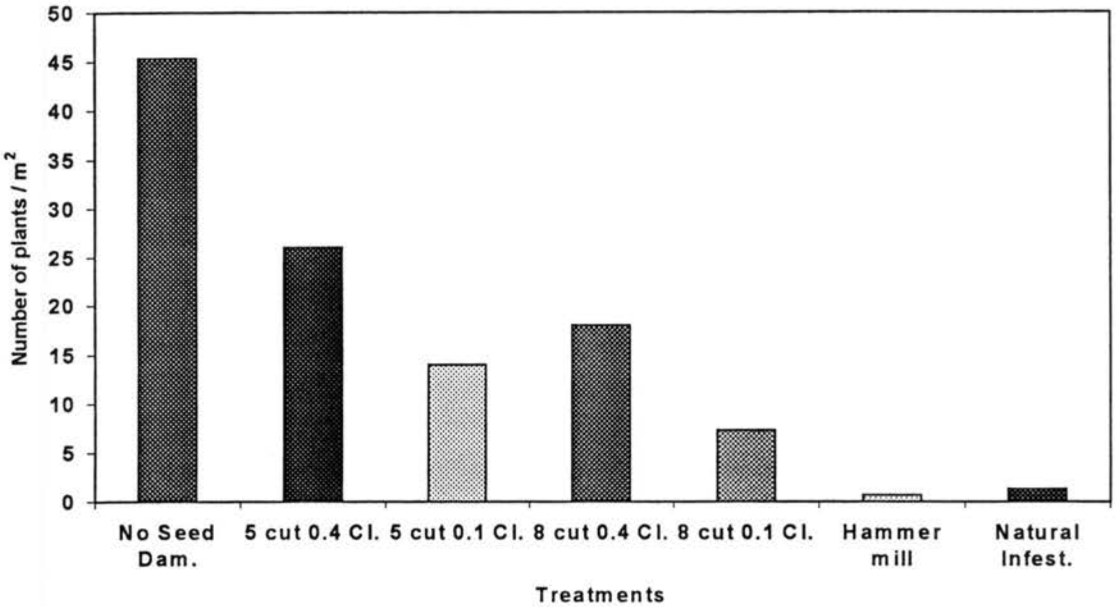
Third Count:



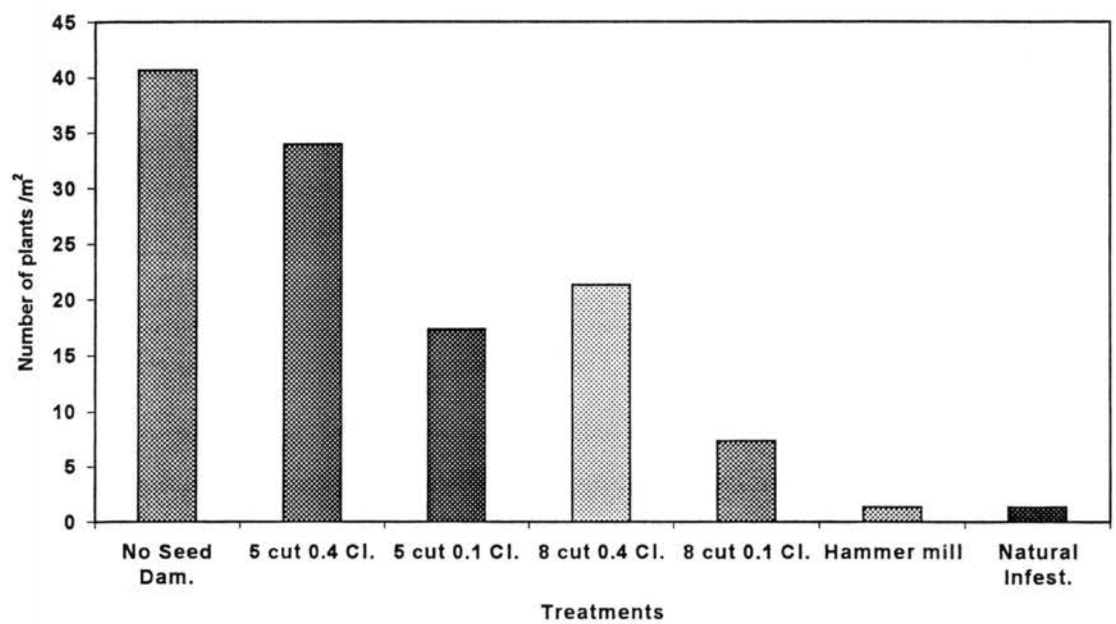
APPENDIX B-4

GERMINATION OF CHEAT SEED FOR

BBROADCAST SEED EXPERIMENT IN THE FALL OF 1996



Stillwater, Jan 3 1997



Lahoma, Jan 3 1997

APPENDIX C

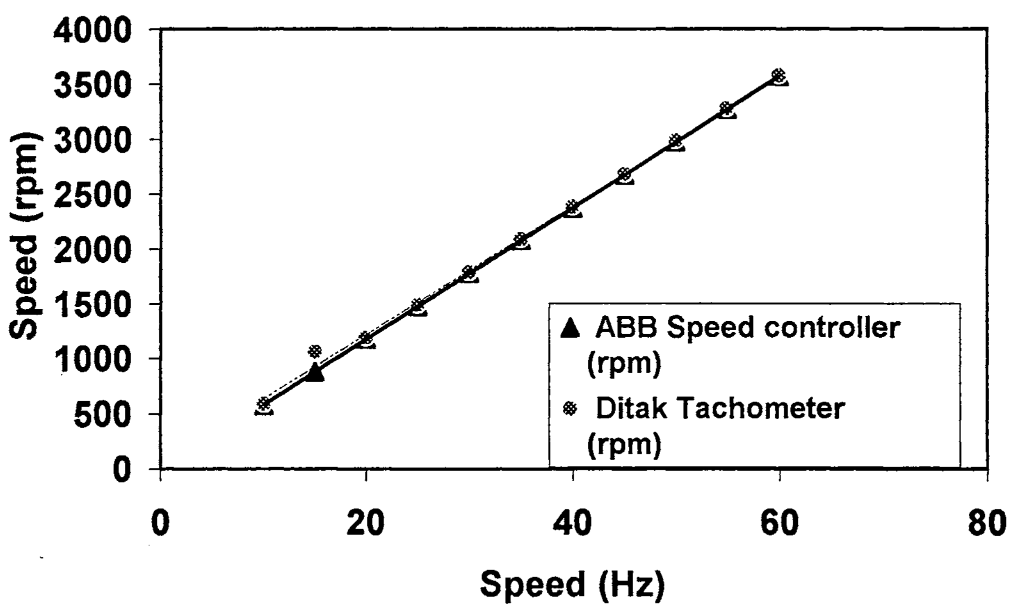
EFFECT OF SHAFT SPEED, SCREEN OPENING SIZE, FEED RATE, AND NUMBER OF HAMMERS ON CHEAT SEED GERMINATION

APPENDIX C-1
HAMMER MILL SHAFT SPEED MEASURED WITH A TACHOMETER
AND A FREQUENCY CONTROLLER SETTING

Frequency (Hz)	ABB Speed controller (rpm)	Ditak Tachometer (rpm)
10	575	587
15	879	1061
20	1180	1190
25	1477	1487
30	1778	1788
35	2079	2087
40	2374	2384
45	2675	2682
50	2976	2984
55	3271	3278
60	3572	3579

For each frequency set, the corresponding speed was read with both the ABB speed controller and a Ditak

***Ditak:** $y = 58.538x + 51.8$ $R^2 = 0.99$; **ABB:** $y = 59.87x - 19.74$ $R^2 = 1$*



Comparison of hammer mill speed measured with a tachometer to shaft with speed indicated by frequency controller setting.

APPENDICX C-2
DATA FOR SHAFT SPEED AND SCREEN OPENING SIZE EFFECT ON CHEAT SEED GERMINATION

Rep #	Screen size	Feed rate (g/sec)	Speed (rpm)	Weight before test (g)	Weight after test (g)	Weight after cleaning (g)	Mt'l collected after test (%)	Identifiable seeds recovered after cleaning (%)	Average germination of identifiable seeds (%)
1	8/64"	70.00	600	210.01	150.30	148.01	71.57	98.48	98.75
1	8/64"	70.18	1200	210.53	199.78	175.18	94.89	87.69	85
1	8/64"	70.19	1800	210.58	196.03	153.14	93.09	78.12	36.75
1	8/64"	70.05	2400	210.14	197.42	142.26	93.95	72.06	13.25
1	8/64"	70.00	3000	210.01	198.69	113.36	94.61	57.05	8.75
1	8/64"	70.11	3600	210.32	195.53	84.29	92.97	43.11	9.75
1	10/64"	70.02	600	210.07	208.86	198.38	99.42	94.98	98.5
1	10/64"	70.04	1200	210.12	208.40	196.81	99.18	94.44	95.25
1	10/64"	70.02	1800	210.05	205.31	177.92	97.74	86.66	79.25
1	10/64"	70.02	2400	210.06	205.17	161.39	97.67	78.66	33.75
1	10/64"	70.03	3000	210.08	205.13	147.99	97.64	72.14	27
1	10/64"	70.03	3600	210.10	203.59	123.03	96.90	60.43	14.25
2	8/64"	70.30	600	210.89	184.71	177.88	87.59	96.30	99.5
2	8/64"	70.08	1200	210.23	202.44	175.62	96.29	86.75	80.25
2	8/64"	70.16	1800	210.49	202.13	156.32	96.03	77.34	40.75
2	8/64"	70.12	2400	210.36	200.24	131.53	95.19	65.69	25.25
2	8/64"	69.99	3000	209.96	199.27	103.24	94.91	51.81	10.5
2	8/64"	70.11	3600	210.34	197.11	70.36	93.71	35.70	11.5
2	10/64"	70.01	600	210.04	206.24	202.01	98.19	97.95	99.5

APPENDICX C-2 (CONT'D)
DATA FOR SHAFT SPEED AND SCREEN OPENING SIZE EFFECT ON CHEAT SEED GERMINATION

Rep #	Screen size	Feed rate (g/sec)	Speed (rpm)	Weight before test (g)	Weight after test (g)	Weight after cleaning (g)	Mt'l collected after test (%)	Identifiable seeds recovered after cleaning (%)	Average germination of identifiable seeds (%)
2	10/64"	72.73	1200	218.18	204.11	189.10	93.55	92.65	97.25
2	10/64"	70.10	1800	210.30	204.50	163.74	97.24	80.07	84.5
2	10/64"	70.04	2400	210.13	204.60	149.76	97.37	73.20	41.75
2	10/64"	70.08	3000	210.23	201.69	138.14	95.94	68.49	29
2	10/64"	70.11	3600	210.32	205.77	112.58	97.84	54.71	23.5
3	8/64"	70.04	600	210.13	174.14	168.96	82.87	97.03	98.75
3	8/64"	70.05	1200	210.15	204.43	175.48	97.28	85.84	78
3	8/64"	70.06	1800	210.18	203.65	142.89	96.89	70.16	36
3	8/64"	70.02	2400	210.07	201.04	135.55	95.70	67.42	17.5
3	8/64"	70.07	3000	210.21	199.45	94.82	94.88	47.54	10
3	8/64"	70.21	3600	210.63	197.67	73.59	93.85	37.23	11.5
3	10/64"	70.20	600	210.61	208.72	192.23	99.10	92.10	99
3	10/64"	70.07	1200	210.22	206.89	188.65	98.42	91.18	97
3	10/64"	70.08	1800	210.25	206.13	145.63	98.04	70.65	78
3	10/64"	70.05	2400	210.15	205.96	150.15	98.01	72.90	43.75
3	10/64"	70.05	3000	210.14	204.46	114.70	97.30	56.10	29.5
3	10/64"	70.09	3600	210.27	203.73	87.42	96.89	42.91	16

Clearance of hammers from from screen: 1/2"; Feed rate: 70 g/s; Number of hammers: 24

APPENDIX C-3
DATA FOR SHAFT SPEED AND FEED RATE EFFECT ON CHEAT SEED GERMINATION (CONT'D)

Rep #	Feed rate (g/sec)	Speed (rpm)	Speed Calculated (rpm)	Weight before test (g)	Weight after test (g)	Mt'l collected after test (%)	Weight after Cleaning (g)	Identifiable seeds recovered after cleaning (%)	Average germination of identifiable seeds (%)
1	50.00	1800	1815.94	150.00	137.08	91.39	110.38	80.52	35.75
1	50.00	2400	2414.64	150.01	139.14	92.75	83.05	59.69	21.5
1	50.00	3000	3013.34	150.00	136.75	91.17	74.58	54.54	13
1	50.00	3600	3612.04	150.01	133.84	89.22	58.72	43.87	6.75
1	70.01	1800	1815.94	210.02	200.68	95.55	154.12	76.80	40
1	70.00	2400	2414.64	210.00	196.47	93.56	140.63	71.58	23.5
1	70.00	3000	3013.34	210.01	191.29	91.09	117.38	61.36	12.25
1	70.01	3600	3612.04	210.02	191.57	91.22	87.56	45.71	8.5
1	85.00	1800	1815.94	255.00	218.96	85.87	169.66	77.48	46.5
1	85.01	2400	2414.64	255.03	220.63	86.51	184.85	83.78	22.75
1	85.01	3000	3013.34	255.02	222.71	87.33	145.52	65.34	12.25
1	85.01	3600	3612.04	255.02	240.64	94.36	117.83	48.97	12.75
2	50.08	1800	1815.94	150.25	143.93	95.79	91.29	63.43	47.25
2	50.01	2400	2414.64	150.02	141.31	94.19	79.10	55.98	19.5
2	50.03	3000	3013.34	150.09	140.69	93.74	55.13	39.19	19
2	50.07	3600	3612.04	150.21	139.32	92.75	41.21	29.58	6
2	70.05	1800	1815.94	210.15	193.69	92.17	125.58	64.84	39
2	70.04	2400	2414.64	210.12	200.40	95.37	112.19	55.98	24.75
2	70.00	3000	3013.34	210.00	195.38	93.04	80.42	41.16	17.5
2	70.08	3600	3612.04	210.24	197.64	94.01	59.03	29.87	20

APPENDIX C-3 (CONT'D)
DATA FOR SHAFT SPEED AND FEED RATE EFFECT ON CHEAT SEED GERMINATION (CONT'D)

Rep #	Feed rate (g/sec)	Speed (rpm)	Speed Calculated (rpm)	Weight before test (g)	Weight after test (g)	Mt'l collected after test (%)	Weight after Cleaning (g)	Identifiable seeds recovered after cleaning (%)	Average germination of identifiable seeds (%)
2	85.07	1800	1815.94	255.20	244.68	95.88	177.16	72.40	41.75
2	85.00	2400	2414.64	254.99	239.61	93.97	141.97	59.25	25.25
2	85.05	3000	3013.34	255.16	238.65	93.53	111.51	46.73	13.5
2	85.04	3600	3612.04	255.13	244.80	95.95	82.30	33.62	10.5
3	50.10	1800	1815.94	150.29	131.44	87.46	86.20	65.58	46.75
3	50.00	2400	2414.64	150.00	137.20	91.47	71.58	52.17	19.5
3	50.02	3000	3013.34	150.07	138.47	92.27	52.65	38.02	16
3	50.02	3600	3612.04	150.06	130.48	86.95	34.21	26.22	14.75
3	69.93	1800	1815.94	209.78	198.39	94.57	127.37	64.20	41
3	70.08	2400	2414.64	210.24	168.53	80.16	95.22	56.50	16.75
3	69.96	3000	3013.34	209.88	187.86	89.51	80.55	42.88	13.75
3	70.09	3600	3612.04	210.26	197.07	93.73	53.52	27.16	13.5
3	84.99	1800	1815.94	254.96	246.95	96.86	155.89	63.13	46.75
3	85.10	2400	2414.64	255.29	242.17	94.86	137.98	56.98	29.25
3	85.09	3000	3013.34	255.26	240.91	94.38	105.05	43.61	15
3	85.04	3600	3612.04	255.13	237.72	93.18	72.44	30.47	12.25

Screen Size: 8/64" Clearance of hammers from Screen: 1/2"
Number of hammers : 24

APPENDIX C-4

DATA FOR SHAFT SPEED AND NUMBER OF HAMMERS EFFECT ON CHEAT SEED GERMINATION

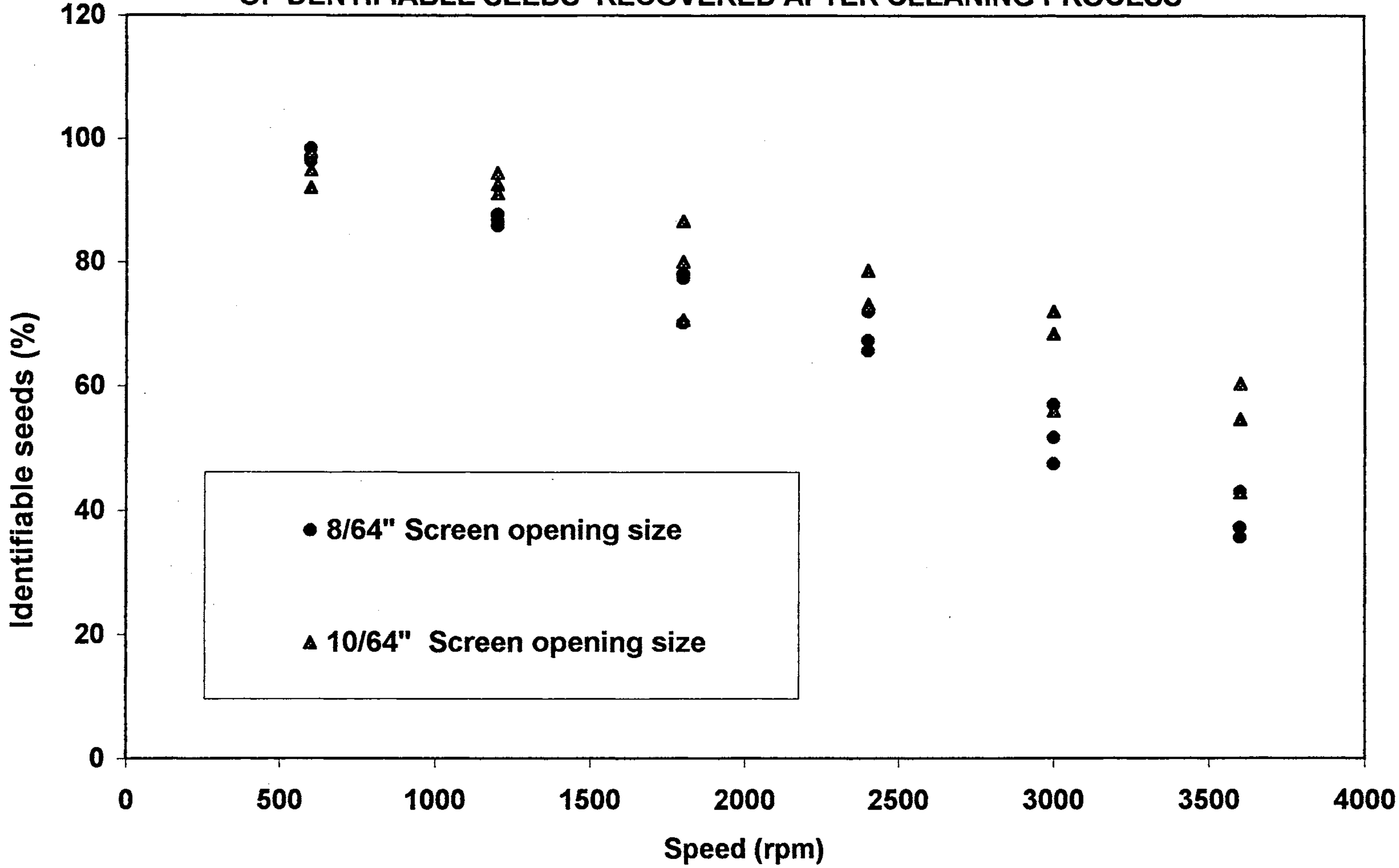
Rep #	# hammers	Feed rate (g/sec)	Speed (rpm)	Weight before test (g)	Weight after test (g)	Weight after cleaning (g)	Mt'l collected after test (%)	Identifiable seeds recovered after cleaning (%)	Average germination of identifiable seeds (%)
1	24	70.00	1800	210.01	202.36	149.22	96.36	73.74	30.75
1	24	70.01	2400	210.03	202.39	124.94	96.36	61.73	18.75
1	24	70.00	3000	210.01	199.86	101.93	95.17	51.00	16
1	24	70.01	3600	210.02	199.40	83.36	94.94	41.81	10.5
1	16	70.01	1800	210.02	200.05	152.90	95.25	76.43	41
1	16	70.00	2400	210.01	202.08	140.62	96.22	69.59	21.25
1	16	70.00	3000	210.00	202.47	116.12	96.41	57.35	13
1	16	70.01	3600	210.02	199.38	88.32	94.93	44.30	10.75
2	24	70.00	1800	210.01	187.49	137.56	89.28	73.37	26.75
2	24	70.12	2400	210.35	192.13	112.52	91.34	58.56	20.75
2	24	70.25	3000	210.74	186.19	86.25	88.35	46.32	5.75
2	24	70.25	3600	210.75	192.31	57.54	91.25	29.92	12
2	16	70.45	1800	211.35	198.60	142.21	93.97	71.61	41.25
2	16	70.12	2400	210.35	192.11	120.67	91.33	62.81	14.5
2	16	70.13	3000	210.38	197.32	98.80	93.79	50.07	11
2	16	70.01	3600	210.04	160.13	53.49	76.24	33.40	11
3	24	70.24	1800	210.71	194.21	137.69	92.17	70.90	33.5

APPENDIX C-4 (CONT'D)
DATA FOR SHAFT SPEED AND NUMBER OF HAMMERS EFFECT ON CHEAT SEED GERMINATION

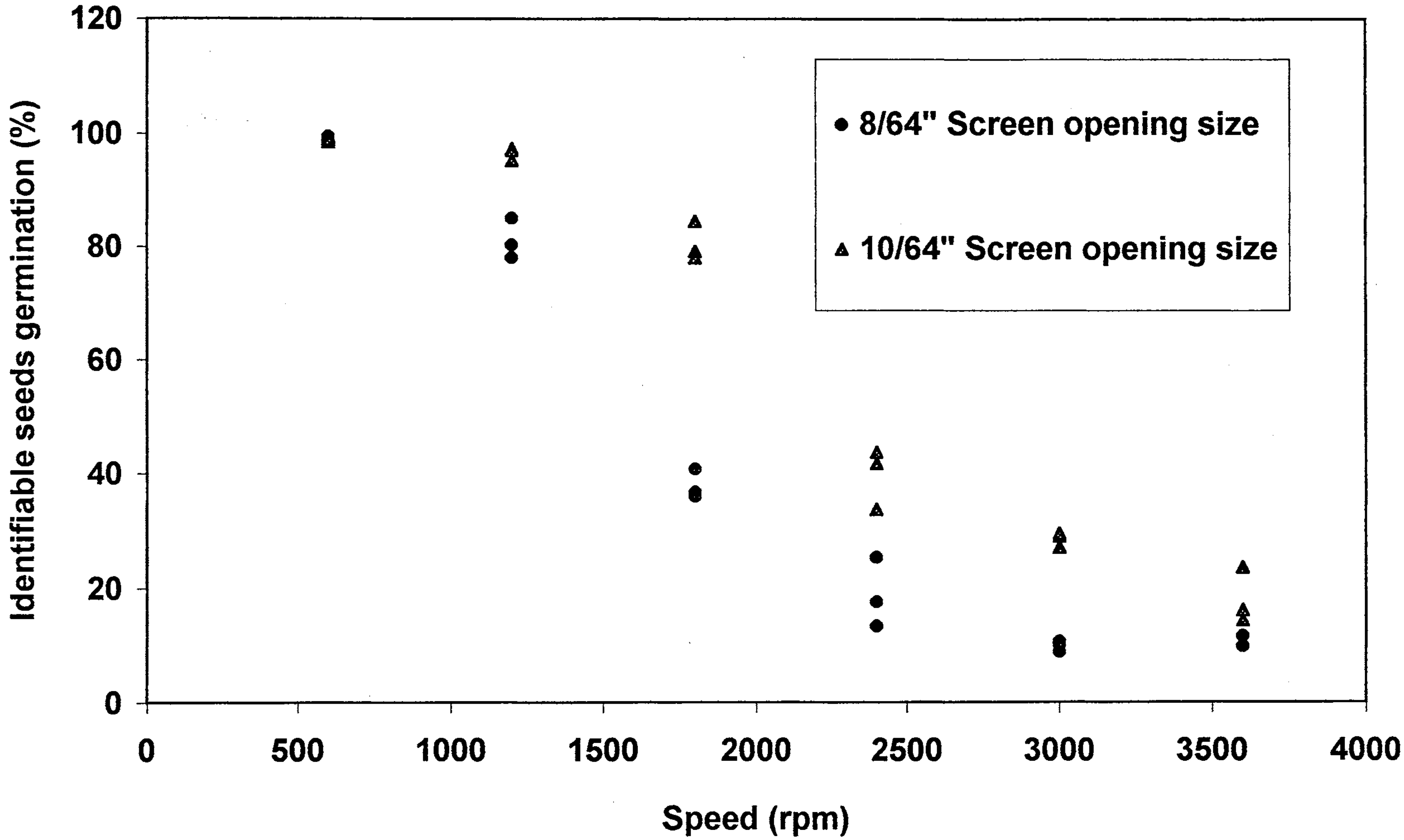
Rep #	# hammers	Feed rate (g/sec)	Speed (rpm)	Weight before test (g)	Weight after test (g)	Weight after cleaning (g)	Mt'l collected after test (%)	Identifiable seeds recovered after cleaning (%)	Average germination of identifiable seeds (%)
3	24	69.93	2400	209.80	195.28	119.58	93.08	61.24	12.75
3	24	70.12	3000	210.35	191.38	81.87	90.98	42.78	13.75
3	24	70.62	3600	211.86	186.38	49.99	87.97	26.82	10
3	16	70.18	1800	210.54	190.49	138.24	90.48	72.57	41.5
3	16	70.25	2400	210.76	185.78	118.65	88.15	63.87	22
3	16	70.28	3000	210.85	181.96	94.05	86.30	51.69	10.75
3	16	70.17	3600	210.50	192.58	63.90	91.49	33.18	10.75

Screen size; 8/64"; Clearance of hammers from screen: 1/2"; Feed rate 70g/s.

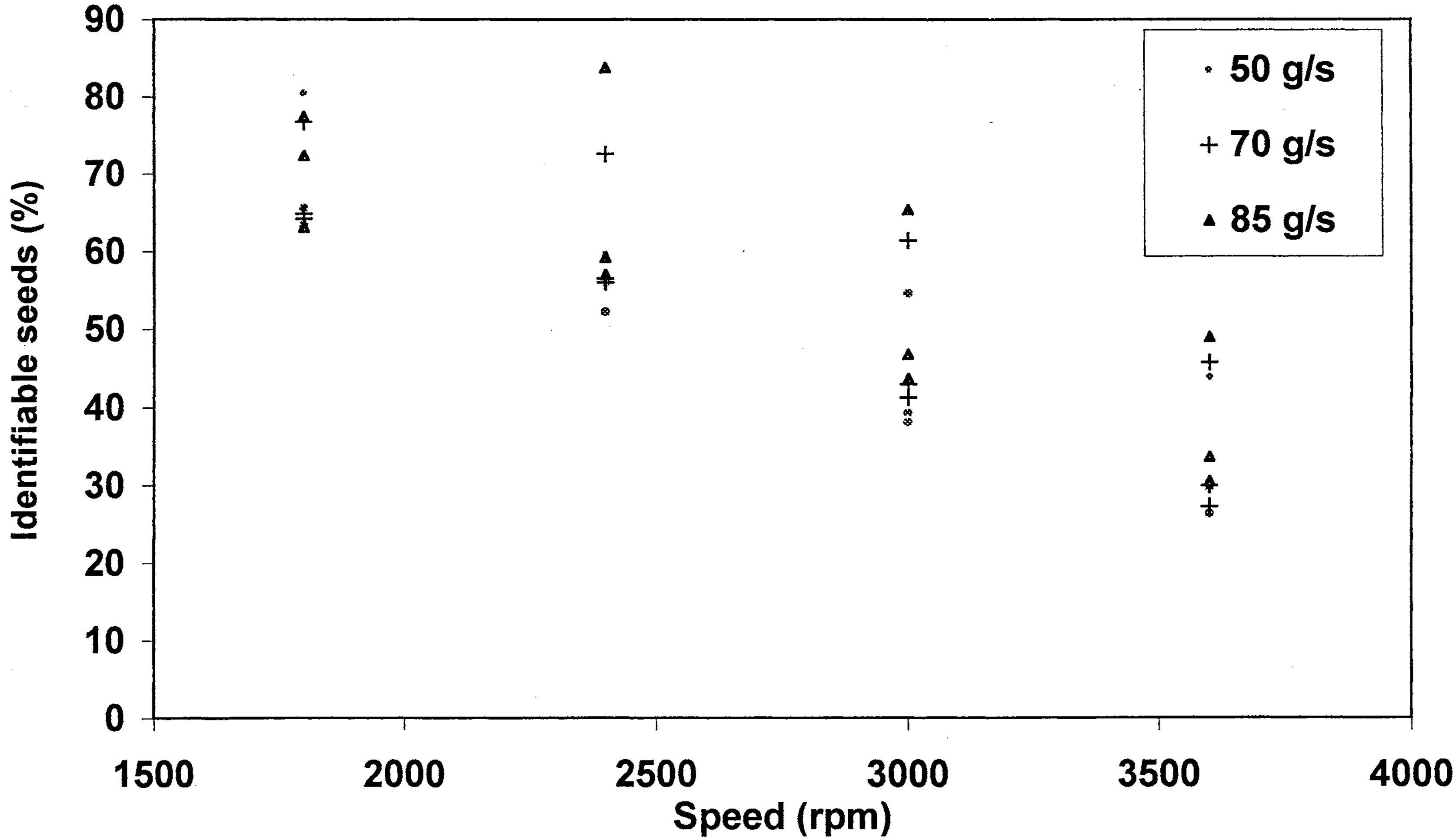
APPENDIX C-5A
EFFECT OF SHAFT SPEED AND SCREEN OPENING SIZE ON PERCENTAGE OF DENTIFIABLE SEEDS RECOVERED AFTER CLEANING PROCESS



APPENDIX C-5B
EFFECT OF SHAFT SPEED AND SCREEN OPENING SIZE ON GERMINATION OF IDENTIFIABLE CHEAT SEEDS

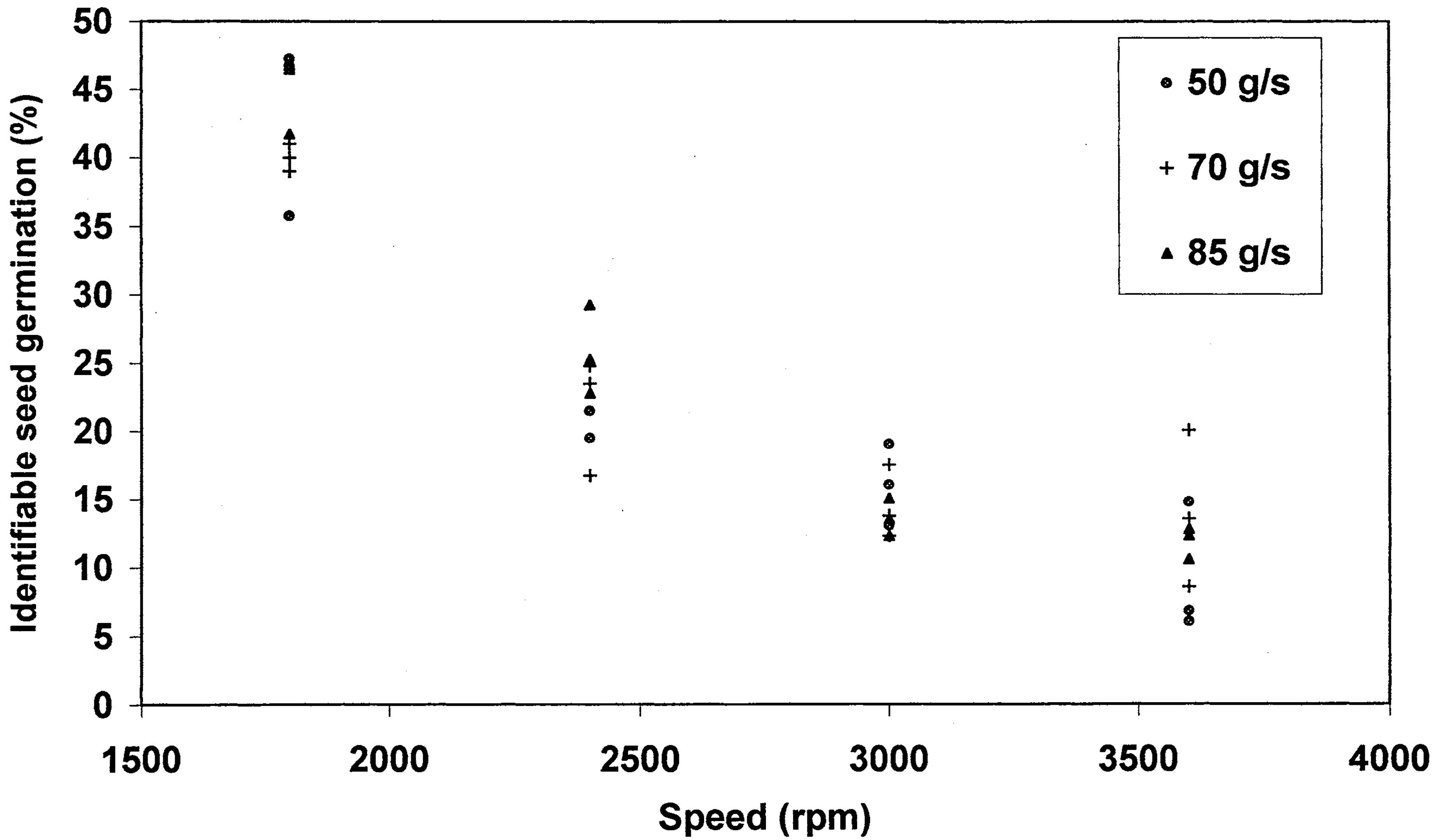


APPENDIX C-6A
EFFECT OF SHAFT SPEED AND FEED RATE ON PERCENTAGE OF IDENTIFIABLE SEEDS RECOVERED AFTER CLEANING PROCESS

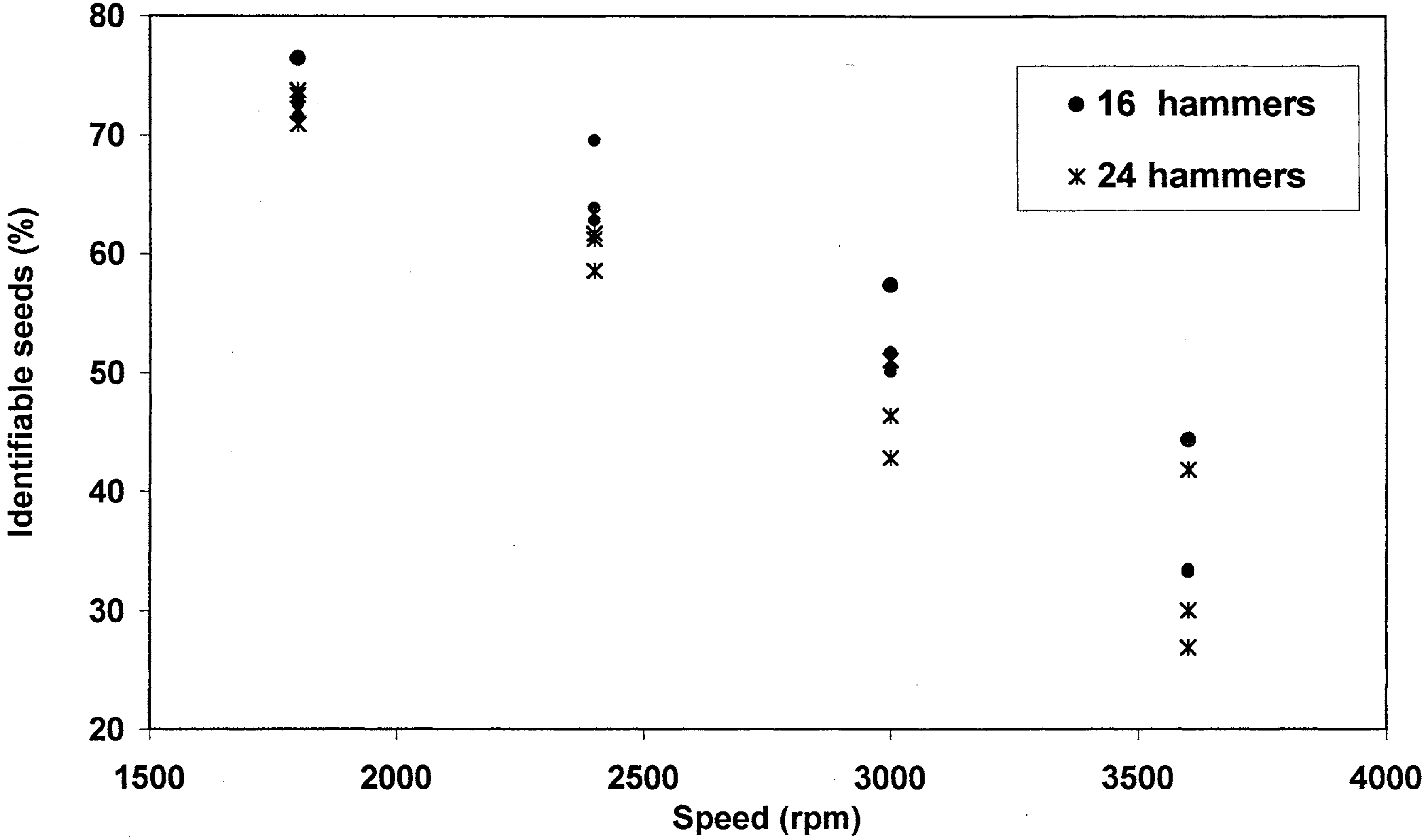


APPENDIX C-6B

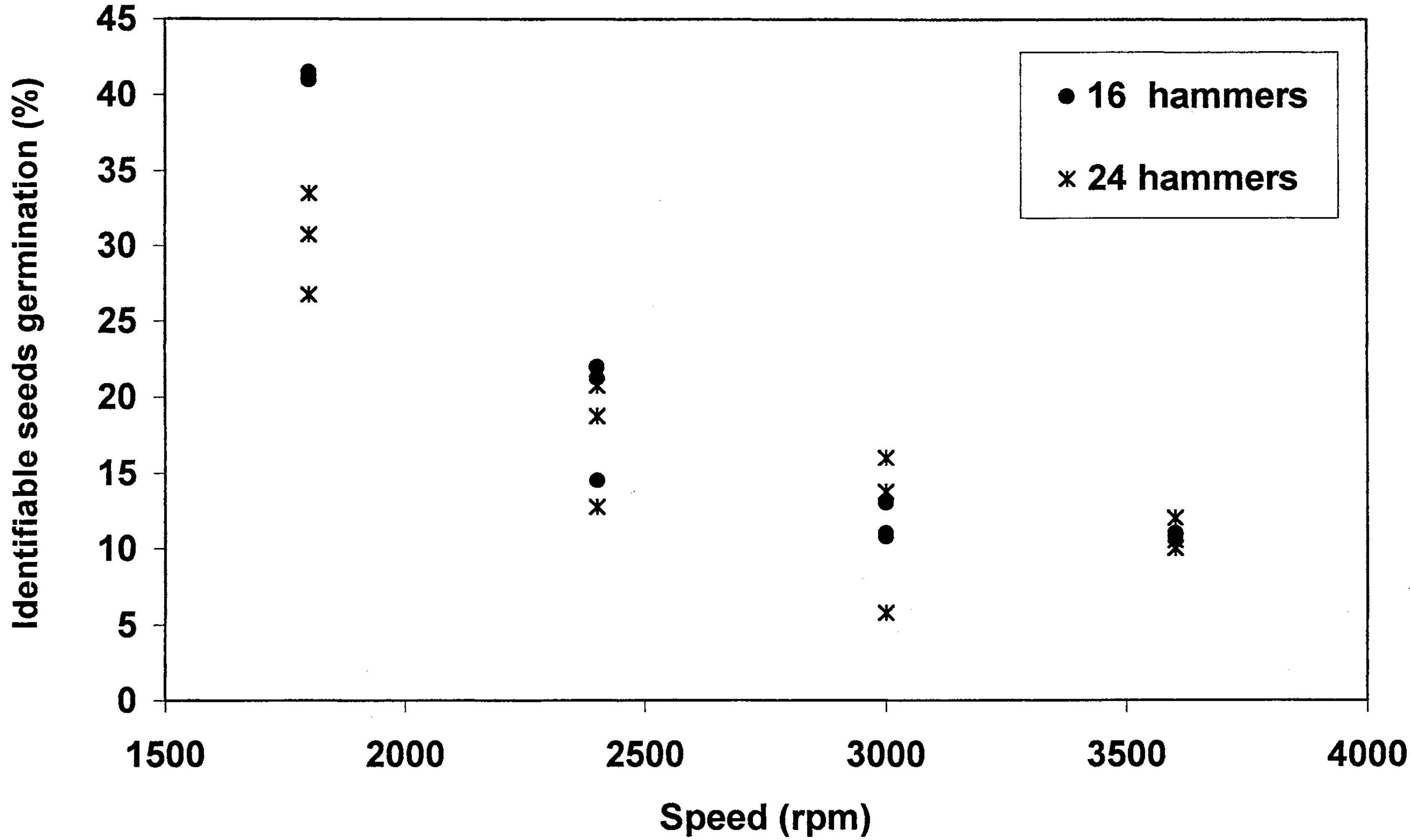
EFFECT OF SHAFT SPEED AND FEED RATE ON GERMINATION OF IDENTIFIABLE SEEDS



APPENDIC C-7A
EFFECT OF SHAFT SPEED AND NUMBER OF HAMMERS ON PERCENTAGE OF IDENTIFIABLE SEEDS RECOVERED AFTER CLEANING PROCESS



APPENDIX C-7B
EFFECT OF SHAFT SPEED AND NUMBER OF HAMMERS ON GERMINATION
OF IDENTIFIABLE CHEAT SEEDS



APPENDIX D

DATA FOR ROLL SPEED DIFFERENTIAL AND ROLL GAP EFFECT ON CHEAT SEED GERMINATION

APPENDIX D-1
DATA FOR ROLL SPEED DIFFERENTIAL AND ROLL GAP EFFECT ON CHEAT SEED GERMINATION

Roll Speed Differential: 1 : 1 ratio

Rep#	Roll gaps (mm)	Weight before test (g)	Weight after test (g)	Weight after Cleaning (g)	Mt'l collected after test (%)	Identifiable seeds recovered after cleaning (%)	Average germination of identifiable seeds (%)
1	0.1	100.21	99.88	91.52	99.67	91.63	6
1	0.2	100.12	99.80	96.97	99.68	97.16	14.75
1	0.4	100.89	100.41	95.15	99.52	94.76	71
1	0.6	100.39	99.96	97.97	99.57	98.01	76.25
1	0.9	100.35	100.04	98.30	99.69	98.26	90.25
2	0.1	100.21	99.66	95.58	99.45	95.91	11.25
2	0.2	100.66	100.31	95.94	99.65	95.64	13.5
2	0.4	99.69	99.51	96.01	99.82	96.48	65.75
2	0.6	100.50	100.21	98.38	99.71	98.17	88.5
2	0.9	99.99	99.74	98.78	99.75	99.04	95
3	0.1	100.31	99.79	93.79	99.48	93.99	12
3	0.2	100.59	100.10	96.08	99.51	95.98	16.5
3	0.4	100.84	100.28	97.97	99.44	97.70	69
3	0.6	100.19	99.66	98.13	99.47	98.46	88.5
3	0.9 mm	100.22	99.68	98.12	99.46	98.43	97.75

Roll Speed Differential: 1 : 1.1 ratio

Rep#	Roll gaps (mm)	Weight before test (g)	Weight after test (g)	Weight after Cleaning (g)	Mt'l collected after test (%)	Identifiable seeds recovered after cleaning (%)	Average germination of identifiable seeds (%)
1	0.1	100.51	100.00	91.46	99.49	91.46	3.75
1	0.2	100.35	99.86	91.65	99.51	91.78	7.75
1	0.4	101.54	100.40	95.81	98.88	95.43	28.5
1	0.6	100.50	98.13	93.39	97.64	95.17	59.75
1	0.9	100.00	99.17	96.17	99.17	96.97	90.25
2	0.1	100.74	100.34	96.29	99.60	95.96	9.25
2	0.2	100.47	100.26	96.18	99.79	95.93	15.25
2	0.4	100.43	99.72	97.60	99.29	97.87	37.25
2	0.6	100.95	100.53	98.25	99.58	97.73	73.25
2	0.9	100.53	99.90	98.62	99.37	98.72	95.75
3	0.1	100.51	100.20	95.84	99.69	95.65	12
3	0.2	100.09	99.89	96.80	99.80	96.91	20.75
3	0.4	100.54	100.18	98.10	99.64	97.92	38.75
3	0.6	100.49	100.34	98.77	99.85	98.44	82
3	0.9	100.74	100.24	98.69	99.50	98.45	97.75

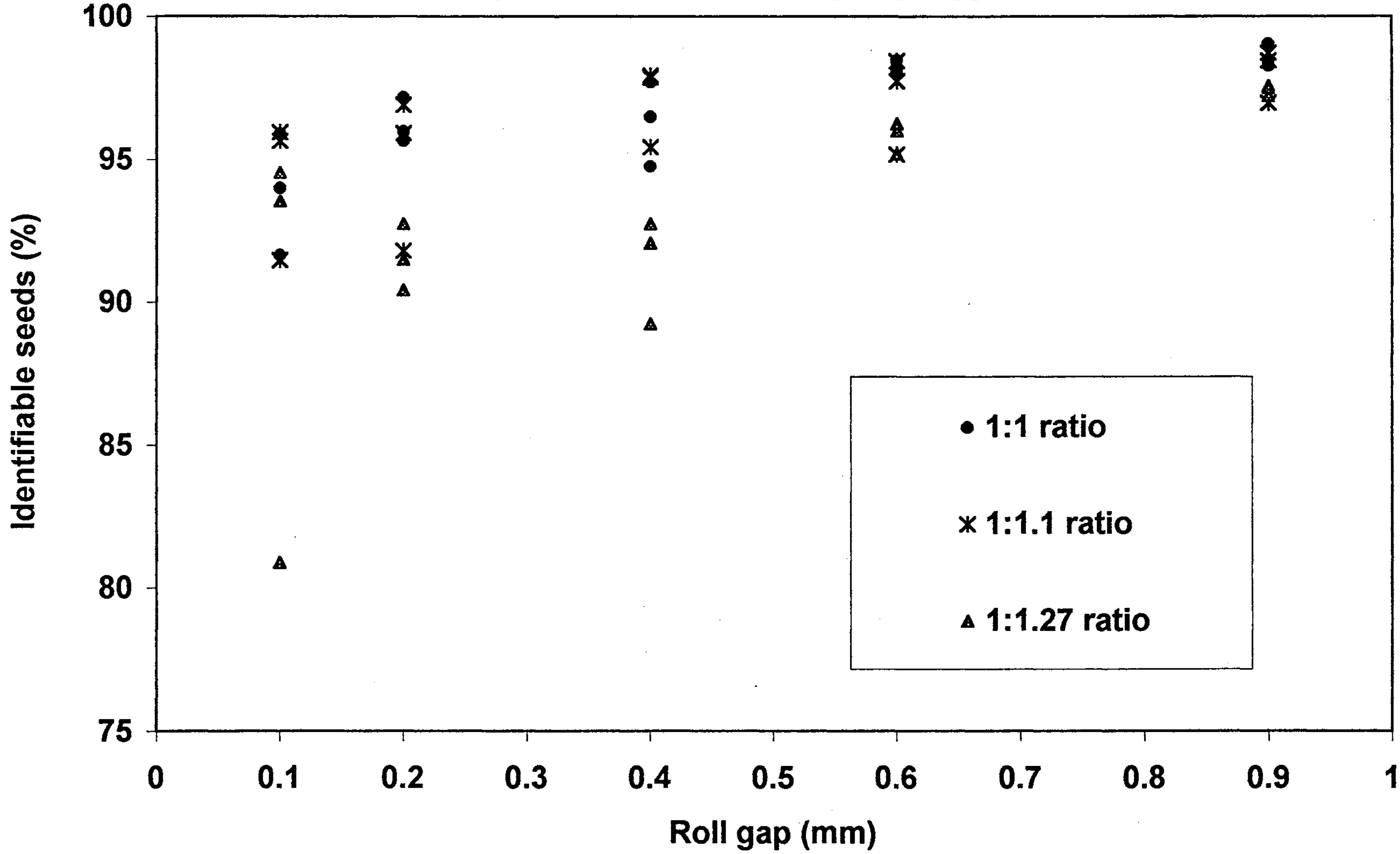
APPENDIX D-1 (CONT'D)
DATA FOR ROLL SPEED DIFFERENTIAL AND ROLL GAP EFFECT ON CHEAT SEED GERMINATION

Roll Speed Differential: 1 : 1.27 ratio

Rep#	Roll gaps (mm)	Weight before test (g)	Weight after test (g)	Weight after Cleaning (g)	Mt'l collected after test (%)	Identifiable seeds recovered after cleaning (%)	Average germination of identifiable seeds (%)
1	0.1	100.69	100.27	81.09	99.58	80.87	1.5
1	0.2	100.61	100.17	90.55	99.56	90.40	6
1	0.4	100.75	100.32	89.50	99.57	89.21	13.75
1	0.6	100.64	100.56	96.53	99.92	95.99	40
1	0.9	101.37	101.15	98.69	99.78	97.57	92.5
2	0.1	100.16	99.55	94.12	99.39	94.55	9.25
2	0.2	100.36	99.39	90.92	99.03	91.48	8.75
2	0.4	100.90	100.33	92.35	99.44	92.05	25
2	0.6	100.43	100.00	95.18	99.57	95.18	39.5
2	0.9	100.88	100.32	97.54	99.44	97.23	93.75
3	0.1	100.54	99.89	93.45	99.35	93.55	5.25
3	0.2	100.42	99.82	92.56	99.40	92.73	8
3	0.4	100.38	99.94	92.67	99.56	92.73	18.5
3	0.6	100.13	89.84	86.46	89.72	96.24	35.25
3	0.9	100.01	99.29	96.82	99.28	97.51	92.5

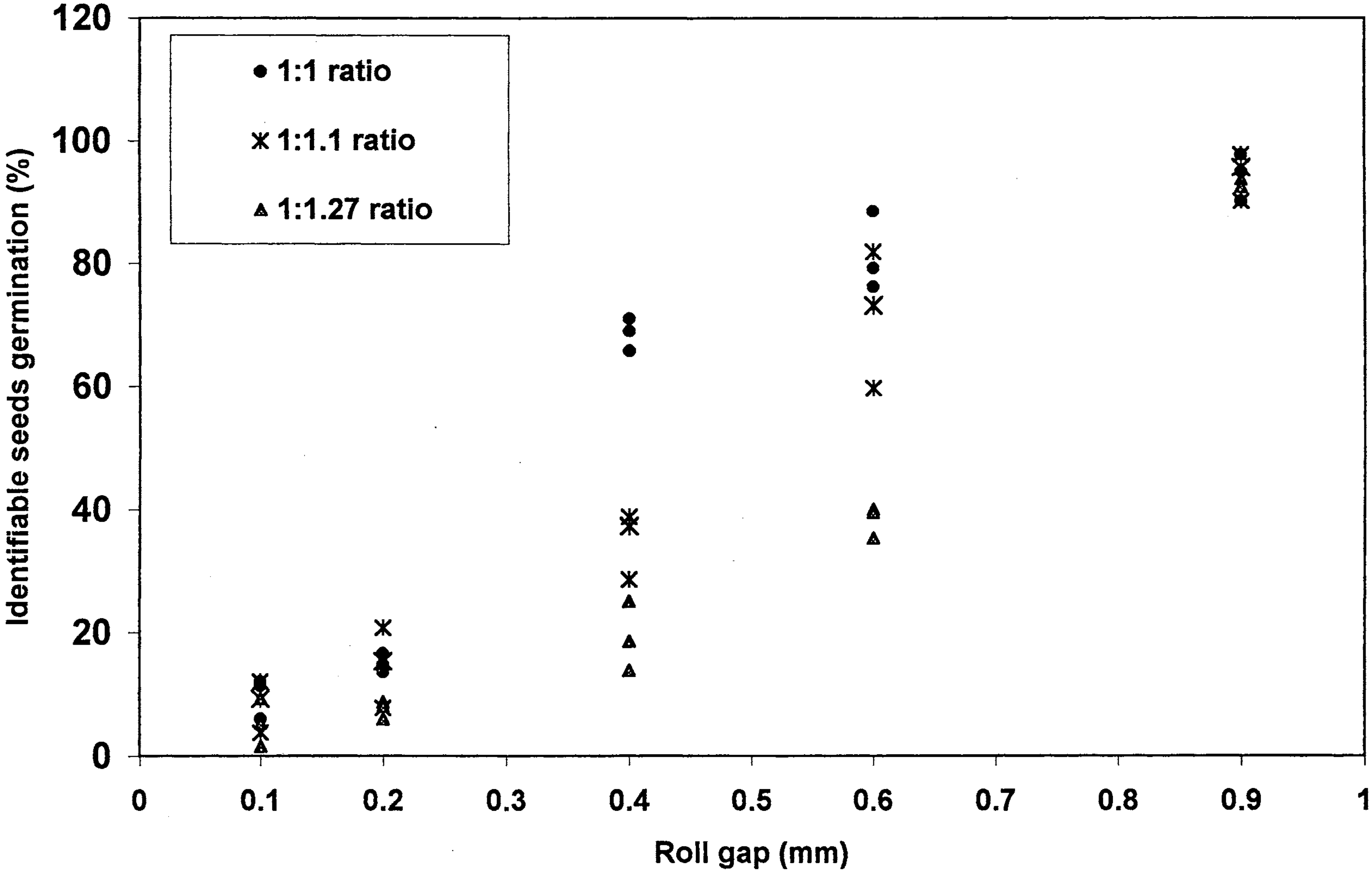
APPENDIX D-2

EFFECT OF ROLL SPEED DIFFERENTIAL AND ROLL GAP ON PERCENTAGE OF IDENTIFIABLE SEEDS RECOVERED AFTER CLEANING PROCESS



APPENDIX D-3

EFFECT OF ROLL SPEED DIFFERENTIAL AND ROLL GAP ON GERMINATION OF CHEAT SEEDS



APPENDIX E

DATA FOR DAMGE EVALUATION OF HAMMER AND ROLL MILLED CHEAT (*Bromus secalinus* L.) SEED

APPENDIX E-1
EFFECT OF SHAFT SPEED AND SCREEN OPENING SIZE ON HAMMER MILL DAMAGE CLASSES AND CALCULATED CHEAT SEED GERMINATION

Rep. #	Treatments	BRS	BRE	WPD	NAD	Measured Germination (%)	Calculated germination (%)
1	10HM8	0	0.34	0.11	99.54	98.75	99.00
2	10HM8	0.69	1.62	4.51	93.18	99.5	96.81
Mean	**10HM8**	**0.35**	**0.98**	**2.31**	**96.36**	**99.13**	**97.91**
1	20HM8	0.21	49.68	9.42	40.69	85	53.13
2	20HM8	0.76	52.32	4.31	42.61	80.25	50.59
Mean	**20HM8**	**0.49**	**51.00**	**6.87**	**41.65**	**82.63**	**51.86**
1	30HM8	0.2	81.25	5.86	12.7	36.75	24.69
2	30HM8	0.3	86.9	4	8.8	40.75	19.58
Mean	**30HM8**	**0.25**	**84.08**	**4.93**	**10.75**	**38.75**	**22.13**
1	40HM8	0.63	91	3.24	5.13	13.25	15.58
2	40HM8	1.41	89.06	4.59	4.94	25.25	16.47
Mean	**40HM8**	**1.02**	**90.03**	**3.92**	**5.04**	**19.25**	**16.02**
1	50HM8	2.32	93.32	1.69	2.67	8.75	11.92
2	50HM8	4.62	91.96	1.11	2.31	10.5	10.92
Mean	**50HM8**	**3.47**	**92.64**	**1.40**	**2.49**	**9.63**	**11.42**
1	60HM8	2.66	92.7	2.58	2.06	9.75	12.07
2	60HM8	6.56	91.61	0.82	1	11.5	9.33
Mean	**60HM8**	**4.61**	**92.16**	**1.70**	**1.53**	**10.63**	**10.70**
1	10HM10	0	1.12	0	98.88	98.5	98.31
2	10HM10	0.59	1.42	5.34	92.65	99.5	97.02
Mean	**10HM10**	**0.30**	**1.27**	**2.67**	**95.77**	**99.00**	**97.67**
1	20HM10	0	18.69	5.35	75.96	95.25	81.88
2	20HM10	0.45	24.92	6.37	68.27	97.75	75.69
Mean	**20HM10**	**0.23**	**21.81**	**5.86**	**72.12**	**96.50**	**78.79**
1	30HM10	0.1	62.62	6.36	30.91	79.25	41.69
2	30HM10	0.32	75.91	5.81	17.96	84.5	29.42
Mean	**30HM10**	**0.21**	**69.27**	**6.09**	**24.44**	**81.88**	**35.56**
1	40HM10	0.69	83.66	4.13	11.52	33.75	22.13
2	40HM10	0.2	73.83	7.4	18.56	41.75	31.30
Mean	**40HM10**	**0.45**	**78.75**	**5.77**	**15.04**	**37.75**	**26.72**
1	50HM10	2.75	89.08	2.04	6.13	27	15.32
2	50HM10	3.35	81.17	4.4	11.09	29	21.75
Mean	**50HM10**	**3.05**	**85.13**	**3.22**	**8.61**	**28.00**	**18.54**
1	60HM10	3.44	91.39	1.32	3.85	14.25	12.59
2	60HM10	5.87	82.68	3.35	8.1	23.5	17.95
Mean	**60HM10**	**4.66**	**87.04**	**2.34**	**5.98**	**18.88**	**15.27**

APPENDIX E-2
EFFECT OF SHAFT SPEED AND FEED RATE ON DAMAGE CLASSES AND CALCULATED CHEAT SEED GERMINATION

Rep. #	Treatment	BRS	BRE	WPD	NAD	Measured Germination (%)	d germination (%)
1	30HM150	0.1	78.96	5.7	15.23	35.75	26.86
2	30HM150	0.21	74	2.85	22.94	47.25	31.51
3	30HM150	0.79	88.45	4.44	6.32	46.75	17.65
Mean	**30HM150**	**0.37**	**80.47**	**4.33**	**14.83**	**43.25**	**25.34**
1	40HM150	0.68	91	2.25	6.07	21.5	15.61
2	40HM150	1.06	87.39	1.83	9.72	19.5	18.56
3	40HM150	1.29	88.76	5.16	4.79	19.5	16.81
Mean	**40HM150**	**1.01**	**89.05**	**3.08**	**6.86**	**20.17**	**16.99**
1	50HM150	2.97	91.45	1.12	4.46	13	13.02
2	50HM150	4.68	89.64	1.8	3.87	19	12.91
3	50HM150	4.04	90.07	1.32	4.57	16	13.20
Mean	**50HM150**	**3.90**	**90.39**	**1.41**	**4.30**	**16.00**	**13.04**
1	60HM150	7.09	85.54	2.36	5.01	6.75	12.59
2	60HM150	7.15	87.32	1.7	3.83	6	11.00
3	60HM150	4.25	92.22	1.81	1.72	14.75	11.00
Mean	**60HM150**	**5.70**	**89.77**	**1.76**	**2.78**	**9.17**	**11.79**
1	30HM210	0.28	68.33	11.07	20.33	40	35.96
2	30HM210	0.21	75.1	4.44	20.25	39	30.38
3	30HM210	0.4	72.16	13.57	13.87	41	32.14
Mean	**30HM210**	**0.30**	**71.86**	**9.69**	**18.15**	**40.00**	**32.83**
1	40HM210	0.48	89.58	3.06	6.88	23.5	17.04
2	40HM210	0.95	87.97	2.08	9	24.75	18.12
3	40HM210	0.84	91.59	1.4	6.17	16.75	14.98
Mean	**40HM210**	**0.76**	**89.71**	**2.18**	**7.35**	**21.67**	**16.71**
1	50HM210	1.95	93.31	0.65	4.09	12.25	12.38
2	50HM210	2.41	89.8	2.69	5.1	17.5	14.95
3	50HM210	3.2	91.99	2.85	1.96	13.75	12.16
Mean	**50HM210**	**2.52**	**91.70**	**2.06**	**3.72**	**14.50**	**13.16**
1	60HM210	5.8	88.03	1.93	4.24	8.5	13.27
2	60HM210	4.69	90.62	2.26	2.43	20	11.98
3	60HM210	4.1	92.05	2.18	1.66	13.5	11.26
Mean	**60HM210**	**4.86**	**90.23**	**2.12**	**2.78**	**14.00**	**12.17**

APPENDIX E-2 (CONT'D)
EFFECT OF SHAFT SPEED AND FEED RATE ON DAMAGE CLASSES AND CALCULATED CHEAT SEED GERMINATION

Rep. #	Treatment	BRS	BRE	WPD	NAD	Measured Germination (%)	Calculated germination (%)
1	30HM255	0.11	75.37	11.1	13.42	46.5	29.70
2	30HM255	0.1	82.69	2.4	14.81	41.75	23.74
3	30HM255	0.1	76	4.59	19.32	46.75	29.67
Mean	**30HM255**	**0.10**	**78.02**	**6.03**	**15.85**	**45.00**	**27.70**
1	40HM255	0.9	90.5	2.35	6.24	22.75	15.83
2	40HM255	0.58	89.21	0.97	9.23	25.25	17.43
3	40HM255	0.86	90.92	1.15	7.07	29.25	15.59
Mean	**40HM255**	**0.78**	**90.21**	**1.49**	**7.51**	**25.75**	**16.29**
1	50HM255	0.31	90.99	1.14	7.56	12.25	16.08
2	50HM255	1.95	91.09	1.19	5.77	13.5	14.36
3	50HM255	3.57	91.57	2.84	2.02	15	12.18
Mean	**50HM255**	**1.94**	**91.22**	**1.72**	**5.12**	**13.58**	**14.20**
1	60HM255	3.82	90.96	1.4	3.82	12.75	12.60
2	60HM255	4.22	90.39	0.54	4.85	10.5	12.79
3	60HM255	4.23	90.38	2.79	2.61	12.25	12.62
Mean	**60HM255**	**4.09**	**90.58**	**1.58**	**3.76**	**11.83**	**12.67**

	Mean Germination (%)
BRS: Broken seed	***0.2***
BRE: Seed with broken or missing embryo	***8.27***
WPD: Whole or partially dehulled seed with embryo present	***91.33***
NAD: Seed with no apparent damage	***99.33***

APPENDIX E-3
EFFECT OF SHAFT SPEED AND NUMBER OF HAMMERS ON DAMAGE CALSSES AND CALCULATED CHEAT SEED GERMINATION

Rep. #	Treatments	BRS	BRE	WPD	NAD	Measured Germination (%)	Calculated germination (%)
1	30HM16	0.2	82.12	8.58	9.09	41	23.66
2	30HM16	0.28	84.59	4.77	10.37	41.25	21.65
Mean	**30HM16**	**0.24**	**83.36**	**6.68**	**9.73**	**41.13**	**22.66**
1	40HM16	0.6	92.75	3.77	2.88	21.25	13.98
2	40HM16	1.56	91.83	2.84	3.76	14.5	13.93
Mean	**40HM16**	**1.08**	**92.29**	**3.31**	**3.32**	**17.88**	**13.95**
1	50HM16	1.69	98.21	3.28	2.88	13	13.98
2	50HM16	6.25	90.29	1.77	1.69	11	10.77
Mean	**50HM16**	**3.97**	**94.25**	**2.53**	**2.29**	**12.00**	**12.38**
1	60HM16	4.22	90.08	1.1	4.59	10.75	13.02
2	60HM16	4.68	90.72	1.73	2.86	11	11.93
Mean	**60HM16**	**4.45**	**90.40**	**1.42**	**3.73**	**10.88**	**12.48**
1	30HM24	0	81.56	2.43	16.01	30.75	24.87
2	30HM24	0.17	88.72	2.43	8.68	26.75	18.18
Mean	**30HM24**	**0.09**	**85.14**	**2.43**	**12.35**	**28.75**	**21.52**
1	40HM24	0.38	87.81	2.11	9.69	18.75	18.81
2	40HM24	2.19	89.42	1.46	6.93	20.75	15.62
Mean	**40HM24**	**1.29**	**88.62**	**1.79**	**8.31**	**19.75**	**17.22**
1	50HM24	1.3	92.12	1.67	4.92	16	14.03
2	50HM24	6.25	90.71	0.87	2.17	5.75	10.46
Mean	**50HM24**	**3.78**	**91.42**	**1.27**	**3.55**	**10.88**	**12.25**
1	60HM24	4.46	91.96	2.5	1.07	10.5	10.96
2	60HM24	8.79	86.86	1.09	3.26	12	11.43
Mean	**60HM24**	**6.63**	**89.41**	**1.80**	**2.17**	**11.25**	**11.20**

APPENDIX E-4
EFFECT OF ROLL SPEED DIFFERENTIAL AND ROLL GAP ON DAMAGE CLASSES AND CALCULATED CHEAT SEED GERMINATION

Rep. #	Treatments	BRS	DPCK	SHCK	THMRK	NAD	Measured germination (%)	Calculated germination (%)
1	1RM0.4	3.63	27.78	28.34	21.09	19.16	71.00	38.79
2	1RM0.4	0.69	48.39	33.53	7.95	9.45	65.75	28.53
3	1RM0.4	0.65	64.67	21.74	7.50	5.43	69.00	23.52
Mean	**1RM0.4**	**1.66**	**46.95**	**27.87**	**12.18**	**11.35**	**68.58**	**30.28**
1	1RM0.1	2.51	48.15	25.21	11.47	12.66	6.00	30.09
2	1RM0.1	1.26	54.08	30.77	5.74	8.15	11.25	26.13
3	1RM0.1	1.42	60.18	26.15	7.99	4.27	12.00	23.87
Mean	**1RM0.1**	**1.73**	**54.14**	**27.38**	**8.40**	**8.36**	**9.75**	**26.70**
1	1.1RM0.4	0.59	33.81	31.68	13.24	20.69	28.50	37.23
2	1.1RM0.4	0.91	54.29	26.74	8.57	9.49	37.25	27.41
3	1.1RM0.4	3.04	73.07	14.55	5.54	3.80	38.75	19.90
Mean	**1.1RM0.4**	**1.51**	**53.72**	**24.32**	**9.12**	**11.33**	**34.83**	**28.18**
1	1.1RM0.1	3.32	52.29	30.32	6.41	7.75	3.75	25.86
2	1.1RM0.1	3.54	67.37	20.91	4.54	3.65	9.25	20.61
3	1.1RM0.1	1.99	71.08	19.65	4.30	2.98	12.00	20.04
Mean	**1.1RM0.1**	**2.95**	**63.58**	**23.63**	**5.08**	**4.79**	**8.33**	**22.17**
1	1.27RM0.4	9.71	57.03	23.77	4.25	5.23	13.75	21.25
2	1.27RM0.4	3.73	60.34	25.27	3.84	6.82	25.00	23.05
3	1.27RM0.4	6.75	70.24	17.13	4.39	1.50	18.50	18.09
Mean	**1.27RM0.4**	**6.73**	**62.54**	**22.06**	**4.16**	**4.52**	**19.08**	**20.80**
1	1.27RM0.1	15.92	49.22	27.73	3.56	3.56	1.50	19.99
2	1.27RM0.1	13.69	61.62	17.74	3.42	3.53	9.25	18.14
3	1.27RM0.1	9.75	67.06	17.66	3.25	2.28	5.25	17.79
Mean	**1.27RM0.1**	**13.12**	**59.30**	**21.04**	**3.41**	**3.12**	**5.33**	**18.64**

VITA

Marilyne HAUHOUOT

Candidate for the Degree of

Doctor of Philosophy

Dissertation: **MECHANICALLY DEVITALIZING CHEAT (*Bromus secalinus* L.) SEED TO REDUCE GERMINATION**

Field of Study: Biosystems Engineering

Biographical:

Personal: Born on December 9, 1971 in Adzopé, Côte d'ivoire, to Hauhouot Assomoa Diambra Odi Appolinaire Denis and Mambo Kousso Mathilde.

Education: 1989 Honor Graduate from Lycée Sainte Marie D'Abidjan, Côte D'ivoire (C.I). Nov. 1991 DUES (University diploma in Sciences) Univeristy of Abidjan, (C.I). Nov. 1993 MST –E.M Master of Sciences and Technology - Major Electromechanics (Electrical/mechanial engineering) with Honors, Univeristy of Abidjan, (C.I). Completed the Requirements for the Doctor of Philosophy degree at Oklahoma State University in July, 1998.

Experience: Oct 1995 – present: Graduate Research Assistant, Dr. John B. Solie OSU. Responsibilities: Design, implementation, and analysis of equipment to devitalize weed seeds during harvest. Duties include: Experimental design, laboratory and field germination tests, analysis of anatomical effect of damaged seeds, image analysis of damaged seeds using machine vision, data management, statistical analysis and evaluation of data, laboratory analysis, preparation of articles for publication in professional journals, coordinating activities for undergraduate project assistants. Jul - Dec. 1993: Internship at Ivorian Metallic Packaging Corporation, CarnaudMetalBox , (C.I). Responsibilities: Create process diagrams and maintenance files for three plants, implement TQM (total quality management) techniques for one plant, modify workplace design to reduce human fatigue and improve productivity. Jul. - Sept. 1991: Internship at the technical services of the University Teaching Hospital of Yopougon, Abidjan – (C.I). Responsibilities: Assist technicians in maintaining and repairing medical equipment.

Professional Memberships: Alpha Epsilon Honor society of Agricultural Engineers, Gamma Sigma Delta Honor society of Agriculture, American Society of Agricultural Engineers (ASAE), Society of Women engineers (SWE), Institute of Food Technologists (IFT)