The Effects of Mechanical Damage to Maize (*Zea mays* L.) Seed on Germination, Seedling Morphology and Subsequent Grain Yield

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ABSTRACT

Mechanical damage is one of the main factors responsible for decreased seed quality. A series of experiments was undertaken with maize (*Zea mays* L.) to determine; (i) the total and types of damage caused during mechanical harvesting, seed processing and planting, and (ii) the effects of the resultant damage on germination, seedling development and morphology, plant development and grain yield. Mechanised harvesting, seed processing, and mechanised planting caused a large proportion (89%) of damaged seed through damage to the seed coat, endosperm, and embryo. This affected germination, seedling development, susceptibility to disease, plant growth and development, and grain yield. Results also show the significance of the site of damage for germination rate and seedling quality. The embryo, specifically the central part of the embryo, was most sensitive to mechanical damage.

Additional index words: **abnormal seedlings, embryo damage, processing, seedling growth, seed quality.**

INTRODUCTION

Mechanical damage is one of the main factors responsible for reducing seed quality (Chazov, 1967; Stron, 1972). Mechanisation of harvest and post-harvest procedures for grain crops increases the incidence of mechanical damage to seed. For the USSR, mechanical damage was reported as high as 85-90% for rye, 48-60% for soft wheat, and up to 100% for hard wheat (Stron, 1980).

Assessment of the germination of wheat and barley has shown that germination after whole-crop harvesting may be reduced by up to 20% compared with hand-harvested or combined grain (Anon., 1979). Raju, Hsiao and McIntyre (1988) found that mechanical damage to the seed coat of wild oats affected seed dormancy. Oatout (1928) and Dongre (1978) found a negative effect of threshing on soybean seed quality, and Park and Webb (1959) found excessive soybean seed damage due to poor adjustments of the combine. A major factor determining mechanical damage during harvest of wheat and barley was found to be grain moisture content (Arnold and Jones, 1963). Lines and cultivars of snap beans resistant to mechanical damage germinated 60-80% compared to under 20% for several major cultivars (Dickson and Boettger, 1976).

For maize, mechanical damage has been reported to be as high as 90-95% (Stron, 1980; Kaliuzhnyi and Litvinenko, 1985). During processing, the seed can be exposed to damage during drying, cleaning, sizing, storage and transport. Tatum and Zuber (1943) found that the relative frequency of damage types varied greatly among samples of commercial maize seed; most of the damage to maize seed occurred during shelling and subsequent operations in processing.

The research work reported in this paper investigated the effects of mechanical damage on maize seed. A series of experiments was undertaken with the objective of determining; (i) the total and types of damage caused during mechanical harvesting, seed processing and planting, and (ii) the effect of the resultant damage on germination, seedling development and morphology, plant development and grain yield.

MATERIALS AND METHODS

Field trials were carried out in 1981 on the Kuban Experimental Farm in Krasnodar (45.02°N, 30.00°E), USSR. Mean annual rainfall is 600 mm and the coldest and warmest months are January and July with mean ambient temperatures of -5.0°C and 23.4°C respectively. The soil type is a chernozem characterised by black colouration, crumbly structure and high humus content to a depth of 120-180 cm. Soil pH is 7.5-8.0. Cultural practices used in the field trials were those typical for the southern zone of the Krasnodar district.

Seed of maize hybrid Krasnodar 303 (a single cross, flint type) was used in all experiments. The seed was obtained from a single Government certified field on a seed production farm. Before machine harvesting the crop using a picker (picks cobs and removes husks), cobs were harvested by hand at random for the purpose of having seed free of possible damage caused by mechanical harvesting. The moisture content of the seed at harvest was 25%. The hand and mechanically harvested cobs were transported immediately to a commercial seed processing factory to be processed separately. Before processing the hand harvested cobs, a randomly selected 200 were retained to be sun dried and hand shelled to obtain a control seed sample free of possible damage due to either mechanical harvesting or processing.

The processing sequence in the factory was: (i) hand sorting of cobs, (ii) drying at 40°C in bins for 50-60 hours, (iii) shelling at 12-14% moisture content using a cylinder

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type sheller, (iv) short term uncontrolled storage of shelled seeds in silos, (v) sizing using a combined air screen and cylinder separator, (vi) chemical treatment using a rotating drum, (vii) mechanical bagging, and (viii) storage. Seed flow from one stage of processing to the next was carried out using conveyor belts.

A series of 6 co-ordinated experiments were then undertaken with the following objectives:

Experiment 1: to estimate the total and types of damage to seed during mechanical harvesting, seed processing and planting.

Experiment 2: to determine the extent of damage caused during each separate stage of seed processing.

Experiment 3: to determine the effects of damage to different parts of the maize seed on (a) seed water uptake, (b) shoot extension and (c) root extension.

Experiment 4: to determine the effects of type of seed damage on first, final and field germination counts.

Experiment 5: to determine the effects of damage to specific parts of the embryo on (a) germination, and (b) morphology (seedling type) of the resulting seedlings.

Experiment 6: to determine the effects of seedling type on survival, plant height, and grain yield.

Measurements

Plant survival (%) - Counts of plant survival were made at the following stages of development: 5 leaves fully expanded, 8 leaves fully expanded, tassel emergence and physiological maturity (Ritchie, Hanway and Benson, 1986). Initiation of each stage of development was considered to be when 10% of the plants began to show characteristics of the respective stage.

Plant height (cm) - This was measured at the following stages of development: 5 leaves fully expanded, 8 leaves fully expanded, tassel emergence and anthesis (Ritchie et al., 1986). Height was measured from the soil surface at the base of each plant to the tip of the highest leaf. After tassel emergence, plant height was measured from the soil surface at the base of the plant to the top of the tassel.

Grain yield - Harvesting was carried out at physiological maturity. Each replicate was harvested by hand separately, dried at room temperature and shelled by hand to obtain the grain yield per replicate. The results are expressed as kilograms per hectare (kg ha^{-1}) at 14% moisture content.

Germination tests - For field germination, the seeds were planted by hand to a depth of 3 cm. The field was watered on the 1st and 3rd day after planting. Seedling counts were made on the 7th day. The proportion of the number of seedlings produced in the field to the number of seeds planted is defined as field germination and is expressed as a percentage.

Laboratory germination (first and final germination counts) was carried out in a germination chamber at 27°C in darkness. Germination trays or petri dishes with 3 layers of sterilised filter paper as a substrate at 60% moisture content were used. First and final germination counts were carried out on the 3rd and 7th days of germination respectively.

Experiments

Experiment 1: Seed damage and damage type. Seed from the mechanically harvested and processed cobs was passed through a maize planter (horizontal plate). The moisture content of the seed was 12%. Representative samples of seed flowing from the drills of the planter were obtained and combined into 4 bulk samples (1 kg per sample). Four replicate subsamples, each containing 100 seeds were taken from each bulk sample. Seeds in each replicate subsample were examined for the presence of mechanical damage (see Table 1) using a magnifying glass (x7) and separated into damaged and undamaged categories. Seeds with insect damage were not included in the mechanical damage group. They were counted as normal (undamaged) seeds. Seeds within the damaged category were further divided according to damage type (Table 1). Total seed damage (%) and damage according to type (%) were recorded.

Table 1. Damage (%) to maize seed during mechanical harvesting, seed processing, and planting.

Type of damage	Damage (%)	s.e.d
broken embryo	7	0.67
embryo with tissue damage	28	0.65
deep damage to seed coat over-laying embryo	12	1.53
surface damage to seed coat over-laying embryo	10	1.20
damage to seed coat over-laying embryo and endosperm	22	0.87
damage to tissue of embryo and endosperm	2	0.85
damage to endospermal tissues	8	0.79
Total damage	89	0.50

Experiment 2: Seed damage during separate stages of processing. Seed was sampled after undergoing the following processing treatments conducted under normal operating conditions in a commercial seed processing factory: drying, shelling, after storage of shelled seed in silos prior to sizing, sizing (seed was sized into 6 grades based on kernel width, thickness and length, and each grade was processed separately), chemical treatment, and bagging. To exclude any damage that might have taken place during mechanical harvesting, cobs that were hand harvested (25% moisture content) were used. A control seed sample (hand harvested, hand shelled and sun dried to 12% moisture content) was retained for subsequent analysis. Representative samples of seed were obtained after each separate stage of processing and combined into 4 bulk (1 kg) samples (4 bulk samples for each stage of processing). Four replicate subsamples, each containing 100 seeds were taken from each bulk sample and inspected for seed damage using a magnifying glass (x7) as in Experiment 1. Total seed damage (%) for each stage of processing was recorded.

Experiment 3: Effects of seed damage on water uptake, shoot extension and root extension. From Experiment 1, damage was partitioned into seven types (Table 1). Two replicates (10 seeds per replicate) of each type of damage were used in experiments a), b) and c) below. The described procedure for seed germination was the same for all three experiments.

(a) Seed water uptake - each seed was reweighed at 2 hourly intervals during the first 24 hours of germination. The uptake of water per seed was calculated as percentage increase in moisture content per two hours [(wet weight - dry weight)/ dry weight) x 100)], and recorded as the mean of 10 seeds.

(b) Rate of shoot and (c) root extension - lengths of the shoot and root were each measured at 24 hour intervals during the first 7 days of germination. The extension per 24 hours was recorded as the mean of 10 seeds.

Experiment 4: Effects of type of seed damage on first, final (laboratory) and field germination counts. First, final (laboratory) and field germination experiments were conducted using seed from the damage types identified in Experiment 1 (broken embryo, embryo with tissue damage, deep damage to seed coat over-laying embryo, surface damage to seed coat over-laying embryo, damage to seed coat over-laying embryo and endosperm, damage to tissue of embryo and endosperm, and damage to endospermal tissues). The same number of replicates (4) and seeds per replicate (100) were used in all three experiments. The temperature of the soil at planting was 12°C (at 3 cm depth).

Experiment 5: Effects of damage to specific parts of the embryo on (a) germination and (b) seedling morphology.

a) In order to study the effects of damage to specific parts of the embryo, damage was artificially induced in undamaged seeds by stabbing with a sterilised needle. The following types of damage were induced: damage to upper area of the embryo, damage to lower area of the embryo, damage to central part of the embryo, damage to one side of the embryo, damage to both lateral sides of the embryo, and damage to all areas of the embryo. Each type of embryo damage had 4 replicates consisting of 100 seeds each. Undamaged seeds were used as a control. First, final (laboratory) and field germination counts were made. The temperature of the soil at planting was 12°C (at 3 cm depth).

b) In order to identify and group different types of seedlings that germinated from seeds with damaged embryos, the embryos of undamaged seeds were artifically damaged as in (a), and germinated (4 reps x 100 seeds per damage type). The resulting seedlings were assessed and grouped according to their morphology (based on shoot, root, coleoptile characteristics and susceptibility of seedlings to infections by bacteria and fungi) using methods developed by Wellington (1973) and Haroshilov and Lihachev (1973). Seedling abnormality types and number of seedlings per type according to the site of embryo damage were recorded.

Experiment 6: Effects of seedling morphological type on survival, plant height, and grain yield. In order to have sufficient numbers of the seedling abnormality types identified in Experiment 5b, damage was induced in undamaged seed by stabbing with a sterilised needle prior to germination. The resulting seedlings were then sorted and grouped using the methods described in Experiment 5b. These seedlings (10 days after germination), together with normal seedlings (the control), were planted by hand in the field (24 cm within rows and 70 cm between rows, 3 cm depth). The temperature of the soil at the planting depth was 15°C. The experimental layout was a randomised complete block consisting of 4 replications per treatment (seedling type) and 100 seedlings per replication. Plant survival, plant height and grain yield were recorded using the methods previously described.

Statistical analysis. Statistical analysis of data collected was carried out according to methods described by Dospehov (1979) for analysis of variance and least significant difference (lsd) determination.

RESULTS AND DISCUSSION

Seed damage and damage type (Experiment 1) - The total level of seed damage due to harvesting/seed processing/ planting was 89% (Table 1), comprising 34% damaged embryos, 2% damaged endosperm and embryo, and 52% damaged pericarp and endospermal tissues. Comparable results were reported for rye (85-90%), hard wheat (up to

100%) and maize (90-95%) (Stron, 1980).

Seed damage during separate stages of processing (Experiment 2) - Each stage of processing caused damage (Table 2). The stages that resulted in greatest damage were shelling (21%) and sizing (21-36% depending on grade). Similar observations were made by Kaliuzhnyi and Litvinenko (1984) where shelling and sizing of maize seeds resulted in 29 and 31% damage respectively. Cold test performance results showed that as much damage occurred in shelling as in all other handling operations (Newlin, 1977). Tatum and Zuber (1943) recorded a much lower level of damage after shelling (4%). This may be due to different processing equipment, a higher seed moisture content, and the hybrid Iowa 939 used by these authors being more resistant to mechanical damage. Drying, chemical treatment and bagging brought about damage of 6%, 5-15% and 2-11% respectively. These results are consistent with those reported for other cereals (Ulric, 1958; Pugachev 1976).

Table 2. Mechanical damage (%) to maize seed after different stages of seed processing.

Stage of processing	**Damage (before sizing)** (%)	**s.e.d**
undamaged unprocessed seed (control)	2	0.63
drying	8	1.00
shelling	29	0.75
storage in silo after shelling	37	0.65

	Damage after sizing (%) / (s.e.d)					
	1[1]	2	3	4	5	6
Sizing	64 (1.19)	58 (0.29)	62 (0.85)	73 (0.85)	69 (0.87)	65 (1.89)
Chemical treatment	72 (1.47)	63 (1.03)	67 (1.70)	79 (0.48)	84 (0.65)	75 (0.86)
Bagging	70 (1.00)	74 (0.85)	63 (1.20)	82 (1.79)	82 (0.87)	84 (0.63)

[1] size grades

Effect of seed damage on water uptake, shoot extension and root extension (Experiment 3) - Damaged seeds imbibed water more readily than undamaged seed (Fig. 1). In particular, seeds with damage to the endosperm and seed coat (pericarp) overlaying the endosperm and embryo, had the highest rates of water uptake and also exhibited rapid initial shoot extension (Figs. 1, 2). The rate of root extension of seeds with damage to the seed coat overlaying the endosperm and embryo was higher than that of normal seeds during the first 6 days (Fig. 3). However, shoot and root extension of undamaged seeds were higher than the damaged seeds after the 6th day of germination. Figures 2 and 3 show two damage type groups, one group with higher root extension and shoot length (closer to the control) in relation to the other. In both figures the higher group contains the same damage types (6, 8 and 5) without direct damage to the embryo, and the lower group consists of damage types 2, 3,4 and 7, with direct injury to the embryo. This indicates the importance of protecting the embryo from damage.

Seed germination can be divided into five basic stages: imbibition, swelling, emergence of the radicle, development of the shoot and seedling establishment (Stron, 1966). The functions of the seed coat are regulation of water movement and protection of the embryo and endosperm (Chazov, 1967). Accordingly, the increase in the rate of water uptake by damaged seeds in comparison to the undamaged seeds is presumably due to the influx of water into the seed as a result of seed coat damage (Taylor and Dickson, 1987).

Effect of type of seed damage on first, final (laboratory)

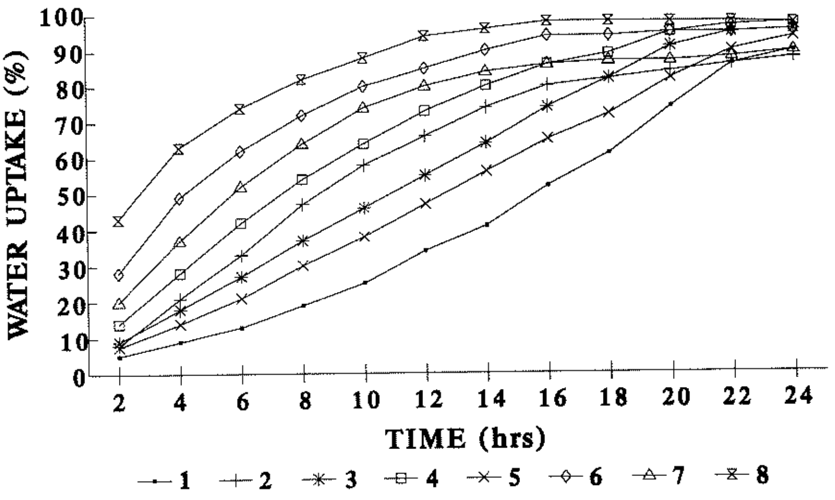

Figure 1:
The effect of seed damage on water uptake. 1. Undamaged seed (control); 2. Broken embryo; 3. Tissue damage to embryo; 4. Deep damage to seed coat overlaying embryo; 5. Surface damage to seed coat overlaying embryo; 6. Damage to seed coat overlaying endosperm and embryo; 7. Tissue damage to embryo and endosperm; 8. Tissue damage to endosperm.

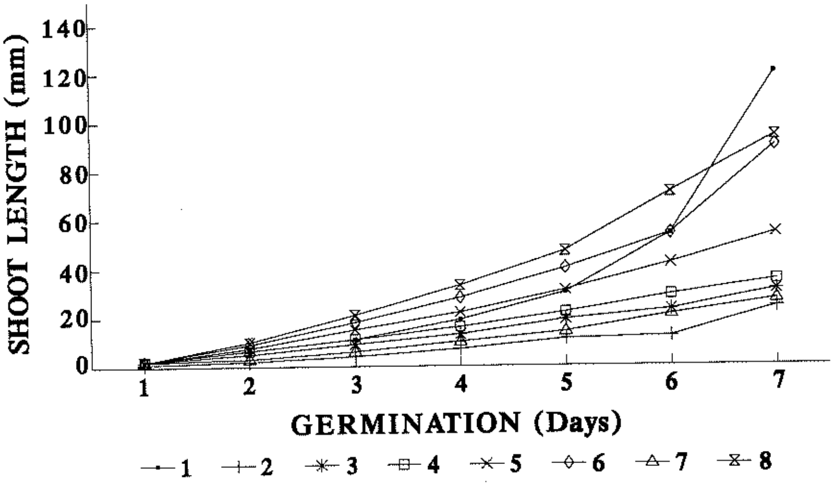

Figure 2:
The effect of seed damage on shoot length. For explanation of key see Fig. 1.

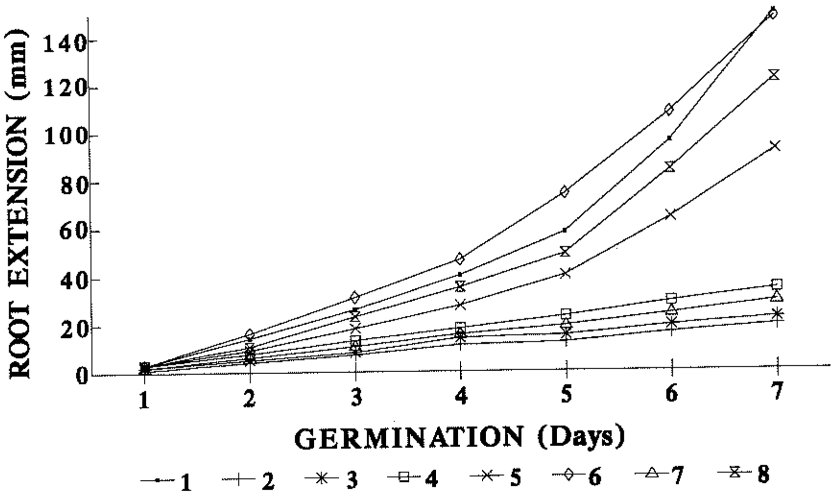

Figure 3:
The effect of seed damage on root extension. For explanation of key see Fig. 1.

and field germination counts (Experiment 4) - Undamaged seeds had relatively low initial germination (62%) but high final (100%) and field germination (98%) counts (Table 3). Seeds with broken embryos had very low first (35%), final (15%) and field germination (3%) counts. Although seeds with damage to the endosperm, seed coat over-laying embryo and endosperm, and surface of the seed coat over-laying the embryo had higher first germination counts (75%, 88% and 73% respectively) than undamaged seeds, final and field germination counts were significantly lower. These results are consistent with the increased initial water uptake and root and shoot extension of damaged seed in experiment 3. Koehler (1957) showed that damage to the seed coat of maize in the crown region and over the plumule resulted in severe reduction in germination in comparison to other seed coat damage. According to Tatum and Zuber (1943), crown injury is harmful but damage over and around the embryo may be of greater importance. The apparent discrepancy between first and final germination results within damage types is a reflection of the fact that by the final count, many seedlings were abnormal, and could not therefore be included as germinated under internationally standardised seed testing rules. These abnormalities were not usually evident at the first count.

Table 3. The effect of mechanical damage to different parts of the maize seed on germination (%).

Damage type	Germination (%) First	Final	Field
seeds without damage (control)	62	100	98
broken embryo	35	15	3
embryo with tissue damage	44	28	19
deep damage to seed coat over-laying embryo	56	42	36
surface damage to seed coat over-laying embryo	73	86	52
damage to seed coat over-laying embryo and endosperm	88	85	74
damage to tissue of embryo and endosperm	46	22	12
damage to endospermal tissues	75	87	77
LSD $P < 0.05$	7	5	4

Effect of damage to specific parts of the embryo on (a) germination, and (b) seedling morphology (Experiment 5) -

(a) Undamaged seeds had high final (96%) and field (82%) germination counts (Table 4). Damage to the upper part, one side, and both sides of the embryo allowed high first germination counts (63%, 58% and 45% respectively). However, final and field germination counts were lower than that of undamaged seed (by 25-31%). Damage to the central part of the embryo was associated with low first, final and field germination (10%, 7% and 2% respectively).

Table 4. The effects of artificial damage to different parts of the maize embryo on percentage germination.

Damage type	Germination (%) First	Final	Field
seeds without damage (control)	48	96	82
damage to upper part of embryo	63	62	55
damage to lower part of embryo	37	64	51
damage to central part of embryo	10	7	2
damage to one side of embryo	58	80	57
damage to both sides of embryo	45	53	53
damage to all parts of embryo	2	6	3
LSD $P < 0.05$	3	3	5

(b) Undamaged seeds developed 86% normal seedlings, 4% weak seedlings and 10% remained ungerminated. Damage to different parts of the embryo tissue resulted in the production of different types of seedling abnormalities which occurred at different frequencies depending on the site of damage. Seedlings with shoot abnormalities were associated with damage to the upper and lower, lateral sides, and between lower and central tissue of the embryo (Table 5). Root defects in seedlings were caused by all types of embryo damage. Coleoptile abnormalities were caused by damage to the upper and lower, between lower and central, and the central tissue of the embryo. The highest seedling bacterial and fungal infections (22%) were associated with damage to the lower tissue of the embryo. Damage to all parts of the embryo, and the central tissue resulted in the greatest number of seeds not germinating (50% and 52% respectively). These results are consistent with those reported for other crops. For example, damage to certain parts of wheat seeds gave rise to abnormal seedlings (Coperman, 1948). According to Budo (1974), a minute

Table 5. The effect of artificial damage to different parts of the maize embryo on seedling morphology (%), disease susceptibility (%) and germination (%).

	Site of embryo damage						
Seedling Morphology	**All parts**	**Upper**	**Lower**	**One lateral side**	**Both lateral sides**	**Between lower & central**	**Central**
Normal seedlings	2	44	53	44	42	47	1
Shoot							
absent	17	14	-	8	3	-	-
weak development	7	4	9	13	26	7	-
Root							
absent	-	-	2	-	-	12	17
weak, fibrous, translucent	10	2	2	3	-	7	11
primary absent, secondary well developed	3	-	2	-	-	3	-
primary developed, secondary absent	-	-	-	2	12	-	8
primary stunted, secondary root absent	7	-	3	-	-	-	-
primary stunted, secondary root developed	-	-	-	-	-	-	7
Coleoptile							
torn	4	23	7	-	-	11	4
rigid	-	2	-	-	-	-	-
Disease Susceptibility							
seedlings infected by bacteria and/or fungi	-	11	22	-	-	-	-
Germination							
ungerminated seed	50	-	-	10	17	13	52
LSD $P < 0.05$	3	3	2	2	3	2	2

aberration on the surface of the embryo is sufficient to cause a decline in vigour. Seeds with damaged embryos either give rise to weak seedlings or result in complete loss of germination (Coperman, 1948; Chazov, 1967). Damage to maize seeds exposes them to infections by different types of fungal pathogens (Koehler, 1957; Tatum and Zuber, 1943).

Effect of seedling abnormality on survival, plant height (during different stages of development), and grain yield (Experiment 6) - Survival to maturity was highest for normal seedings (95%) and lowest for seedlings with thin and translucent shoots (34%) and seedlings with roots absent (28%) or diseased (34%) (Table 6). Seedlings with weak, fibrous and translucent roots, primary stunted/secondary absent or torn coleoptiles, had medium survival (about 40-50%) to maturity.

Highest yields were produced from plants developed from normal seedlings (7.8 t ha^{-1}) or from seedlings with the shoot in a spiral form (7.4 t ha^{-1}) and rigid coleoptile (8.1 t ha^{-1}) (Table 7). The rest of the abnormalities had negative effects on grain yield. The lowest yields were from plants developed from seedlings that had bacterial and fungal infections (1.4 t ha^{-1}), torn coleoptiles (1.5 t ha^{-1}), and roots weak, fibrous and translucent (1.7 t ha^{-1}). The effect of seedling type on plant height was variable. At anthesis, plants developed from normal seedlings were among the tallest group (200-260 cm). This group was generally associated with the highest yieldings plants (5.3-8.1 t ha^{-1})

The results reported in this study show that mechanised harvesting, seed processing, and mechanised planting caused a large proportion of damaged seed (89%) associated with

Table 6. The effect of seedling morphology and disease susceptibility on plant survival at four stages of development of the maize plant.

	Plant Survival (%)			
Seeding morphology	**5 Leaves**	**8 Leaves**	**Tassel emergence**	**Physiological maturity**
normal seedlings (control)	98	98	95	95
all parts of seedling weakly developed	72	69	63	63
Shoot				
developed weakly	91	87	84	84
spiral form	95	93	93	93
lacking geotropism	97	94	94	90
thin/translucent	54	43	38	34
Root				
absent	94	31	28	28
short and stunted	92	79	64	62
weak, fibrous and translucent	92	76	52	41
primary absent, secondary developed	96	93	93	93
primary developed, secondary absent	95	92	90	90
primary stunted, secondary absent	98	63	48	42
Coleoptile				
torn	63	57	57	53
rigid	99	98	98	94
stunted	85	85	81	80
Disease Susceptibility				
seedlings with bacterial and/or fungal infections	34	34	34	34
LSD $P < 0.05$	1	1	1	1

damage to the seed coat, endosperm, and embryo. Shelling and sizing caused the highest level of seed damage during processing. This supports observations made by Tatum and Zuber (1943). Seed damage affected germination, seedling development, susceptibility to disease, plant growth and development, and grain yield. The maximum difference in grain yield of plants developed from normal seedlings and those from abnormal seedlings was 6.4 t ha^{-1}. These results are consistent with results from previous studies. Tatum and Zuber (1943) and Koehler (1957) showed that seed coat damage reduced seed vigour and yield; seed coat damaged maize yielded 0.416 t less than undamaged seed (Koehler, 1957). The influence of seed coat damage on disease susceptibility from *Pythium spp.*, *Penicillium spp.*, *Aspergillus spp.*, and other fungi has been proposed as the primary factor for reduced germination and yield of damaged maize (Tatum and Zuber, 1943; Koehler, 1957).

Results from this study also showed the significance of site of damage for germination rate and seedling quality. The embryo, specifically the central part of the embryo, was most sensitive to mechanical damage. Damage to the embryo results in injuring the delicate structures that constitute the future plant and disrupts normal physiological activities of the seed (Kizilov, 1960; Ovcharov, 1969; Suhorukov, 1974). Seedlings from damaged seeds developed abnormalities which affected plant survival, development, and grain yield. This confirms the importance of using undamaged seed. Funk, Anderson, Johnson and Atkinson (1962) concluded that significant differences in field performance and seed yield obtained from plants grown from different seed lots of the same hybrid, were partially associated with seed physical quality. Their work

Table 7. The effect of maize seedling morphology and disease susceptibility on plant height (cm) during four stages of plant development and grain yield (t ha^{-1}).

	Plant height (cm)				
Seedling type	**5 leaves**	**8 leaves**	**Tassel emergence**	**Anthesis**	**Grain yield (t ha^{-1})**
normal seedlings (control)	15	156	204	246	7.8
all parts of seedling weakly developed	12	118	169	198	4.4
Shoots					
developed weakly	30	140	187	215	6.4
spiral form	70	148	214	239	7.4
lacking geotropism	15	161	201	253	6.9
thin/translucent	10	113	156	169	2.1
Root					
absent	18	65	103	118	2.6
short and stunted	15	109	148	176	3.1
weak, fibrous and translucent	17	84	134	168	1.7
primary absent, secondary developed	14	140	193	256	6.7
primary developed, secondary absent	13	145	189	247	6.7
primary stunted, secondary absent	16	109	134	168	2.5
Coleoptile					
torn	10	119	173	206	1.5
rigid	15	150	216	246	8.1
stunted	15	150	216	246	5.3
Disease Susceptibility					
seedlings with bacterial and/or fungal infections	9	99	135	176	1.4
LSD $P < 0.05$	3	2	2	2	0.4

also showed that plants produced from poor quality seed were slow in emergence, had less seedling vigour and reduced competitive ability, and were low yielding in comparison to plants developed from high quality seed.

Results from the six experiments emphasise the importance of protecting seed from mechanical damage during harvest and post harvest activities. In spite of the logistical advantages of mechanising harvesting, seed processing and planting activities, it is important to adopt practices that minimise damage, and also protect injured seed. This may be achieved by using preventive measures against seed damage during harvest and post harvest activities, and seed treatment to protect damaged seed before planting. Differences in sources, rates and types of seed damage are brought about by factors such as harvesting and processing equipment, machine operating speeds and seed storage. These factors vary among processing plants (Tatum and Zuber, 1943). This makes it difficult to recommend standard procedures that could be used to reduce seed damage during harvest and post harvest activities. An effective procedure to control mechanical seed damage during harvest and post harvest activities could be regular inspection of cobs or processed seed lots for injury, and adjusting the machines accordingly. This procedure would especially be useful when using new equipment where sharp edges and rough surfaces that cause damage might be present. As demonstrated by Tatum and Zuber (1943) a reduction in mechanical seed damage can be obtained by processing seed at moisture contents higher than 14%. According to Boyd *et al.* (1975) maize seed is not extremely sensitive to mechanical damage at 16-17% moisture content. Use of conveyor belts for transport of seed will minimise damage in comparison to the use of augers. Decreasing the distance of seed falling to reduce impact when loading into bins and silos should minimise damage.

Differences in the resistance of maize seed to mechanical damage have been recorded within and between hybrids (Funk et al., 1963; Tatum and Zuber, 1943). This indicates the possibility of genetic improvement for mechanical damage resistance in maize, similar to that in snap beans (*Phaseolus vulgaris* L.) (Dickson and Boettger, 1976). Seed coat damage increases the possibility of infection by soil pathogens (Tatum and Zuber, 1943; Koehler, 1957). Seed coating of processed maize seed prior to planting is a useful way of protecting damaged seed from pathogens. Seed coating of maize has been used for protection against soil insects, pests and diseases (Scott, 1989). Kaliuzhnyi and Litvinenko (1985) used hydrophobic seed coating prior to planting processed seed (hybrid Krosnodar 303 TB) and increased emergence by 37%. Breeding for rapid seed germination and seedling emergence will reduce the time available for soil pathogen infection, and thus provide a better response from damaged seed.

Methods to control mechanical seed damage and reduce the deleterious effects of seed injury should be integrated into harvest and post harvest activities. This will enhance production of high quality seed, and result in increasing field germination, decreasing seedling abnormalities, increased plant survival, better plant development, and increased grain yield.

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