MECHANICAL INJURY TO PEA BEAN SEED TREATED AT THREE MOISTURE LEVELS

Thesis for the Degree of M. S.

MICHIGAN STATE UNIVERSITY

Celio Barriga Solorio

1959

MECHANICAL INJURY TO PEA BEAN SEED TREATED AT THREE MOISTURE LEVELS

By

Celio Barriga Solorio

A THESIS

Submitted to the College of Agriculture of Michigan State University of Agriculture and Applied Science in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Department of Farm Crops

1959

ACKNOWLEDGMENT

The author wishes to express his sincere appreciation to Dr. A. L. Andersen for suggesting the problem, and to Dr. S. T. Dexter and Dr. M. W. Adams for their guidance in the course of this investigation and preparation of the manuscript.

The author is grateful for the financial assistance of the Rockefeller Foundation.

MECHANICAL INJURY TO PEA BEAN SEED

TREATED AT THREE MOISTURE LEVELS

By

Celio Barriga Solorio

AN ABSTRACT

Submitted to the College of Agriculture of Michigan
State University of Agriculture and Applied Science
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Farm Crops

1959

Approved M. W. Adams

ABSTRACT

Seeds of 41 strains of white pea beans at 3 moisture contents were mechanically beaten in a motor-driven rotor. Simple examination determined visible injury, whereas invisible or internal injury was determined by germination in sand.

The analysis of the data relating to normal and abnormal seedlings (invisible injury) indicated highly significant differences between strains and between moisture levels. Both visible and internal damage were greater in beans at low than at higher moisture contents. The number and the vigor of normal seedlings decreased as the moisture content of the seed decreased.

When seed that was not beaten was planted, initial moisture contents (from 9 to 15.7%) made no difference in vigor or extent of germination.

Loss of one cotyledon and loss of the plumule ("baldheads") were the two commonest abnormalities in the injured seedlings, but many other types were observed.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Pea beans are a particularly important agricultural crop in the central and east central portions of the lower Peninsula of Michigan. According to Agricultural Statistics Michigan produced in 1955 and 1956, respectively, 4.5 and 5.3 million 100 pound bags of pea beans. The value of the 1956 crop amounted to 33.4 million dollars. Michigan is the leading producer of white pea beans for commercial canning.

Mechanical damage during harvest or subsequent handling is an important problem with this crop. Split seeds or seeds with broken or loosened seed coats are unacceptable to the canners. Roughly treated seed beans often produce "baldhead" or other abnormal seedlings in which loss of cotyledons, terminal bud or primary leaves leads to unsatisfactory growth. These are general problems in the pea bean industry, whether in California, Colorado, Idaho, Michigan or New York. In Michigan, some years have been marked by extended periods of relatively low humidity during harvest which often leads to a considerable percentage of seed injured by mechanical harvesting.

The main object of this experiment was to find out whether any differences exist among strains of pea beans in susceptibility to damage when the seeds were subjected to mechanical beating at various levels of seed moisture.

In addition, the experiment was designed to provide some information about the level of moisture at which the seeds being beaten suffer considerable damage, and the relationship between visible and internal damage and reduction in germination or seedling vigor.

REVIEW OF LITERATURE

Damage incurred by bean seed either in threshing or during the cleaning processes or by both operations, are classified in the literature as visible or as internal injury, the latter not being detectable until germination.

At the turn of the century, practically all the bean seed was grown in the eastern states, but seedborne blights and anthracnose, which are easily spread under humid conditions, forced the seed industry to move to the semi-arid regions of the west. After the move west, seed germination problems became more serious. This was probably due to effects related to lower humidity at harvest time, new varieties, and increased mechanization.

The percentage of visible and internal injury of seed is a function of the variety used, the level of maturity or moisture of the seed at harvest time and the violence of the mechanical handling.

Mechanical harvesting operations. Harter (7) reported "baldhead" in 0-30 per cent of dry beans seedlings and in 10-20 per cent of snap bean seedlings. Whitney (16) reported in the summer of 1929 that an alarming deficiency in stand of certain lots of California-grown lima beans was experienced by certain growers in the East. Borthwick (4) studied various types of mechanical injuries in baby lima beans in California and found that "baldhead" occurs in a range of 2 to 10 per cent. On the basis of examination of 105 samples of bean seed offered for sale in Maine seed stores, Steinbauer (14) concluded that the frequency of "baldhead" varied from 1 to 25 per cent. Ingalls' (8) survey of commercial bean samples showed "baldheads" varying in a range of 0-17 per cent. Associated Seed Growers, Inc., (1) found that the percentage of seed broken by mechanical means varied from 1 to 30 per cent for the variety Tendergreen.

Harter (7) was the first to study the cause of "baldhead" or "snakehead" in common field beans *Phaseolus vulgaris* (L).In the "baldhead" seedlings the plumule may be entirely absent or only vestiges of it might remain. The plumule may at times appear to remain attached to the epicotyl although it is fractured just beneath the primary leaves, thus rendering normal development impossible. He reported that the per cent of loss from "baldhead" plants varies according to the variety, the method of handling the crop, and the season. He concluded that "baldhead" results from three distinct causes: one cause, which is by far the most common, is mechanical injury, the second is bacteria and the third insects.

Zaumeyer and Thomas (17) defined "snakehead" as an injury of germinating bean seed, which is caused by the seed corn maggot Hylemya cillicrura (Rond). This insect causes serious damage to beans throughout the United States; it is a pest of beans particularly in the East, from Virginia northward and in Michigan. The symptoms of "snakehead" differ from those of "baldhead" in that the plumule and other affected parts are made ragged by the chewing insects, whereas with "baldhead" the fracture or injury is clean cut. In the case of "baldhead" caused by bacteria Harter (7) pointed out that the entire plumule might be more or less completely lost or that the primary leaves might be badly mutilated, the terminal bud often being destroyed by the organism. "Baldhead" plants yield less than normal plants (5, 11, 14, 15). They mature later (5, 6, 8, 12, 15) and they are smaller than normal plants (8, 12).

According to Associated Seed Growers, Inc., (1) and Harter (7) "baldhead" plants usually develop axillary shoots between the joints of the cotyledons and hypocotyl.

Harter (7) found that the epicotyl is fractured just below the plumule by the threshing machine and that the average diameter of the epicotyl in the embryonic stage is less in snap beans susceptible to "baldhead" than in more resistant field beans.

Atkin (2) found that seed coats of resistant varieties generally adhere much more tightly to the cotyledons than do those of susceptible varieties and that the cotyledons of some varieties fit much more closely together than do those of others. Tight seed coats and close fitting cotyledons could prevent or reduce movement of the cotyledons and thus protect the embryo from damage.

Borthwick (4) reported that the damage found in baby lima bean seedlings from machine threshed seed indicates that practically every part of the embryo is susceptible to some kind of threshing injury. Types of injury in seedlings of the lima beans are described (3, 4) in the following way:

Injuries to hypocotyl and radicle. Complete loss of the radicle is of comparatively frequent occurrence. In these cases the lower end of the hypocotyl calluses over and gives rise to adventitious roots. As a result, insufficient hypocotyl remains to raise the cotyledons above ground in the manner characteristic of these beans. The cotyledons themselves remain below ground, and the epicotyl only elongates. More commonly fracture of the hypocotyl or root does not extend completely across it.

Injury to the cotyledons. One cotyledon may be broken at its point of attachment to the stem, the other functioning normally; or both cotyledons may be absent although the plumule is uninjured. In many cases the cotyledon is not broken completely from the plant, but remains attached by small strands of tissue. Callus tissue develops at the broken surfaces, and not infrequently adventitious roots arise from this callused area of the cotyledon. When on a seedling a cotyledon is found with a crack crossing it transversely, although the outer end is still attached, the food reserve in the loosely attached part has not been used as has that of the lower part of the cotyledon.

McCollum (10) reported that hand picked and hand shelled snap beans showed marked varietal differences in susceptibility to cotyledonal cracking during germination. A high incidence of cracking was found in strains B 1762, B 1229-1-2-6, Rival and Top-crop. No cracking was observed in the variety Cherokee except where the testae were broken. In the most susceptible strain tested, B 1762, the maximum cotyledonal breakage occurred after storage at a relative humidity of 15 per cent, and a minimum breakage at 56 per cent. The injury to the hypocotyl, the radicle and the cotyledons often retarded the growth of the seedlings (1, 3, 4).

McAlister and Orland (9) reported that during germination and early development of Earlyana and Lincoln soybeans 1/3 of the phosphorus, 2/3 of the potassium, 1/2 of the ether extractable substances, 1/3 of the protein and nearly all of the sugars had been transferred to the seedling. Very little of the magnesium and none of the calcium left the cotyledons. Removal of the cotyledons from the seedlings of either of the varieties at emergence or 2 days later resulted in a decreased plant size throughout the growing season.

Handenburg and Eto (6) artificially produced "baldhead" bean plants under controlled conditions both in the greenhouse and in the field, using California-grown red kidney seed. The amputation treatment took place 6 days and 11 days respectively after planting in the greenhouse and in the field. They found that of the various types of abnormalities only that one which involved the loss of both primary leaves was sufficient to cause a significant reduction in yield. Loss of the terminal bud did not affect yield. The primary leaves were specially important in the early growth of the plant as they enhanced development of the root system, drew nutrients from the cotyledons and stimulated growth of the terminal bud.

Loss of one primary leaf was unimportant because apparently the loss had a compensating action tending to accelerate the growth of the remaining vegetative tissue.

Atkin (2) found that varieties differ significantly in their susceptibility to injury. The resistance to injury of the white seeded variety Streamliner in comparison with white seeded Tendergreen that is susceptible indicates that desirable white seeded varieties resistant to seed injury can probably be developed by plant breeding.

Bainer and Borthwick (3) worked with bean seed at 5.8, 9.6, 14.1 and 15.9 per cent of moisture and they found that beans of low moisture were damaged to a greater extent by a threshing machine. The cylinder speeds required to produce 15 per cent of total damage in Fordhook beans containing 15.9, 17.3 and 18.8 per cent of moisture were 1,150, 1,330 and 1,600 feet per minute respectively. Beans of 10.6 per cent moisture content, rolled down a 45° slide, showed a total damage of approximately 4.5, 8.6 and 15.3 per cent respectively for slide distances of 6.4, 10.5 and 15 feet.

Associated Seed Growers, Inc., (1) reported that seed of 8, 10 and 12 per cent moisture were dropped several times from different heights. The results showed that mechanical damage to bean seed is cumulative; many low drops may cause as much loss in germination as one or two high drops. They found also that moisture content of the seed is related to susceptibility to injury; the lower the seed moisture content, the greater the damage.

Perry (13) reported in the variety Michelite that the damage, splits and checked seed coats, was about proportional to height of the drop up to 45 feet and the damage was reduced considerably at higher temperatures and higher moisture contents.

According to the data cited above moisture content and perhaps temperature are of fundamental importance in the threshing of seed beans.

MATERIALS AND METHODS

Forty one strains of white pea beans were used in this study. They were grown at Saginaw, Michigan, and were harvested in September, 1958. See Table No. 1 . The plants were hand threshed. The seed was passed over a round hole 16/64 screen on the top and 12 3/4/64 screen on the bottom to obtain seed of uniform size. From each one of the strains 450 grams (2100-2700 seeds), of seed were selected. In order to obtain three levels of moisture in the seed samples, subsamples were stored in three 20-gallon-capacity sheet iron cans containing saturated solutions of sodium chloride, sodium bromide and calcium chloride, to give relative humidities, at equilibrium, of approximately 75%, 58% and 32% respectively at room temperatures. These solutions were placed in the bottoms of the containers. A small motor was attached to the outside of the cover of each can, with a small connected fan inside to stir the air. A rod, vertically placed in each container, was used to agitate the saturated solutions from time to time. See Figure 1.

The seed samples were placed in perforated plastic cups. The cups were arranged at five different levels

Figure 1. Container showing the way in which different relative humidities were obtained.

as shown in Figure 2. In this way the seed was kept in the cans for 36 days.

Immediately after removing the cups from the cans, five samples from every level of the seed were drawn in order to determine the moisture content.

Seed samples were dried in an electric oven at 100° C. for 60 hours. After this period they had reached approximately constant weight. Water content was calculated from loss of weight in the oven. Another portion of each seed sample was mechanically beaten with a small machine in which the beans dropped into a motor-driven plastic paddle-wheel, rotating at 977 r.p.m. See Figure 3. Visible injury was detected in the following way: (a) Counting the number of seeds with no visible injury; (b) counting the number of seeds with visible injury; and (c) counting the number of seeds split or broken.

Internal injury was detected by a germination test as follows: The seed, after having been mechanically beaten, was kept in open bags for 40 days at room temperature. This allowed all samples, including the check lots (not beaten) to reach essentially the same moisture content before planting. From every strain, at each successive level of moisture, 150 seeds with no visible injury were selected.

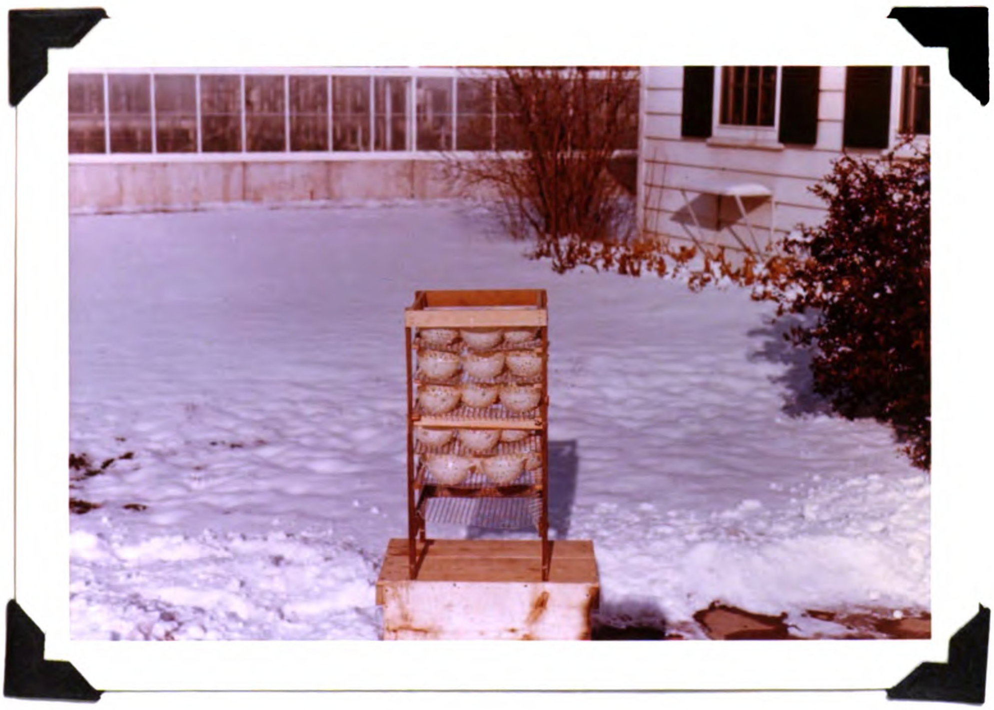

Figure 2. Showing the way in which the seed was arranged in the containers.

Figure 3. Showing a small machine used for beating the seed.

These seeds were then planted in flats filled with steamed sand. There were four treatments, the check (unbeaten), the high, the medium and the low moisture beans without visible injury. Two rows of each, with 25 seeds per row, were planted in each flat. Fifty seeds were considered a replicate. Three replications in a split plot design were used.

Twelve days after planting, the numbers of the following types of abnormal bean seedlings were recorded. (a) Normal seedlings with two cotyledons, two primary leaves, terminal bud present and no deformation of the hypocotyl; (b) seedlings that had lost one cotyledon; (c) "baldhead" seedlings which had lost both the terminal bud and the primary leaves; (d) seedlings that had lost both cotyledons; (e) seedlings that had lost one primary leaf; (f) seedlings that had lost both primary leaves, but not the terminal bud.

In March, 1959, after examining the results of the first experiment, ten strains were selected and a second test performed.

Levels and determination of moisture were obtained in the same way as in the first study.

From each strain 100 grams of the sample were mechanically beaten and the rest of the sample was not.

From every level of moisture, both the seed mechanically beaten and the unbeaten check lots were planted at once, at the moisture contents that the seed had reached in each conditioning can. A check, at equilibrium with room moisture conditions, was used in addition.

The seed was planted as in the first experiment, using the same design. However, the number of seeds (without visible injury), used per strain was 75, so 25 seeds were planted in each of three replications. In this experiment only the internal injury was tested.

RESULTS

In the first experiment, bean seed at about 15.5, 12.3 and 9.7 per cent of moisture was mechanically beaten. Tables 1 and 1A give the percentages of visibly injured seed, germination and the weight per seedling.

Table 1

Visible injury in 41 strains of bean seed, per cent of germination and the average weight per seedling.

Entry Number	Varieties	Per cent of Moisture	Per cent of visibly injured seed	Per cent with cracked seed coat	Per cent of broken or split seed	Per cent of germination	Weight, grams, aerial part per seedling
		check				100.0	1.00
1	Mich-elite	15.5	2.9	2.2	0.7	98.0	1.00
		12.3	41.6	18.3	23.3	77.3	0.83
		9.7	54.1	18.9	35.2	67.3	0.76

		check				100.0	0.88
2	Sani-lac	15.5	3.3	2.7	0.6	94.0	0.81
		12.3	30.6	15.2	15.4	62.0	0.63
		9.7	59.9	27.8	32.1	34.7	0.54
	Row Number 1958 Saginaw Planting						
		check				99.3	1.05
3	860	15.5	4.4	3.8	0.6	92.0	1.02
		12.3	44.2	25.3	18.9	52.0	0.70
		9.7	60.8	33.6	27.2	34.7	0.60
		check				100.0	0.93
4	863	15.5	4.6	3.7	0.9	98.0	0.88
		12.3	48.5	27.7	20.8	66.0	0.64
		9.7	64.4	27.7	36.7	45.3	0.63
		check				99.3	0.91
5	864	15.5	5.8	4.4	1.4	98.7	0.90
		12.3	47.2	23.6	23.6	63.3	0.67
		9.7	63.2	27.2	36.0	34.0	0.56

		check				99.3	1.00
6	840	15.5	13.4	9.3	4.1	90.7	0.97
		12.3	63.7	31.1	32.6	61.3	0.67
		9.7	81.0	33.8	47.2	43.3	0.66
		check				99.3	0.93
7	841	15.5	8.5	6.7	1.8	92.0	0.87
		12.3	47.7	27.4	20.3	64.7	0.69
		9.7	66.7	29.0	37.7	46.7	0.64
		check				100.0	0.91
8	842	15.5	5.5	3.4	2.1	88.7	0.86
		12.3	51.6	24.4	27.2	54.7	0.63
		9.7	66.6	19.3	47.3	38.7	0.57
		check				100.0	1.00
9	845	15.5	5.5	3.8	1.7	94.7	0.99
		12.3	50.2	22.5	27.7	64.0	0.74
		9.7	68.0	26.7	41.3	56.7	0.71
		check				99.3	0.93
10	847	15.5	5.3	5.3	0.0	92.0	0.90
		12.3	48.1	23.2	24.9	54.0	0.63
		9.7	65.9	27.5	38.4	40.7	0.64

		check				100.0	0.90
11	848	15.5	10.2	8.7	1.5	92.0	0.85
		12.3	55.4	31.9	23.5	64.7	0.60
		9.7	72.5	34.3	38.2	43.3	0.56
		check				100.0	0.88
12	850	15.5	14.3	12.3	2.0	92.7	0.85
		12.3	66.4	41.1	25.3	54.0	0.63
		9.7	83.8	30.8	53.0	40.0	0.53
		check				100.0	0.98
13	851	15.5	7.2	5.0	2.2	94.7	0.90
		12.3	60.3	27.8	32.5	52.0	0.63
		9.7	79.0	27.5	51.5	40.0	0.60
		check				100.0	1.08
14	852	15.5	8.0	6.3	1.7	95.3	0.98
		12.3	57.9	25.0	32.9	58.0	0.67
		9.7	72.3	23.8	48.5	55.3	0.67
		check				99.3	0.98
15	854	15.5	4.0	3.5	0.5	94.7	0.94
		12.3	56.9	25.2	31.7	58.0	0.69
		9.7	70.4	21.6	48.8	40.7	0.64

		check				100.0	1.04
16	855	15.5	5.5	4.5	1.0	94.0	0.99
		12.3	50.8	24.3	26.5	50.7	0.74
		9.7	72.3	25.0	47.3	47.3	0.64
		check				100.0	0.99
17	856	15.5	4.3	3.1	1.2	100.0	0.98
		12.3	63.0	27.7	35.3	61.3	0.74
		9.7	75.7	21.6	54.1	51.3	0.72
		check				94.7	0.99
19	866	15.5	4.5	3.7	0.8	99.3	0.93
		12.3	55.9	31.9	24.0	46.0	0.64
		9.7	76.0	32.2	43.8	35.3	0.65
		check				100.0	1.03
20	867	15.5	18.4	16.8	1.6	93.3	0.87
		12.3	60.8	32.5	28.3	35.3	0.59
		9.7	78.4	31.0	47.4	34.7	0.66
		check				98.7	0.97
21	868	15.5	7.7	5.8	1.9	94.7	0.90
		12.3	59.5	28.5	31.0	54.7	0.69
		9.7	75.9	23.4	52.5	34.0	0.63

		check				100.0	0.98
22	870	15.5	7.6	6.0	1.6	97.3	0.93
		12.3	53.9	23.7	30.2	64.7	0.68
		9.7	72.8	23.3	49.5	43.3	0.67
		check				100.0	0.94
23	871	15.5	8.2	7.2	1.0	100.0	0.89
		12.3	58.5	30.5	28.0	71.3	0.71
		9.7	72.8	21.4	51.4	60.0	0.64
		check				100.0	0.99
24	872	15.5	4.2	3.4	0.8	96.0	0.95
		12.3	53.7	25.0	28.7	58.0	0.80
		9.7	70.3	20.9	49.4	49.3	0.69
		check				100.0	0.99
25	873	15.5	1.6	1.3	0.3	99.3	0.95
		12.3	42.6	14.9	27.7	79.3	0.85
		9.7	63.3	17.7	45.6	66.7	0.75
		check				98.0	1.04
26	874	15.5	2.3	1.6	0.7	98.0	0.96
		12.3	34.7	16.8	17.9	77.3	0.80
		9.7	56.4	15.2	41.2	52.0	0.74

		check				100.0	0.95
27	876	15.5	2.5	2.1	0.4	96.7	0.90
		12.3	51.7	28.9	22.8	59.3	0.67
		9.7	69.5	24.1	45.4	40.0	0.63
		check				99.3	0.93
28	877	15.5	1.9	1.6	0.3	94.7	0.83
		12.3	41.6	19.5	22.1	42.7	0.55
		9.7	63.5	28.2	35.3	28.0	0.57
		check				99.3	0.97
29	878	15.5	2.0	2.0	0.0	86.0	0.92
		12.3	50.4	32.8	17.6	40.7	0.59
		9.7	68.0	29.7	38.3	37.3	0.58
		check				100.0	0.93
30	879	15.5	2.0	1.6	0.4	96.7	0.87
		12.3	44.0	27.2	16.8	45.3	0.53
		9.7	64.4	26.5	37.9	25.3	0.56
		check				99.3	0.94
31	880	15.5	4.6	4.0	0.6	98.7	0.85
		12.3	46.4	23.6	22.8	58.7	0.60
		9.7	69.8	28.6	41.2	45.3	0.57

		check				100.0	0.93
32	882	15.5	6.4	5.5	0.9	88.7	0.81
		12.3	54.3	32.7	21.6	32.7	0.52
		9.7	72.7	30.1	42.6	28.0	0.60
		check				99.3	1.10
33	883	15.5	10.5	8.6	1.9	92.7	1.08
		12.3	59.9	29.6	30.3	50.0	0.78
		9.7	69.8	27.1	42.7	28.7	0.79
		check				99.3	0.88
34	884	15.5	10.0	8.6	1.4	93.3	0.80
		12.3	60.6	30.7	29.9	50.0	0.49
		9.7	77.8	31.2	46.6	32.7	0.50
		check				100.0	0.90
35	885	15.5	21.3	18.9	2.4	93.3	0.81
		12.3	61.5	33.3	28.2	57.3	0.58
		9.7	81.8	33.9	47.9	35.3	0.60
		check				100.0	0.92
36	886	15.5	19.8	17.6	2.2	98.7	0.88
		12.3	65.4	33.1	32.3	67.3	0.64
		9.7	77.0	29.0	48.0	49.3	0.60

		check				99.3	0.96
37	887	15.5	6.3	5.5	0.8	95.3	0.83
		12.3	51.2	29.0	22.2	48.0	0.67
		9.7	67.8	28.4	39.4	37.3	0.67
		check				98.7	0.92
38	889	15.5	12.7	11.0	1.7	86.7	0.77
		12.3	55.6	33.6	22.0	39.3	0.48
		9.7	70.5	32.9	37.6	28.0	0.56
		check				100.0	0.96
39	890	15.5	8.7	7.9	0.8	88.0	0.80
		12.3	52.9	28.9	24.7	30.0	0.55
		9.7	72.8	33.8	39.0	23.3	0.59
		check				100.0	0.91
40	891	15.5	7.0	5.5	1.5	98.0	0.93
		12.3	53.0	27.7	25.3	61.3	0.60
		9.7	70.0	27.5	42.5	42.0	0.51
		check				98.7	0.95
41	892	15.5	3.3	3.0	0.3	97.3	0.92
		12.3	49.6	26.3	23.3	59.3	0.70
		9.7	72.1	30.4	41.7	42.0	0.55

		check				96.0	0.93
42	893	15.5	10.7	9.2	1.5	96.7	0.89
		12.3	50.5	27.0	23.5	54.0	0.58
		9.7	70.8	35.5	35.3	39.3	0.67

Table 1A

Average per cent of seed with visible injury. 41 strains were mechanically beaten at three moisture levels.

Per cent of moisture	Per cent of visibly injured seed	Per cent of cracked seed coat	Per cent of broken or split seed
15.5	7.2	6.0	1.2
12.3	52.2	27.0	25.5
9.7	70.3	27.3	43.0

In all the forty one strains of beans, the percentage of damage varied inversely with the level of seed moisture. In general, the strains that showed slight visible injury at a high level of moisture, also showed a relatively low percentage of visible injury at medium and low percentages of moisture. See Table 1. According to Table 1A the seed suffered considerable visible damage at 12.3 per cent of moisture or less.

Seed with no visible injury was planted in moist sand. 19,703 seedlings had come up 12 days after planting, and were classified as follows:

(a) "Normal" seedlings 15,523; (b) seedlings that had lost one cotyledon 2384; (c) "baldhead" seedlings 1727; (d) seedlings that had lost both cotyledons 5; (e) seedlings that had lost one primary leaf 27; (f) seedlings that had lost both primary leaves 37.

Baldhead seedlings in general emerged later than did normal seedlings and their cotyledons remained green longer than did those of the other seedlings as shown in Figure 4.

A few seedlings showed combinations of the above abnormalities but were included as shown below. Seedlings that had lost one cotyledon and one primary leaf were included in category (b); seedlings that had lost both one leaf and two cotyledons were included in category (d); seedlings that had lost both one cotyledon and two primary leaves were included in category (f). A few exceptional seedlings occurred in which their cotyledons were attached to the hypocotyl by callus tissue. In this case the cotyledons remained green. Some of the abnormalities are illustrated in Figures 4 and 5. In seedlings that came up 15 days after planting abnormalities of a different

Figure 4. Showing, from left to right, a normal seedling, a seedling that had lost one cotyledon and one primary leaf, a seedling that had lost both primary leaves and one cotyledon, and a "bald-head" seedling.

Figure 5. Showing, from left to right, a normal seedling, a seedling that had lost one cotyledon, a "baldhead" seedling, and a seedling that had lost one primary leaf.

kind were observed: the cotyledons remained below the sand level (hypogeous); in this case only the epicotyl (plumule or first leaves and terminal bud), elongated; these seedlings had no primary roots but a set of adventitious or secondary roots developed between the hypocotyl and the epicotyl where the cotyledons are attached as shown in Figure 6. In this study, however, these seedlings were considered as non-germinated seed.

In the "per cent of germination" were included only seedlings of the categories (a), (b), and (e), and in the determination of the weight per seedling were included all the seedlings that had come up (for every level of moisture plus the check) 12 days after planting. The per cent of germination and the weight per seedling for every level of seed moisture plus the check are shown in Table 1. In all three levels of moisture, seedlings that had lost one cotyledon were smaller than those with both cotyledons. See Figure 7.

The vigor of the normal seedlings of the check (T) was equal to that of the normal seedlings obtained from seed high in per cent of moisture, but was superior to that of the normal seedlings obtained from seed of medium and low per cent of moisture. See Figures 8, 9, 10, 11 and 12.

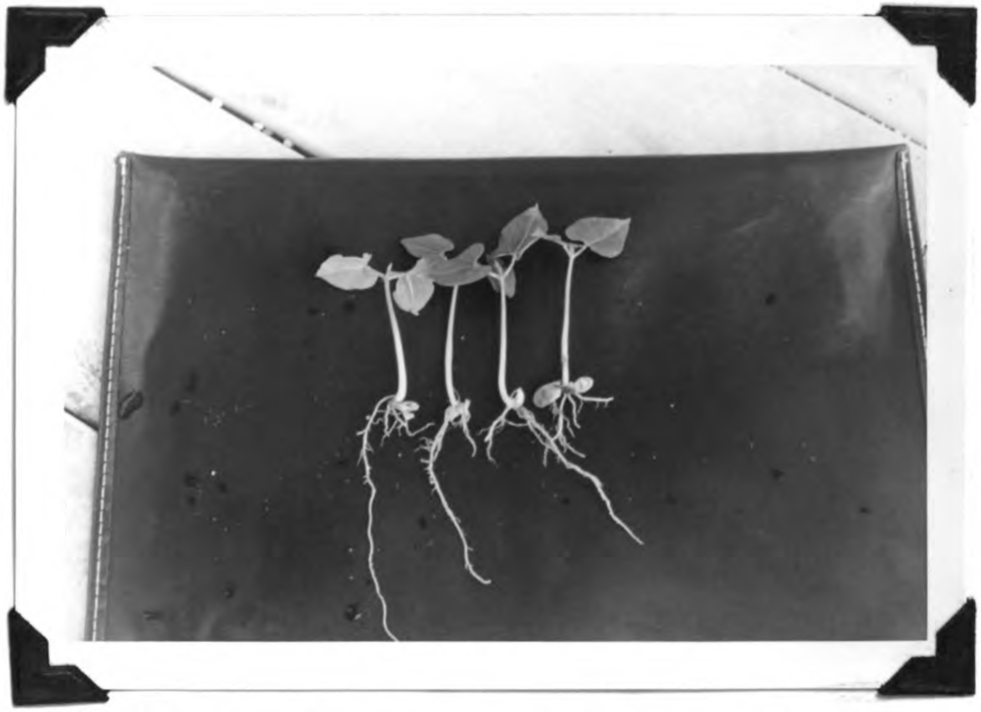

Figure 6. Seedlings that had lost the hypocotyl and the primary root.

Figure 7. Showing the effect of the loss of one cotyledon: from left to right, the check (T) and the three moisture levels.

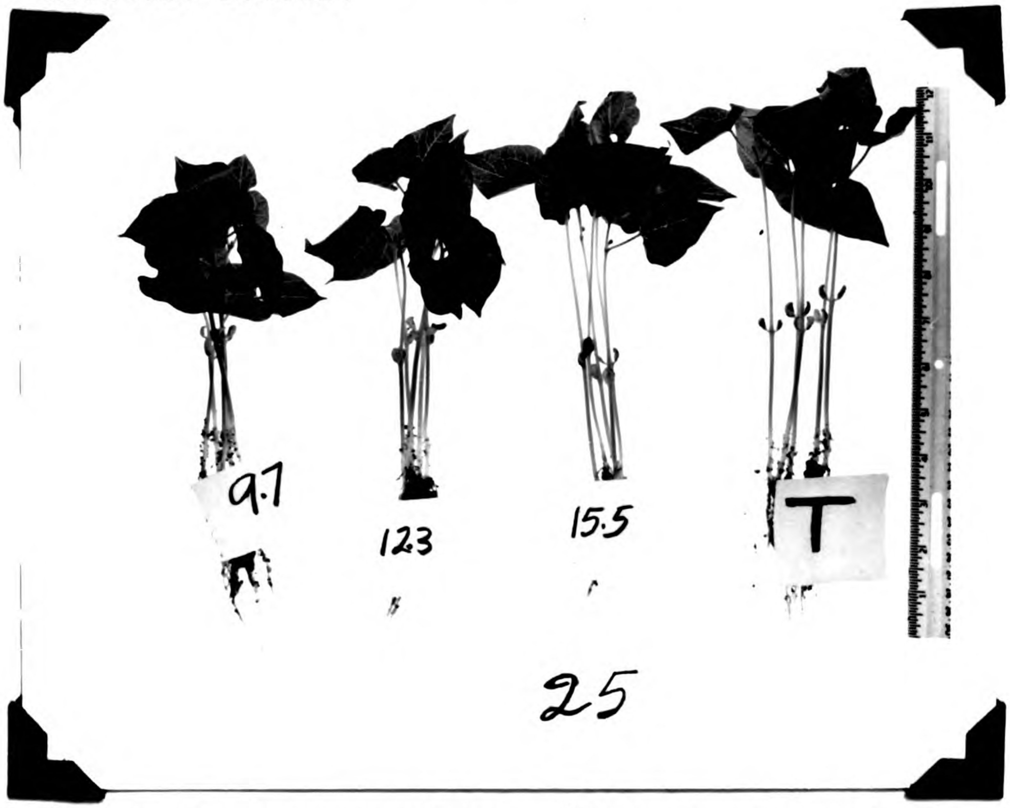

Figure 8. Vigor of normal seedlings (12 days after planting), at three moisture levels plus the check (T) in the strain No. 25.

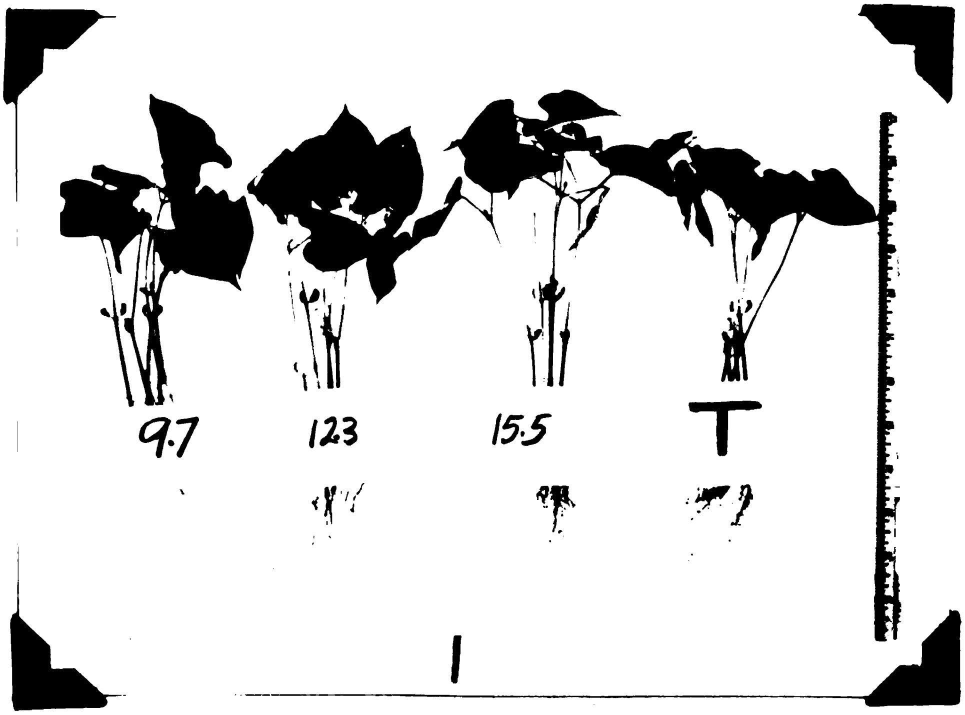

Figure 9. Vigor of normal seedlings (12 days after planting), at three moisture levels plus the check (T) in the strain No. 1.

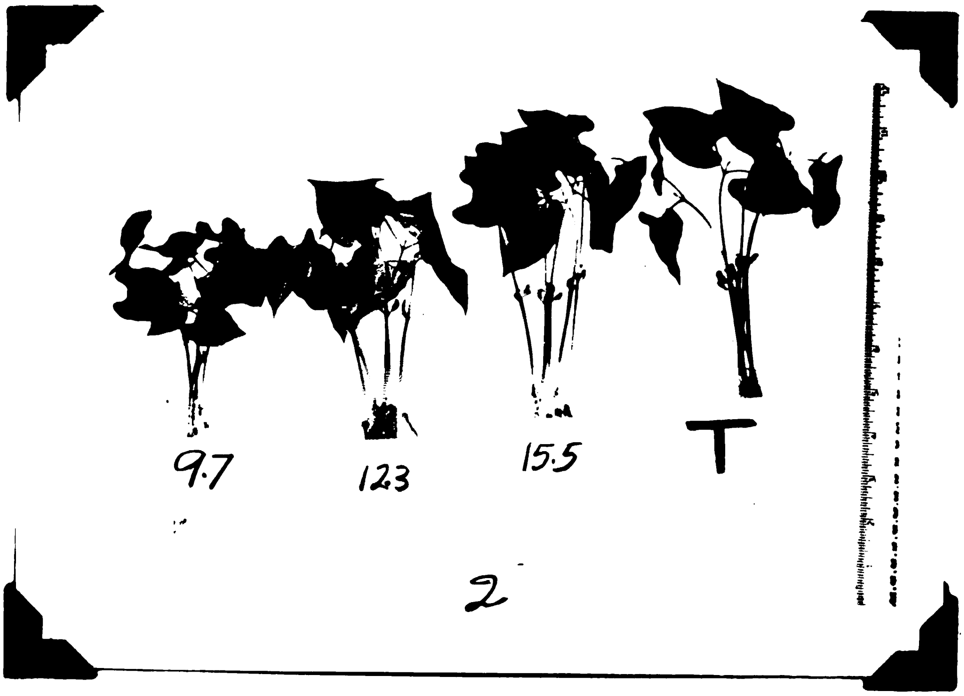

Figure 10. Vigor of normal seedlings (12 days after planting), at three moisture levels plus the check (T) in the strain No. 2.

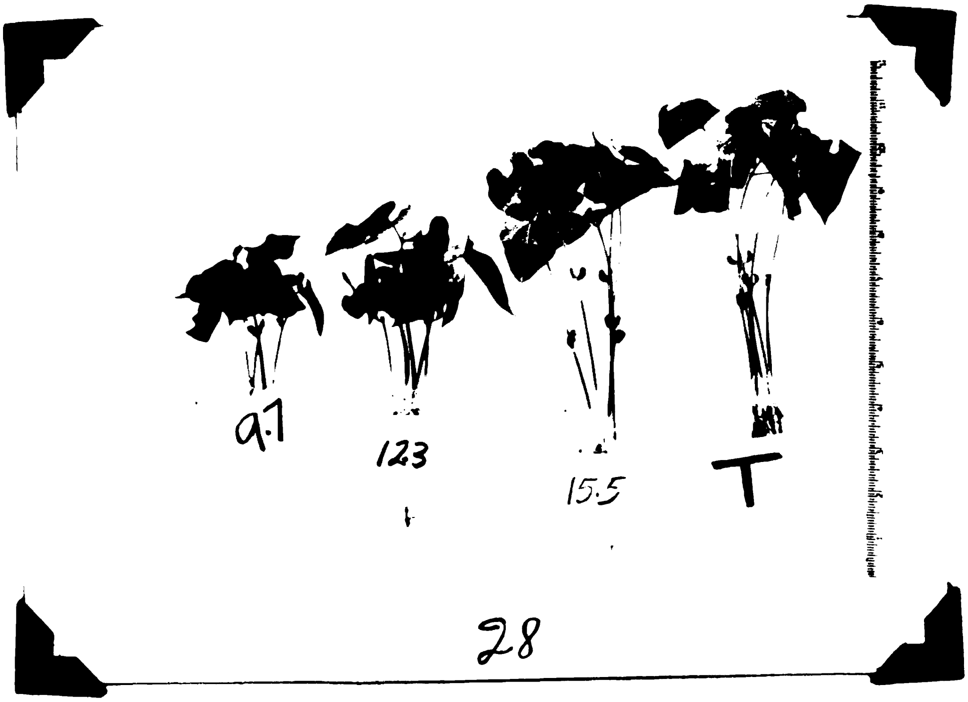

Figure 11. Vigor of normal seedlings (12 days after planting), at three moisture levels plus the check (T) in the strain No. 28.

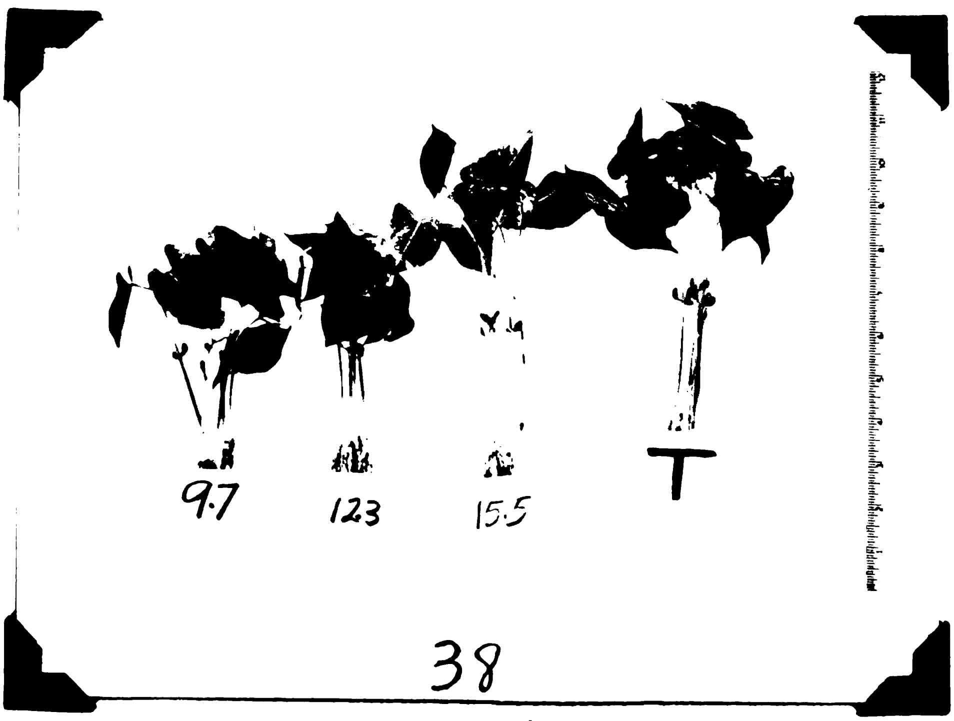

Figure 12. Vigor of normal seedlings (12 days after planting), at three moisture levels plus the check (T) in the strain No. 38.

The abnormalities in the seedlings as well as the differences in germination, vigor and average weight per plant in the three levels of moisture and those of the check (T) are to be attributed to the mechanical beating of the seed. See Figures 13, 14, 15 and 16.

Analysis of variance of the data relating to the number of normal seedlings, and the seedlings with various injuries are shown in Tables 2 to 9, and in general are self-explanatory. There were highly significant differences between strains, between moisture levels, and sometimes between replications for the number of normal and injured seedlings. A highly significant interaction was found between strains times moisture levels for seedling injury.

Table 2

Analysis of variance of the number of normal seedlings in pea beans.

Source	DF	SS	MS	F
Total	491	139561.73		
R	2	186.51	93.25	14.57**
S	40	5206.31	130.16	20.34**
Error (a)	80	512.16	6.40	
T	3	127997.29	42665.76	6034.76**
S X T	120	3919.46	32.66	4.62**
Error (b)	246	1740.00	7.07	

**Significant at the 1% level
R = Replications
S = Strains (of beans)
T = Treatments (levels of moisture plus the check)

Table 3

Average number of normal seedlings.

	Treatments				
Entry number	Check	15.5	12.3	9.7	$\overline{S}$
1	50.0	48.7	31.3	26.3	39.0
2	50.0	45.0	21.0	10.3	31.6
3	49.7	44.0	17.3	8.0	29.8
4	50.0	47.3	18.7	12.3	32.1
5	49.7	49.0	19.7	11.0	32.4
6	49.7	45.0	23.3	13.3	32.8
7	49.7	45.3	27.0	18.0	35.0
8	50.0	43.3	18.3	12.3	30.1
9	50.0	46.3	23.0	20.3	34.9
10	49.7	45.7	20.0	18.7	33.5
11	49.7	44.3	22.0	10.3	31.6
12	50.0	41.7	16.0	10.7	29.6
13	50.0	45.7	16.3	11.7	30.9
14	50.0	47.7	16.7	17.0	32.8
15	49.7	46.3	20.7	13.7	32.6
16	50.0	46.7	19.7	15.3	32.9
17	49.7	50.0	25.0	17.0	35.4
19	47.3	47.0	10.0	8.7	28.3

20	50.0	42.0	9.3	10.7	28.0
21	49.3	45.0	17.3	11.0	30.7
22	50.0	47.7	21.3	15.3	33.6
23	50.0	49.0	27.3	18.7	36.3
24	50.0	47.3	23.7	14.3	33.8
25	50.0	48.3	36.7	27.0	40.5
26	49.0	49.0	31.0	18.3	36.8
27	50.0	46.0	16.3	10.0	30.6
28	49.7	46.0	12.0	8.7	29.1
29	49.7	39.3	9.7	10.0	27.2
30	50.0	44.7	9.3	8.3	28.1
31	49.7	44.3	17.0	11.3	30.6
32	50.0	40.0	7.0	8.3	26.3
33	49.3	45.0	17.7	10.0	30.5
34	49.7	44.3	11.3	9.0	28.6
35	50.0	45.3	19.0	10.7	31.3
36	50.0	45.7	19.0	13.3	32.0
37	49.7	42.0	15.3	14.0	30.3
38	49.3	36.3	6.3	7.0	24.7
39	50.0	39.3	8.0	7.3	26.2
40	50.0	46.7	18.0	8.0	30.7
41	49.3	47.3	18.7	11.3	31.7
42	48.0	47.0	15.0	10.3	30.1
Treatment average	49.7	45.3	18.4	12.9	

Differences:	L.S.D. 5%	L.S.D. 1%	R.E. 5%	R.E. 1%
Between strains means	2.05	2.72	2.56	3.39
Between treatments means	0.67	0.88	0.72	0.94
Between treatments within a strain	4.27	5.64	4.65	6.00
Between strains within a treatment or within different treatments	4.26	5.65	5.32	7.01

Table 4

Analysis of variance of the number of seedlings that had lost one cotyledon.

Source	DF	SS	MS	F
Total	491	11652.26		
R	2	80.27	40.14	7.69**
S	40	781.09	19.53	3.74**
Error (a)	80	417.90	5.22	
T	3	7652.50	2550.83	433.81**
S X T	120	1274.00	10.62	1.81**
Error (b)	246	1446.50	5.88	

** Significant at the 1% level
R = Replications
S = Strains (of beans)
T = Treatments (levels of moisture plus the check)

Table 5

Average number of seedlings that had lost one cotyledon.

	Treatments				
Entry number	Check	15.5	12.3	9.7	$\overline{S}$
1	0	0.3	7.0	7.0	3.6
2	0	2.0	10.0	7.0	4.8
3	0	2.0	8.7	9.0	4.9
4	0	1.7	14.3	10.0	6.5
5	0	0.3	12.0	6.0	4.6
6	0	0.3	7.3	8.3	4.0
7	0	0.3	5.3	5.3	2.8
8	0	1.0	9.0	7.0	4.3
9	0	0.7	9.0	8.0	4.4
10	0	0.3	6.7	1.7	2.2
11	0.3	1.7	10.3	11.3	5.9
12	0	4.7	11.0	9.0	6.2
13	0	1.7	9.7	8.3	4.9
14	0	0.0	12.0	10.3	5.6
15	0	1.0	8.3	5.7	3.8
16	0	0.3	5.7	8.3	3.6
17	0.3	0.0	5.3	8.7	3.6
19	0	2.7	13.0	9.0	6.2

20	0	4.7	4.7	6.7	4.9
21	0	2.3	10.0	6.0	4.6
22	0	1.0	11.0	6.3	4.6
23	0	1.0	8.3	11.3	5.2
24	0	0.7	5.3	10.3	4.1
25	0	1.3	3.0	6.3	2.7
26	0	0.0	7.7	7.7	3.8
27	0	2.3	13.3	10.0	6.4
28	0	1.3	9.0	5.3	3.9
29	0	3.7	10.3	8.7	5.7
30	0	3.7	13.3	4.3	5.3
31	0	5.0	12.3	11.3	7.2
32	0	4.3	9.3	5.7	4.8
33	0.3	1.0	5.3	4.0	2.7
34	0	2.3	13.7	7.3	5.8
35	0	1.3	9.7	7.0	4.5
36	0	3.7	14.7	11.3	7.4
37	0	5.7	8.7	4.7	4.8
38	0	7.0	13.3	7.0	6.8
39	0	4.7	7.0	4.3	4.0
40	0	2.3	12.0	13.0	6.8
41	0	1.3	11.0	9.7	5.5
42	0	1.0	12.0	9.3	5.6
Treatment average	0.0	2.0	9.6	7.8	

Differences:	L.S.D.		R.E.	
	5%	1%	5%	1%
Between strains means	1.85	2.46	2.31	3.01
Between treatments means	0.61	0.80	0.66	0.86
Between treatments within a strain	3.90	5.14	4.22	5.46
Between strains within a treatment or within different treatments	3.88	5.14	4.83	6.42

Table 6

Analysis of variance of the number of "baldhead" seedlings.

Source	DF	SS	MS	F
Total	491	6418.95		
R	2	18.12	9.06	N.S.
S	40	701.70	17.54	4.56**
Error (a)	80	308.38	3.85	
T	3	3594.33	1198.11	312.64**
S X T	120	856.25	7.13	1.87**
Error (b)	246	940.17	3.82	

** Significant at the 1% level
N.S. = Not significant
R = Replications
S = Strains (of beans)
T = Treatments (levels of moisture plus the check)

Table 7

Average number of "baldhead" seedlings

Entry number	Treatments				
	Check	15.5	12.3	9.7	$\bar{S}$
1	0	0.3	6.7	9.0	4.0
2	0	1.3	4.3	5.3	2.8
3	0	1.0	8.3	6.0	3.8
4	0	0.7	2.7	2.7	1.5
5	0	0.7	7.0	6.7	3.6
6	0.3	3.7	7.3	9.7	5.3
7	0	3.7	10.0	7.0	5.2
8	0	3.3	9.0	10.3	5.7
9	0	2.0	10.7	8.7	5.3
10	0	3.0	14.3	10.7	7.0
11	0	1.3	5.0	3.3	2.4
12	0	3.3	1.7	3.7	2.2
13	0	2.3	7.7	8.3	4.6
14	0	2.0	8.0	7.3	4.3
15	0	2.0	8.7	7.0	4.4
16	0	1.7	8.7	5.7	4.0
17	0	0.0	8.3	5.7	3.5
19	0	0.0	2.7	3.3	1.5

20	0	3.3	8.7	5.3	4.3
21	0	2.0	8.7	7.7	4.6
22	0	1.0	5.7	5.7	3.1
23	0	0.0	4.7	4.3	2.3
24	0	1.0	6.0	3.3	2.6
25	0	0.0	3.7	4.3	2.0
26	0	0.3	5.0	6.0	2.8
27	0	1.0	4.3	7.0	3.1
28	0	2.3	7.7	5.0	3.8
29	0	5.0	7.3	3.3	3.9
30	0	2.3	5.7	4.0	2.8
31	0	0.7	8.0	3.3	3.0
32	0	3.3	5.3	4.7	3.3
33	0	3.0	9.7	4.7	4.3
34	0	2.7	7.3	5.7	3.9
35	0	2.7	6.3	6.0	3.8
36	0	0.0	1.0	5.3	1.4
37	0	2.0	5.0	4.7	2.9
38	0	3.7	4.0	2.0	2.4
39	0	4.0	8.7	4.7	4.3
40	0	0.7	7.0	4.7	3.1
41	0	0.7	3.7	4.3	2.2
42	0	1.0	6.7	4.0	2.9
Treatment average	0.0	1.8	6.6	5.6	

Differences:	L.S.D. 5%	L.S.D. 1%	R.E. 5%	R.E. 1%
Between strains means	1.59	2.11	1.96	2.60
Between treatments means	0.49	0.65	0.54	0.70
Between treatments within a strain	3.13	4.13	3.38	4.37
Between strains within a treatment or within different treatments	3.18	4.22	3.96	5.25

In the second experiment seed from 10 strains was mechanically beaten by a small machine (as in the first experiment), at about 15.7, 12.0, 9.0 and 9.7 (room moisture not beaten seed), per cent of moisture.

The 4,556 seedlings that had come up 12 days after planting were classified as shown below.

(a) Normal seedlings 4136; (b) seedlings that had lost one cotyledon 224; (c) "baldhead" seedlings 196.

The per cent of germination and the weight of the aerial part of the normal seedlings were taken for each treatment and the check.

There was no difference in per cent of germination and vigor of the normal seedlings, 12 days after planting, from the seed not mechanically beaten and planted with initial moisture of about 15.7, 12.0, 9.0 and 9.7 per cent.

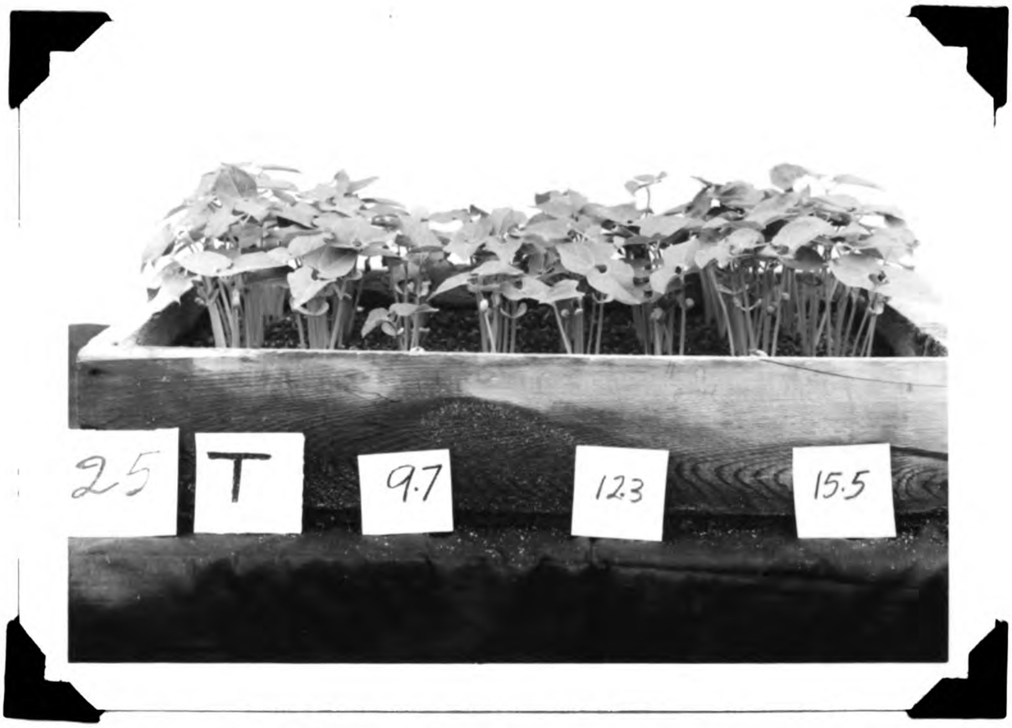

Figure 13. Showing the effect on the seedlings (10 days after planting), of the mechanical injury to seed at three moisture levels plus the check (T) in the strain No. 25.

Figure 14. Showing the effect on the seedlings (10 days after planting), of the mechanical injury to seed at three moisture levels plus the check (T) in the strain No. 1.

Figure 15. Showing the effect on the seedlings (10 days after planting), of the mechanical injury to seed at three moisture levels plus the check (T) in the strain No. 2.

Figure 16. Showing the effect on the seedlings (10 days after planting), of the mechanical injury to seed at three moisture levels plus the check (T) in the strain No. 3.

Table 8

Analysis of variance of the number of normal seedlings in the second experiment.

Source of variation	DF	SS	MS	F
Total	119	9455.5		
R	2	12.0	6.00	4.55*
S	9	206.7	22.97	17.40**
Error (a)	18	23.8	1.32	
T	3	8968.2	2989.40	1916.28**
S X T	27	151.3	5.60	3.59**
Error (b)	60	93.5	1.56	

**Significant at the 1% level
*Significant at the 5% level
R = Replications
S = Strains (of beans)
T = Treatments (levels of moisture plus the check)

Table 9

Average number of normal seedlings in the second experiment.

Entry number	Treatment Check	15.7	12.0	9.0	$\overline{S}$
1	25.0	24.7	11.3	8.3	17.3
2	25.0	24.0	7.7	4.7	15.3
3	25.0	23.3	8.7	4.7	15.4
4	25.0	25.0	7.7	6.3	16.0
25	25.0	25.0	14.0	9.3	18.3
26	25.0	24.3	11.3	6.7	16.8
28	25.0	24.7	6.0	3.3	14.8
35	25.0	22.7	6.7	5.0	14.8
36	25.0	22.3	8.3	5.0	15.2
38	25.0	20.7	5.3	3.7	13.7
Treatment average	25.0	23.7	8.7	5.7	

Differences:	L.S.D. 5%	L.S.D. 1%	R.E. 5%	R.E. 1%
Between strains means	0.99	1.35	1.13	1.55
Between treatments means	0.64	0.85	0.77	1.00
Between treatments within a strain	2.00	2.66	2.40	3.12
Between strains within a treatment or within different treatments	2.10	2.88	2.42	3.34

There was a small number of seedlings of the category (b) and (c); for this reason these were not analyzed.

The results from the analysis of the number of normal seedlings in both the first and the second experiment and the determination of visibly injured seed in the first experiment showed that there was a highly significant difference in susceptibility to internal injury by seed and that there was a slight relationship between the visible and the internal injury of these strains.

DISCUSSION

The study of mechanical damage in beans is complicated not only by the number of factors that are involved in it, but also by the deficiency of information concerning the parts of the seed that are responsible for the resistance possessed by some varieties. This resistance can be established by a visible examination and by germination of mechanically beaten seed. Examination of the data on visible injury, in Table 1, shows no consistent differences between strains. This may well be due to the lack of replications, the small size of the samples, variability in the operation of the mechanical beater, and the difficulty in observing injury.

Examination of the data on germination and abnormal seedlings, however, shows highly significant differences between varieties. Perry (13) had a similar experience in determining injury to beans from dropping. In general, however, the strains with the least visible injury showed the least abnormalities in germination. In all the strains the per cent of germination in the beaten seed was less when the moisture in the seed was low.

The specific pattern of injury varied considerably in the 41 strains. For example, strain 36 was the most susceptible to injury involving loss of one cotyledon; strain 10 was the most resistant. (See Table 5.) Strain 10, however, was the most susceptible to injury in the plumule ("baldhead") and strain 36 the most resistant. (See Table 7.) These findings indicate that the injury in these two strains varies according to the part of the seed that is more susceptible to injury in each variety. An anatomical study of these strains might establish some of the reasons for greater resistance of various types of injury in some strains than in others. Harter (7) attributed the resistance of varieties to mechanical injury to the larger diameter of the hypocotyl in the embryonic stage. Atkin (2) attributed this resistance to the closer adherence of the seedcoats and cotyledons in resistant than in susceptible varieties.

Food used during germination and in the early stages of seedling growth is largely derived from the accumulations in the thick cotyledons. More seedlings were found with one lost cotyledon than with all other abnormalities combined. McAlister (9) found that the removal of the cotyledons from soy beans in the early stages of seedlings development decreased plant size.

Leaves are the food-making organs of the plant. In this study, in seedlings that had lost both primary leaves, the terminal buds often turned chlorotic and died. In "baldhead" seedlings the cotyledons remained green for some time. In seedlings that had lost one primary leaf chlorosis was not found but the vigor of these seedlings was less than that of normal plants. Figure 5.

Handenburg and Eto (6) who artificially produced "baldhead" bean plants, from 6 to 11 days after emergence, reported that loss of the terminal bud did not affect yield and that the loss of one primary leaf was unimportant in plant development. The differences in vigor between normal seedlings from seed of the same strain but with three levels of moisture is shown in Figures 8, 9, 10, 11 and 12. These differences are believed to be due to invisible injury in mechanically beaten seed. In this case the seed suffered injury that may have had some effect in the physiological processes of the seed; there may have been some chemical reactions in the seed, or obstructions in the movement of the food reserves in the cotyledons. In this study the cotyledons of these 41 strains showed cross cracks but only in the seed that was beaten at 12.3 and 9.7 per cent of moisture.

McCollum (10) reported that hand picked and hand shelled snap beans of the varieties and strains, Cherokee wax, 49-3, Commodore, Top Crop, Rival, B_{1229}-1-2-6 and B_{1762} all showed cotyledonal cracking during germination when germinated under an excess of water, except the variety Cherokee.

In the second experiment seed planted with initial moisture of about 15.7, 12.0, 9.7 and 9.0 per cent in these strains (not beaten seed), did not have any effect on the germination or vigor of the seedlings 12 days after planting.

Ingalls (10) found that when beans at 20 per cent of moisture were germinated in sand the seedlings were more uniform than were seedlings from seed of 10 and 15 per cent of initial moisture.

SUMMARY

Forty one strains of pea beans were brought to three moisture levels, and were mechanically beaten to find out if there are differences among strains in susceptibility to mechanical damage.

A. Visible injury

1. Strains differed considerably in degree of visible injury due to mechanical beating.

2. There was an obvious relationship between the per cent of visible injury and the moisture content in each strain, the lower the moisture content of the seed, the greater the visible damage. At about 12.5 per cent of moisture in the seed, a considerable visible and internal damage was observed, when the seed was beaten at 997 r.p.m.

B. Invisible injury, as determined in germination tests.

1. There were highly significant differences between strains and between moisture levels in the number of (a) normal seedlings, (b) various types of abnormal seedlings.

2. The number of "normal" seedlings and the per cent of germination in beaten seed decreased as the content of seed moisture decreased.

3. The per cent of initial moisture (15.7, 12.0, 9.7 and 9.0), in these strains (not beaten seed), did not have any effect on the germination or vigor of the seedlings 12 days after planting.

C. Study of germination abnormalities is a far more sensitive measure of mechanical damage than is simple examination for visible injury.

LITERATURE CITED

1. Associated Seed Growers, Inc. A study of mechanical injury to seed beans. Asgrow Monograph. 1:1-45. 1949.

2. Atkin, John D. Relative susceptibility of snap beans varieties to mechanical injury of seed. Amer. Soc. Hort. Sci. Proc. 72:370-373. 1958.

3. Bainer, Roy, and Borthwick, H. A. Thresher and other mechanical injury to seed beans of the lima type. Calif. Agric. Exp. Sta. Bull. 580. 1934.

4. Borthwick, H. A. Thresher injury in baby lima beans. Jour. Agr. Res. 44:503-510. 1932.

5. Crosier, Willard. Baldheads in beans, occurrence and influence on yields. Proceedings of the Association of Official Seed Analysts. 118-123. 1942.

6. Handenburg, E. V., and Eto, W. H. The role of snakehead plants in beans. Amer . Soc. Hort. Sci. Proc. 51:486-492. 1948.

7. Harter, L. L. Thresher injury a cause of baldhead in beans. Jour. Agr. Res. 40:371-384. 1930.

8. Ingalls, R. A. A study of the occurrence of baldheads in beans and a comparison of their field performance with that of normal plants. Proceedings of the Association of Official Seed Analysts. 177-183. 1945-1946.

9. McAlister, Dean F., and Orland A. Krober. Translocation of food reserves from soybean cotyledons and their influences on the development of the plant. Plant Physiology 26 (3):525-538. 1951.

10. McCollum, J. P. Factors affecting cotyledonal cracking during the germination of beans (Phaseolus vulgaris). Plant Physiology 28: (2):267-274. 1953.

11. Murphy, Donald M. Bean improvement and bean diseases in Idaho. Idaho Agr. Exp. Sta. Bull. 238. 1940.

12. Nutile, G. E. Growth and yield of baldhead bean plants in the field. Proceedings of the Association of Official Seed Analysts 184-188. 1946.

13. Perry, J. S. Mechanical damage to pea beans as affected by moisture, temperature, and impact loading. Thesis for the degree of Ph.D., Mich. State Univ. 1959.

14. Steinbauer, G. P. Effect of baldhead injury in bean seedlings on yield of dry beans. Me. Agr. Exp. Sta. Bull. 438, p. 657. 1945.

15. Wester, R. E. Comparison of yield between normal and baldhead snap beans plants. Seed World 61 (2): 8-10. 1947.

16. Whitney, W. A. Mutilated seed a contributing factor in defective stands of Lima beans (abstract). Phytopath. 20:134-135. 1930.

17. Zaumeyer, W. J., and Thomas, H. Rex. A monographic study of bean diseases and methods for their control. U.S.D.A. Tech. Bull. 868. 1957.