Impact Effects on Germination and Seedling Vigor of Sugar Beets[1]

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The germination percentage of monogerm sugar beets is often lower than desired. This is of concern to farmers who wish to space-plant the seed to get a uniform stand.

This research was undertaken to determine if certain phases of the mechanical handling and processing operations of the seed may affect its germinating ability or seedling vigor. Sugar beet fruits are processed before planting. This processing operation, which involves decortication, removal of fruits containing no seeds and sizing, usually does not visibly harm the seed. Work by Perry and Hall[3] at Michigan State University has indicated that visible damage is an unsatisfactory measure for determining germination decreases of pea beans resulting from processing operations.

Two factors, inherent in the processing operations, which may cause germination decreases or loss of seedling vigor are moisture content of the seed and impact-loadings experienced during the processing operation. Higher or lower moisture contents may make the seed more or less subject to damage by the processing operation. Perry and Hall found that pea beans having relatively high moisture content are less subject to processing damage than are beans having a lower moisture content.

Impact-loads may result either from processing equipment striking the non-moving sugar beet fruit or from moving fruits striking an object. In either case the impact-load may be concentrated at a point or it may be distributed over an area depending upon the position of the fruit. Hence there appear to be at least three factors related to impact conditions which may lower seed germination or seedling vigor. These are magnitude of the impact energy; the time rate, or period, during which this impact energy is absorbed by the seed; and the point of

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[3] Perry, John S. and C. W. Hall, 1960. Germination of pea beans as affected by moisture and temperature at impact-loadings. Michigan Agricultural Experiment Station, Quarterly Bulletin 43(1): 33-39. Michigan State University. East Lansing, Michigan.

impact-loading the seed, e.g., seed position as related to impact-loads.

Although these factors may be obvious, precise measurement of them presents problems of considerable magnitude. Theoretically the most severe impact condition would be that in which the total impact energy is dissipated in a single contact on the smallest seed surface in the shortest period of time. The rate of energy absorption would be the greatest under this condition. Relative to the seed, the most severe impact-loading may actually be a small impact on the fruit which is transmitted to a point of the seed that is particularly sensitive.

Materials and Methods

Varieties of sugar beet seeds used were hybrids 62B24-20, 63B11-6 and (SL 126 × 128) ms × 5822-0. All three varieties were selected because of their demonstrated high germination capability. They were hand-processed as necessary for each experiment. Fruits were maintained at 68° F and at 40% relative humidity (approximately 10% moisture content, dry basis) or higher prior to treatment and were placed on a blotter to germinate the seed within 24 hours after treatment. Only those fruits which experienced no visual physical damage from the impact treatments were used in the tests. Daily counts were made of germinated seeds. Following a 7- or 10-day period, root and shoot lengths of all seedlings were measured in centimeters. Fruits with ungerminated seeds were bisected to determine if the fruit contained a developed seed.

Steel-sphere impact-loads

Sugar beet fruits, positioned on a ½-inch steel base-plate, were impact-loaded by dropping steel spheres through glass tubes (Figure 1). Appropriate cylindrical indentations were made in the base-plate to restrict or limit seed movement during the impacting process. A stand was used to hold the glass tubes in a vertical position. Clearance between the steel plate and the end of the glass tubes was about one-half the diameter of the sphere used. Glass tubes of different diameters were used to accommodate the steel spheres of different sizes. Combinations of tube-lengths and sphere-weights were used to get the desired impact-energies.

Differently shaped indentations were made in the base-plate to accommodate the fruits in various positions. Cylindrical indentations with flat bottoms were utilized while impacting fruits placed cap down in the base-plate. Cylindrical indentations with a conical base were used for impacting fruits on the cap. Two

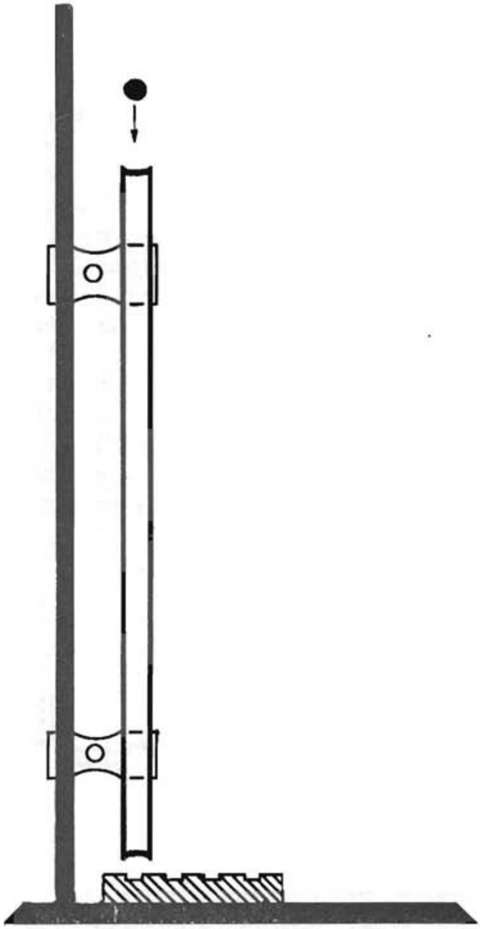

Figure 1.—Stand with glass tube, steel sphere and impact base-plate.

½-inch steel plates separated by shims were used to hold fruits which were impacted on their edge. Additional impressions were machined in the steel plates to hold the fruits so that their edges would be in a vertical plane.

The following imperfections in the above treatments are recognized: 1) generally the fruit was not in a completely unstrained condition when impact-loading occurred, 2) in nearly every case of impact-loading there was some rebound of the steel sphere. This indicated that the total energy had not been retained by the fruit during the initial impact. The magnitude of the rebound varied considerably from fruit to fruit.

Pneumatic impact-loads

The second method of impact-loading the individual sugar beet fruits was developed by F. H. Peto[4] of the British Columbia Sugar Refining Company in Vancouver, Canada. This method utilized compressed air, a venturi tube, and a steel impact-plate (Figure 2). The compressed air was connected to the venturi tube. Slight modifications were made in the apparatus to permit reasonably accurate reproduction of the tests. A gage, which measured static pressure only, was installed in the air line immediately before the venturi tube. The distance between the end of the venturi tube and the 3/8-inch steel impact-plate could be varied to whatever distance was desired. A screen cylinder approximately 8 inches in diameter was built using the steel impact-plate as one end. A circular screen section with a 1/2-inch diameter hole at its center was used to enclose the other end. Fruits could then be projected against the base-plate through the 1/2-inch opening. The screen cylinder retained all fruits treated in this manner.

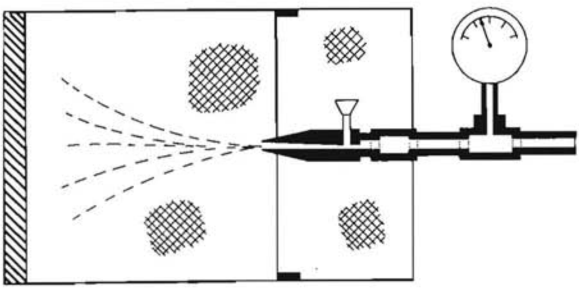

Figure 2.—Screen cylnder with 3/8" steel impact-plate on the left and sliding circular screen section inserted on the right. Seed was dropped through small funnel into high velocity air stream. Gage recorded static pressure.

Fruits were hand-processed and sized into 1/64-inch diameter classes (7/64, 8/64, 9/64 and 10/64). The venturi tube could not accommodate fruits larger than 10/64 inches in size. The air pressure could be regulated by manipulation of a valve. Fruits were dropped individually into the venturi tube and impacted against the steel plate. All the pneumatic tests were conducted with a pressure differential of 2 psi and a distance of 6 inches between the venturi exhaust and the steel impact-plate.

[4] F. H. Peto described this method in correspondence with F. W. Snyder and loaned the venturi tube to conduct the pneumatic impact experiments.

Results

Impact-energies of 63 gram-centimeters applied with a steel sphere were found to be detrimental to the fruit in any of the positions listed in Table 1. Each treatment consisted of 25 to 28 seeds and germination tests were over a 10-day period. Impact on the seedcap caused approximately 50% reduction in seedling vigor. Treatments on the butt of the fruit or perpendicular to the radicle of the seed caused about a 30% reduction in growth. Impact-loads on the micropyle were the least detrimental but still caused about a 14% decrease in seedling vigor. Seeds impacted by the steel sphere generally germinated. This was true even if the seedcap had been cracked or broken by the impact-load. However, vigor was impaired.

Table 1.—Effect of a single 63 gram-centimeter impact on different parts of processed fruits of sugar beet variety 62B24-20 with 25 to 28 seeds in each treatment.

Treatment	Average length		Percent of control	
	Root	Shoot	Root	Shoot
	Cm.	Cm.		
No impact	6.1	2.5	—	—
Impact on butt	—	—	67*	73*
Impact on micropyle	5.2	2.2	85	88
Impact perpendicular to radicle	4.2	1.8	69	72
Impact on cap	2.5	1.4	41	56

* Averages for 2 tests.

In another experiment, two steel spheres (0.44 and 1.03 grams) were used to apply impact-loads of various magnitudes (Table 2). These data represent three sub-experiments. Each treatment in a sub-experiment consisted of 25 to 28 seeds. Germination tests were over a 7-day period. Impact-energies as small as 25 gram-centimeters caused some reduction in root and shoot growth. Treatments of 43 and 65 gram-centimeters with the heavier sphere had nearly equal effects. The average reduction in growth was approximately 40% for the root and shoot. The

Table 2.—Effect upon seedling vigor of a single impact on seedcap when varieties 63B11-6 were used in sub-experiments A and B and (SL 126 $\times$ 128)ms $\times$ 5822-0 was used for sub-experiment C.

Impact energy / Sub-experiment	Percent of control					
	Root			Shoot		
	A	B	C	A	B	C
25 gram-centimeters, light sphere	98	80	98	79	79	83
43 gram-centimeters, heavy sphere	57	49	73	39	64	61
51 gram-centimeters, light sphere	104	95	92	93	107	78
65 gram-centimeters, heavy sphere	55	51	81	36	86	65

variation between experiments suggests that more research may be necessary to accurately evaluate impact-loads of this magnitude. The trend, however, is apparent.

Results of the 51 gram-centimeter impacts with the light sphere do not agree with the trends produced by the other impact-loadings. The diameter of this sphere was 0.475 centimeters while that of the glass tube was 0.500 centimeters. Fired ends of the glass tubes as received from the factory were generally contracted enough to prohibit passage of the sphere. These were removed before the tubes were used. Otherwise there were no indications of friction between the sphere and the tube. Results from the treatments (Table 2) implied that energy was consumed in the drop. Therefore in another experiment, a glass tube with a diameter of 0.600 centimeters was used (Table 3). Each treatment consisted of 50 to 52 seeds and the growth period was 7 days. A greater reduction in growth was experienced for both root and shoot with the larger tube when 25 gram-centimeters of impact-energy were used. For the 51 gram-centimeter impact-energies, the data from the larger diameter tube showed an 8% reduction in root growth but a 2% increase in shoot growth. This inconsistency is attributed to the biological variation in the seed. The same seed variety was used for sub-experiment C in Table 2 as was used for determining the data in Table 3.

Table 3.—Percent of control growth resulting after a single impact on the seedcap when the light steel sphere was dropped on (SL 126 × 128)ms × 5822-0 fruits*.

Tube diam. centimeters	0.500		0.600	
Impact-energies gram-centimeters	25	51	25	51
Root	99	94	95	86
Shoot	98	82	97	84

* Control root length 6.7, shoot length 3.1 cm.

Pneumatic impact-loads

Sugar beet fruits may be impact-loaded when conveyed by air or when striking a surface or object after a free fall through the air. Fruits were hand-processed and the 7-10/64-inch diameter fruits were used in the pneumatic system. Air pressure differential was reduced to a level (2 psi) where virtually no observable physical damage occurred to the fruit from a single impact. Later calculations indicate that this impact-energy was of the order of 29 gram-centimeters for a fruit having a weight of 0.0125 grams. Repeated application of the impact-load caused some fruits to shed their caps.

Table 4.—Effect of pneumatic impact on germination and vigor of seedlings of processed sugar beet fruits, (SL 126 × 128)ms × 5822-0.

No. impacts	Percent seeds germinated	Average length		Percent of control	
		Root	Shoot	Root	Shoot
		Cm.	Cm.		
0	94	4.9	2.0	----	----
1	95	----	----	----	----
3	92	3.5	1.5	71	75
5	77	3.2	1.3	65	65

Table 5.—Comparison of type* and number of impacts on seedling vigor of hand-processed (SL 126 × 128)ms × 5822-0 fruits.

Treatment	Fruit diam. inches		Growth as percent of control**				
			Number of impacts				
			1	2	3	4	5
Sphere	9/64	Root	96	93	92	80	81
		Shoot	97	92	93	80	84
	8/64	Root	----	----	79	77	72
		Shoot	----	----	74	74	73
	Average	Root	----	----	86	79	77
		Shoot	----	----	84	77	79
Pneumatic	9/64	Root	85	78	70	66	60
		Shoot	78	70	64	64	73
	8/64	Root	----	----	60	53	64
		Shoot	----	----	60	53	64
	Average	Root	----	----	65	60	62
		Shoot	----	----	62	59	68

* Steel-sphere impacts of 32 gram-centimeters or pneumatic impacts using 2 psi pressure differential.
** 9/64-inch fruits—control, root length 6.3, shoot length 2.4 cm.
8/64-inch fruits—control, root length 6.8, shoot length 3.2 cm.

The pneumatic impact-load applications reduced vigor similar to that caused by the steel spheres (Table 4). Each treatment consisted of 110 to 120 seeds with a 7-day growth period. Three impacts reduced root growth 29% and shoot growth 25%, while five impacts reduced both root and shoot growth 35%. The data indicate that the seeds were capable of withstanding three impacts of this magnitude without a serious decrease in germination, however, five impacts reduced their germination capability by 17%.

Another experiment using the steel sphere and the pneumatic systems of impact-loading confirmed that both methods were capable of reducing seedling vigor (Table 5). Each treatment consisted of 50 to 56 seeds and a 7-day growth period. The re-

Table 6.—Comparison of type* and number of impacts on percentage germination of seeds in hand-processed (SL 126 × 128)ms × 5822-0 fruits.

Treatment		Number of impacts 1	2	3	4	5
Sphere	Exp. 1	92	95	98	93	95
	Exp. 2	----	----	96	98	98
	Average	----	----	97	96	97
Pneumatic	Exp. 1	96	96	93	79	79
	Exp. 2	----	----	94	81	84
	Average	----	----	94	80	82

* Steel-sphere impacts of 32 gram-centimeters or pneumatic impacts utilizing 2 psi pressure differential.

lationship between fruit size and a given impact-load is illustrated in the steel-sphere treatments. The seeds in the larger fruits suffered less growth reduction from repeated impacts of a given energy level than did the seeds in the smaller fruits. For the given conditions, these results imply that fruits with larger than 9/64-inch diameters would have suffered even less reduction while fruits with smaller than 8/64-inch diameters would have suffered an even greater reduction in seedling vigor. Similar reductions were obtained from the pneumatic treatments. No attempt was made to distinguish between energy levels when 8/64 or 9/64-inch diameter fruits were used in the pneumatic system.

Results for the five pneumatic impacts in Tables 4 and 5 are in good agreement, each showing an average reduction in root and shoot growth of 35%. Results from the three pneumatic impacts are not in such close agreement. The percentage reductions of root and shoot growth usually followed each other very closely for either method of impact-loading. Therefore, when a sufficiently large number of seeds are used in an experiment, a measurement of root growth should generally be adequate to determine reductions resulting from impact treatments.

Germination percentages in this experiment were not decreased by the steel sphere impact-loading but were decreased by repeated pneumatic impact-loads (Table 6). The first three pneumatic impacts caused virtually no decrease in percentage germination of the seed. After the fourth impact, however, there was a definite decrease. This observation is in agreement with results in Table 4 where the percentage germination decreased significantly between the third and fifth pneumatic impacts. Therefore the fourth pneumatic impact seemed to be of critical significance.

Discussion

Energy of steel-sphere impacts

The two methods of impact-loading can be subjected to a more critical analysis. The potential energy of the steel sphere is equivalent to the weight of the sphere multiplied by the height that it is suspended above the sugar beet fruit. When the sphere is dropped, the potential energy is converted to kinetic energy. At impact the kinetic energy is absorbed by the fruit if no rebound occurs. A sample energy calculation is shown below.

$$1.03 \text{ gram} \times 31 \text{ centimeters} = 32 \text{ gram-centimeters}$$

If rebound occurs, the fruit returns part of the energy to the steel sphere. This rebound may be of a variable nature depending on the conditions of impact. If the fruit shifts its position while impact-loading occurs, some energy is utilized in producing this movement and the sphere is deflected against the glass tube. The resulting rebound is of a smaller magnitude and the fruit itself often rebounds. Consequently the second impact resulting from the rebound may strike the fruit at a different point. With a 31-centimeter drop for the heavier sphere, maximum rebounds of slightly over 10 centimeters were observed. Hence the energy retained by the fruit during the initial impact was only about 20 gram-centimeters. The importance of the rebound seemed less significant, however, than the overall effect of impact-loading the fruit. Neglecting friction and impact losses between the sphere and glass tube, the total kinetic energy was finally absorbed by the fruit.

If the sphere is dropped several times from a given height on a fruit, the net effect is not additive and does not compare to a single drop involving the same net energy. For example, a fruit may be able to absorb two impact-loads of 25 gram-centimeters each but may not be able to withstand a single impact-load of 50 gram-centimeters. The difference is caused by the time during which the fruit absorbs the energy.

Energy of pneumatic impacts

The pneumatic method of impact-loading proved to be very capable of injuring the seed. Preliminary tests were run using 10, 15 and 20 psi pressure differentials across the venturi tube. Impacts produced with these pressure differentials mutilated nearly every fruit. Consequently the pressure difference was reduced to a final value of 2 psi. Calculations were made to estimate the kinetic energy of a sugar beet fruit when accelerated by this pressure difference.

To make these calculations, the pressure gage and venturi tube were connected to a pressure regulating valve installed in a steel pressure cylinder. This container was filled with compressed air and weighed. The air was then exhausted at a rate which gave a 2 psi pressure differential across the venturi tube. Diameters of the venturi throat and exhaust were 0.188 and 0.290 inches, respectively. The time required to exhaust about 80% of the air was determined and then the cylinder was weighed again. By using the time interval required to release a definite weight of air, we calculated the velocities at the venturi throat and exhaust to be 430 and 165 ft/sec, respectively. If 10% additional air was drawn in through the seed injection tube, the final velocity at the venturi exhaust was near 180 ft/sec.

When a fruit was dropped into the venturi tube, the flow of air was restricted thus causing an instantaneous pressure build-up. This caused the air velocity to increase around the perimeter of the fruit which was being accelerated. Flotation velocities for 8/64 and 9/64-inch diameter hand-processed sugar beet fruits were found to be approximately 17 ft/sec. With the assumption of a 50% velocity increase around the fruit perimeter, calculations of particle acceleration in an air stream indicated an impact velocity of 70 ft/sec.

The kinetic energy of a fruit weighing 0.0125 grams and moving with a velocity of 70 ft/sec may be calculated as shown below.

$$
\begin{aligned}
KE &= \tfrac{1}{2}mv^2 = \tfrac{1}{2}\frac{w}{g}v^2 \\
&= \tfrac{1}{2}\ \frac{(0.0125)}{(32.2)}\ (70)^2 = \text{gram-ft} \\
&= \tfrac{1}{2}\ \frac{(0.0125)}{(32.2)}\ (70)^2\ (12)\ (2.54) \\
&= 29 \text{ gram-centimeters}
\end{aligned}
$$

The observable physical damage, if any, was about equal when the 32 gram-centimeters of impact-energy applied with the steel sphere were compared with the 29 gram-centimeters applied with the pneumatic system. The exact nature of the seed damage resulting from either the steel sphere or the pneumatic impact-loads is not known. During the germination tests several cases of seed fracture were observed. The reduction in seedling vigor as well as some deformed and abnormal growths were the most prominent characteristics of the treated seeds. The abnormal seedlings possibly developed from injured embryos which could not support normal growth. For the given magnitudes of impact-energy, the data (Table 5) indicate that the physical damage to the true seed was greater from pneumatic impact-loading.

Fruits which were subjected to repeated treatments with the steel sphere eventually failed by chipping or cracking of the seedcap. The nature of the loading, however, tended to keep the cap in position even though it may have been cracked or loosened. Hence, if the seed had the ability to begin germination, it may have had little difficulty in emerging from the fruit. This may have been possible even if the seedling was damaged and never developed normal growth.

Shedding of the seedcap was the most common physical damage observed when fruits were treated repeatedly with the pneumatic system. The implication was, however, that the seed inside the fruit could be damaged without any apparent damage to the fruit. If this was the case, the damaged seed may have never developed enough energy to force the seedcap from its base, and hence an ungerminated seed resulted.

Impact-energy from free fall

Hand-processed fruits impelled vertically into the air with the pneumatic system traveled to various heights. Possible reasons for the height variations are: 1) configuration of the fruit, 2) fruit trajectory, 3) density of the fruit and 4) extent to which fruit was processed.

Configuration of the fruit obviously had an influence on its trajectory. Fruits which stayed in the air stream after leaving the venturi were impelled higher than those whose trajectory carried them out of this stream. Weight or density of the fruit also was an important factor. Weights of individual (SL 126 $\times$ 128) ms $\times$ 5822-0 fruits with diameters of 7/64-inch or larger varied as much as six-fold. Extent of processing affected the density of the fruits. In this research only hand-processed fruits were used. Omitting extreme values, most fruits when projected through the venturi at 2 psi pressure differential were impelled to heights of 15 to 20 feet. Since the density of the fruit was relatively low, the air had a considerable impedance effect. This may be visualized from a study of the flotation or terminal velocities of hand-processed sugar beet fruits. Preliminary work indicated this maximum velocity to be approximately 25 ft/sec. Therefore, in a vacuum, the atmospheric flotation velocity would be achieved in approximately eight-tenths of a second, as calculated below.

$$s = 16.1\ t^2$$

$$\frac{ds}{dt} = v = 32.2\ t$$

$$\frac{25}{32.2} = t = 0.8\ \text{sec}$$

The distance within which this velocity would be achieved in a vacuum is

$$s = (16.1)\ (.64) = 10.3\ \text{ft}$$

In the air, the fruit would not accelerate as rapidly and theoretically would never reach its flotation velocity. The implication is, however, that near flotation velocity is reached within a relatively short distance.

If flotation velocity in the air is 25 ft/sec and this velocity is achieved in a vacuum after a 10.3-foot free fall, then the maximum kinetic energy of the fruit can be calculated. Assume the individual fruit has a weight of 0.0125 gram.

$$0.0125\ \text{gram} \times 10.3\ \text{feet} = \text{energy, gram-feet}$$

$$0.0125 \times 10.3 \times 12 \times 2.54 = 3.9\ \text{gram-centimeters}$$

The kinetic energy of a hand-processed fruit (0.0125 gram) experiencing a free fall should never be very much in excess of 3.9 gram-centimeters. The heaviest but not necessarily the most dense hand-processed fruit encountered in this research weighed 0.0312 grams. Its flotation velocity was less than 25 ft/sec. The impact energy resulting from an unlimited free fall of this fruit would approach 9.8 gram-centimeters. These energy levels are quite small when compared to the impact-loads of 25 gram-centimeters or greater per impact which were applied with the steel spheres. Therefore the conclusion may be drawn that hand-processed sugar beet fruits normally should not experience reduction in vigor or germination capability from impacts received after free falls of virtually any length.

Conveying velocities are often as much as 50% higher than flotation velocities. If physical damage to the fruit is disregarded, maximum velocities are limited only by the equipment used. This research has indicated that reduction in germination and seedling vigor is possible before observable physical damage occurs to the fruit. Conveying velocities equivalent to two or three times the flotation velocities may cause fruits to reach energy levels which are detrimental to germination and seedling growth. Numerous impacts of a smaller magnitude may produce a similar reduction. Therefore caution is suggested when pneumatic systems are used to convey sugar beet fruits. The minimum air velocity which will successfully convey the fruits is recommended.

Summary and Conclusions

Hand-processed sugar beet fruits were impact-loaded by dropping steel spheres through glass tubes onto the fruits and also by accelerating the fruits with a pneumatic system and projecting them against a steel impact-plate. Fruits were impact-loaded in different positions with a steel sphere. Reduction in seedling vigor was most apparent when fruits were treated on the seed-cap. Single impact-loads as small as 25 gram-centimeters applied by a steel sphere reduced root growth approximately 6% and shoot growth 13%. Single pneumatic impacts having an estimated impact-energy of 29 gram-centimeters reduced the root growth 15% and the shoot growth 22%. Five pneumatic impact-loads of this same magnitude reduced root and shoot growth approximately 35%. Smaller fruits suffered more reduction in germination and seedling vigor than did larger fruits for a given level of impact-energy applied repeatedly with a steel sphere. Generally, the percentage reductions in root and shoot growth were so similar that root measurements would have been sufficient for determining the reduction in seedling vigor.

Theoretical considerations combined with experimental results indicate that neither seedling vigor nor germination should be reduced by impacts resulting from free falls of any distance by a sugar beet fruit. Impact-energies are dependent upon the velocity and weight of the fruit. In practical applications the impact energy of 29 gram-centimeters is approximated by an impact-velocity of 70 ft/sec when the fruit weight is 0.0125 grams.

Seedling vigor and percentage germination can be reduced through the application of impact-loads without visibly harming the sugar beet fruit. Seeds which were impact-loaded three times with the pneumatic system showed a small reduction in percentage germination. Seeds which were impact-loaded four times experienced a considerably greater reduction in percentage germination. The fourth pneumatic impact seemed to be of critical significance.