THE EFFECT OF IMPACT ON GREEN STOCK CARPEL STRENGTH AND BRINE STOCK QUALITY FOR CUCUMBERS CUCUMIS SATIVUS L.

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ABSTRACT

THE EFFECT OF IMPACT ON GREEN
STOCK CARPEL STRENGTH AND BRINE
STOCK QUALITY FOR CUCUMBERS
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By

Alan W. Hooper

Knowledge about the effect of a given impact on cucumber quality would be valuable information to both the manufacturer and the design engineer. Quality was measured by green stock carpel strength and by bloater occurence in brine stock. The purpose of this study was two fold: (a) to determine the relationship of controlled impact on green stock carpel strength and brine stock quality, and (b) to investigate methods for improvement of accuracy in measurement of green stock carpel strength.

Controlled impact was accomplished with a drop impactor. Cucumbers were then brined or tested for green stock carpel strength. Two relaxation tests (force-relaxation and deformation-relaxation) and a carpel separation test (probe forced through a cross-sectional slice) were used for the evaluation of carpel strength.

Brine stock quality, as measured by the size and frequency of internal voids (lens or balloon bloat) decreased as impact levels increased. Impacts on the center region of the cucumber resulted in more severe internal

damage than impacts on the blossom end. Single impacts resulted in an increased frequency of lens bloating whereas it was questionable if a single impact increased the frequency of balloon bloating.

A decrease in carpel strength due to an impact was detectable if measured soon after impact. However, the ability to detect a decrease tended to be more difficult as time after impact increased. Relaxation tests, performed on a cross-sectional slice, seemed to be the most suitable method for detection of an impact.

Carpel strengths varied between varieties of pickling cucumbers as shown through application of the carpel separation test. Additional parameters, primarily related to product texture, hindered the objective measurement of both relaxation tests evaluated. Although more variable, the carpel separation test was best suited for the measurement of carpel strength between varieties.

APPROVED:

D. R. Heldman
Major Professor

D. R. Heldman
Department Chairman,
Agricultural Engineering

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure | Page

NOMENCLATURE

AREA-D	A number proportional to the area under the force-relaxation curve.
AREA-F	A number proportional to the area under the deformation-relaxation curve.
CSF	Carpel separation force, gmf.
DEF	Deformation recorded for the force-relaxation test, cm.
g	Gravitational acceleration, m/sec^2.
h	Height of drop, in.
m	Mass of Impactor, Kg.
LSR	Statistic calculated from Tukeys w-procedure.
PE	Potential energy, Kg m^2/sec^2.
PEAK FORCE	Peak force value from deformation-relaxation curve, gmf.
R	Ratio of rebound impact force to initial impact force.

CHAPTER I

INTRODUCTION AND OBJECTIVES

Before the development of canning and mechanical refrigeration, vegetables, meat, and fish were preserved by either salt and acid, or by dehydration. It is desirable yet today to store and cure pickling cucumbers (*Cucumis sativus* L.) in a salt and acid solution (brine). This facilitates the extension of the processing period by allowing storage for a portion of the large volume of cucumbers that are harvested over a short period of time. Those cucumbers not stored are used in the manufacture of various pickle products from the fresh cucumbers (fresh pack).

A reoccurring problem in the pickling industry is the bloating of cucumber fruits. Bloating is caused by gas pressures produced during the brining process which lead to internal voids. Two types of bloating (voids) occur; (1)balloon bloat, and (2) lens bloat. A balloon bloat is formed when the carpel suture separates thus leaving an internal void parallel with the longitudinal axis of the cucumber. A lens bloat is a void that has formed within the carpel with its major axis generally perpendicular to the longitudinal axis of the cucumber. Researchers may refer to a series of lens separations as "honey comb" bloat. The lens bloat is usually smaller than a balloon bloat.

The loss in quality of cucumbers during the brining process is a primary interest to the processor. Bloating, both lens and balloon, causes a cucumber to be of lower quality by reducing the acceptability of appearance. The value of this product to the consumer and the processor is therefore reduced.

In terms of economic value, a balloon bloat reduces the sale value of a cucumber by at least 50% or more. A lens bloat does not generally produce as severe a loss as a balloon bloat. The unaffected area of a lens bloat can be used for products other than relish, whereas balloon bloating usually channels the entire cucumber towards relish stock. In addition, the labor cost required to separate the good cucumbers from the defective ones increases the overall economic loss.

Increased handling of cucumber fruits prior to brining may result in an increased frequency of bloater formation (Marshall et al. (1971)). This indicates that frequency and/or magnitude of impacts of cucumber fruits throughout the handling process leads to the observed increase in bloater frequency. In addition, it has been illustrated that, as the carpel suture strength increases, the potential for balloon bloating decreases (Hooper et al. (1972b)). It follows therefore, that the observed occurrence of bloating can, at least indirectly, be attributed to both internal and external parameters.

The overall objective of this study was to determine the effect of handling on green stock carpel strength and brine stock quality through the use of simulated impact, and to evaluate the accuracy of different methods for measuring carpel strength of cucumbers. This objective can be summarized in the following specific areas:

(1) To determine the effect of controlled impact on bloating frequency and severity.

(2) To determine the effect of impact magnitude on the carpel strength.

(3) To determine the effect of variety on the carpel strength.

(4) To compare carpel strength as measured by carpel separation and relaxation tests.

CHAPTER II

LITERATURE REVIEW

Significant impacts on any biological product damages, internally and/or externally, at least a portion of that product. Humphries (1968) found that the probability of internal rupture of cucumber fruits increased both as the magnitude of the impact and the size of the fruit increased. Humphries (1968) also found that impacts on the blossom end parallel to the longitudinal axis resulted in the highest frequency of internal rupture. The effect of mechanical handling on green stock cucumbers was evaluated by Marshall et al. (1972), and revealed that cucumbers harvested mechanically accounted for more broken, smashed, and damaged cucumbers than those harvested by hand. Marshall et al. (1971) also evaluated the effect of handling on the brine stock quality of cucumbers and found that both lens and balloon bloating increased as the stage of handling progressed.

Duplication of product handling, through the use of controlled impact, has been investigated for several products. Fluck and Esam (1972) discuss five different types of impacting equipment: (1) drop impactor, (2) pendulum impactor, (3) pheumatic impactor, (4) spring loaded arms, and (5) arms rotated by electric motors. Nelson and Mohsenin (1968) and Park (1963) were able to correlate bruise volume with absorbed impact energy. Horsfield et al. (1970) and Fridley and Adrian (1966) found that the same injury was caused either by multiple impacts of low energy per impact or fewer impacts with more energy per impact. Fluck and Esam (1972) provided evidence to support a hypothesis that the critical element in the occurrence of impact damage was the peak force of the force-time curve.

Using a drop impactor, Stout and Norris (1970) and Segerlind and Moerdyke (1971) presented results indicating that the occurrence of lens bloat increased as the impact energy increased. However, different levels of impact did not seem to affect the frequency of balloon bloating.

Jones et al. (1954) found that variety was a factor associated with bloating potential. The frequency with which green stock carpel separation occurred was reported by Sneed and Bowers (1970) to have a negative correlation with bloating. Hooper et al. (1972a) developed a technique for the measurement of carpel strength for cucumber fruit slices. This technique provided a tool for measuring carpel strengths of cucumbers which did not have visible carpel separation already present. Hooper et al. (1972b) found a significant difference between carpel strength of different varieties. In addition, results showed an inverse relationship between the frequency of balloon bloating and carpel strength.

Another aspect which must be considered when conducting tests for bloaters is the role of yeasts and bacteria in bloater formation. Etchells *et al*. (1968) found bloating to be associated with gaseous fermentation caused chiefly by yeasts. However, acid forming bacteria (*Lactobacillus brevis*) was also found to cause bloating of the same form as that attributed to yeasts.

Sorbic acid has been examined in several research studies for its control of bloating frequency. Costilow *et al*. (1955) found that sorbic acid inhibited the growth of yeasts effectively at pH 5.0 and below. The lactic acid bacteria were not greatly affected by the sorbic acid at any pH. Costilow (1957) also showed that sorbic acid delayed the curing of salt stock cucumbers with the delay increasing as sorbic acid concentrations increased. For concentrations between .02 and .1% sorbic acid, the occurrence of bloaters was significantly reduced.

To describe the effect of impact damage on bloating, one must first visualize the anatomical structure of the cucumber. Connor (1969) describes this structure and a representative cross-sectional view is given in Figure 1. In the development process, the ovary begins as a trimerous structure. Continued growth results in the formation of three carpels joined together by a carpel suture. The edges of the carpels remain T shaped with the infolded edges forming the placenta. From the placenta, the ovules arise.

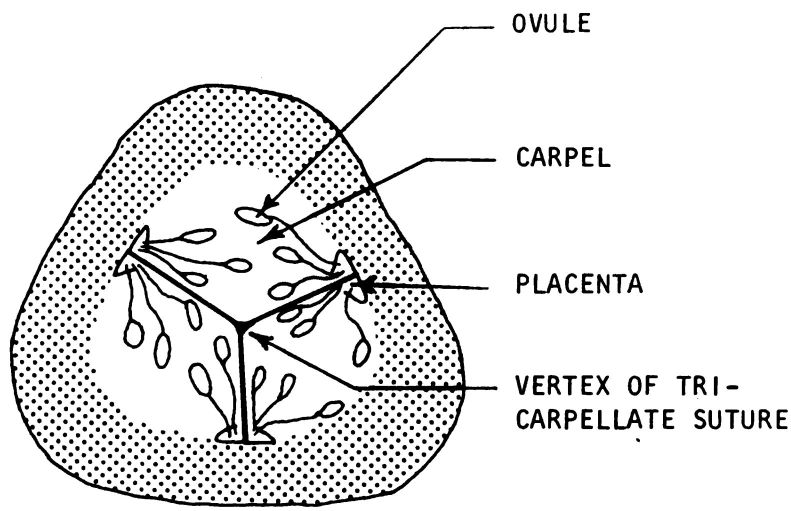

FIGURE 1 DIAGRAMMATICAL SKETCH OF A CROSS-SECTIONAL CUCUMBER SLICE.

CHAPTER III

MATERIALS AND METHODS

The following discussion is divided into four separate sections. The first section describes three methods for evaluation of carpel strength. The second section describes the materials and methods used for the impact experiments. Brining procedures for the impacted samples are detailed in section three, while the last section deals with definitions of defects and brine stock analysis.

Carpel Strength Tests

All carpel strength tests used the experimental apparatus shown in Figure 2. The components of this setup were: (1) an Instron Universal Testing Machine with an area integrator; (2) a Magness-Taylor shape probe (Magness and Taylor, (1925)), 3/16 in. diameter; (3) a slice support (1.375 in. inside diameter); (4) a load cell (0-50 Kg sensitivity); and (5) a cucumber slice, (0.25 in. thickness taken cross-sectionally). Uniform slices were obtained using the slicer shown diagrammatically in Figure 3. A diagrammatical closeup of the slice support and probe is shown in Figure 4.

FIGURE 2 PHOTOGRAPH OF THE INSTRON MACHINE AND AREA INTEGRATOR USED FOR CARPEL STRENGTH TESTS.

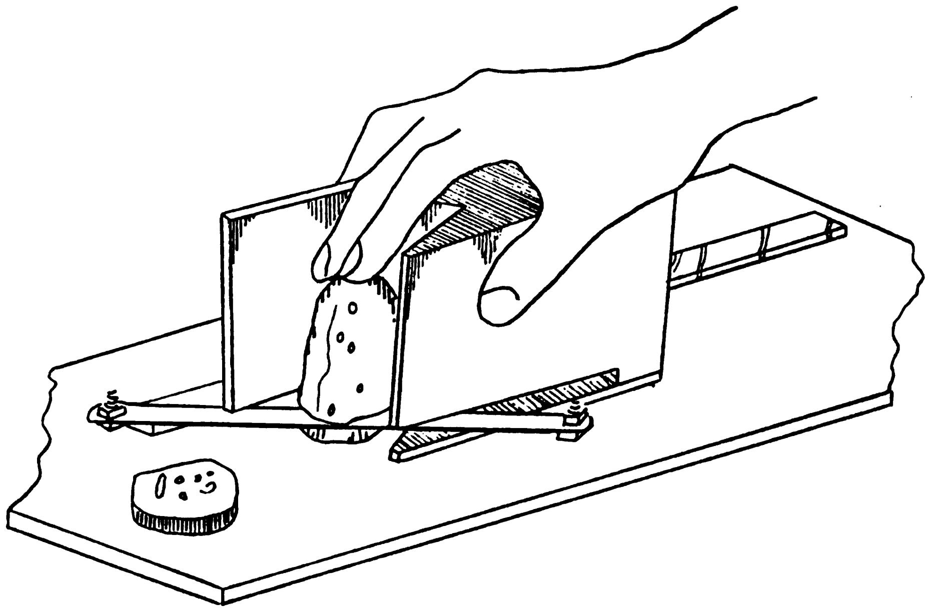

FIGURE 3 DIAGRAMMATICAL SKETCH OF THE CUCUMBER SLICER USED FOR OBTAINING UNIFORM SLICES.

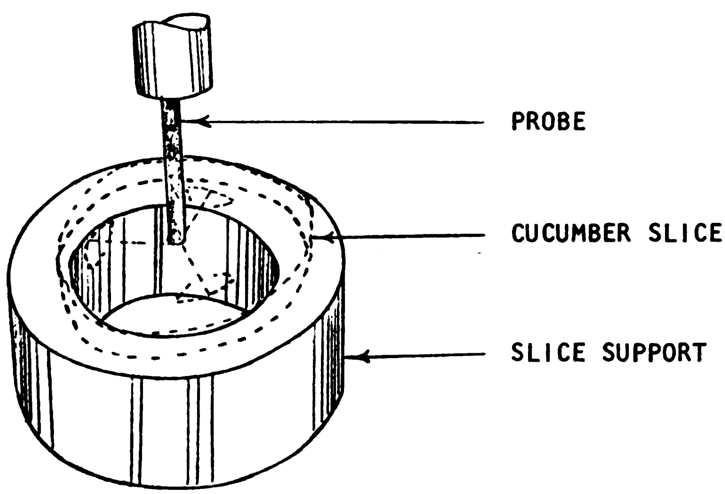

FIGURE 4 DIAGRAMMATICAL CLOSEUP OF THE SLICE SUPPORT AND PROBE.

Mohsenin (1970) discussed various tests used to study viscoelastic materials. Among these tests were stress-strain, creep, stress relaxation, and dynamic tests. The test of interest in this study was the relaxation test. Ideally, a specimen is suddenly brought to a given deformation and the stress required to hold that deformation is measured. The time of relaxation is one of the more important parameters obtained from the stress relaxation test (i.e. time required for the stress to decay to 1/e of the initial stress).

A force level or deformation level was applied, in this study, using a probe speed of 2 cm/min. When a given force level or deformation level had been obtained, then the probe was stopped and the specimen was allowed to relax.

The carpel strength was measured using three different methods. The first method was the carpel separation test as described by Hooper et al. (1972a). This method involved separating the carpels of a cross-sectional slice by forcing a 3/16 in. diameter Magness-Taylor shape probe through the vertex of the tri-carpellate suture. The peak force (CSF, in units of gm-force) for this separation was recorded. The probe speed for this test was 10 cm/min. Figure 5 illustrates a typical curve obtained from the carpel separation test.

The second test used was a deformation-relaxation test. In this test, the probe was lowered until contact with the slice was made. After contact, the probe descended at a rate of 2 cm/min until a slice deformation of 0.3 cm had been obtained. The probe was then stopped and held at that position for one minute (time was measured from the time of initial probe slice contact). The peak force (PEAK FORCE, in units of gm-force) and a number (AREA-F) from the integrator proportional to the area under the curve was recorded. Figure 6 illustrates a typical curve obtained from a deformation-relaxation test.

The third test was the force-relaxation test. It was the same as test no. 2 with the exception that the probe was stopped and held after a force level of 150 gm-force had been obtained. The deformation (DEF, in units of cm) required for that force level and a number (AREA-D) from the integrator proportional to the area under the curve was recorded. A typical curve obtained from the force-relaxation test is shown in Figure 7. AREA-F and AREA-D can be converted to actual area with units of gm-force-sec upon multiplication by 6.0. For ease of writing, gm-force will be written hereinafter as gmf.

All cucumbers tested for carpel strength were prepared in the same manner. The length and diameter of the cucumber was recorded. A position 0.25 in. from the middle of the

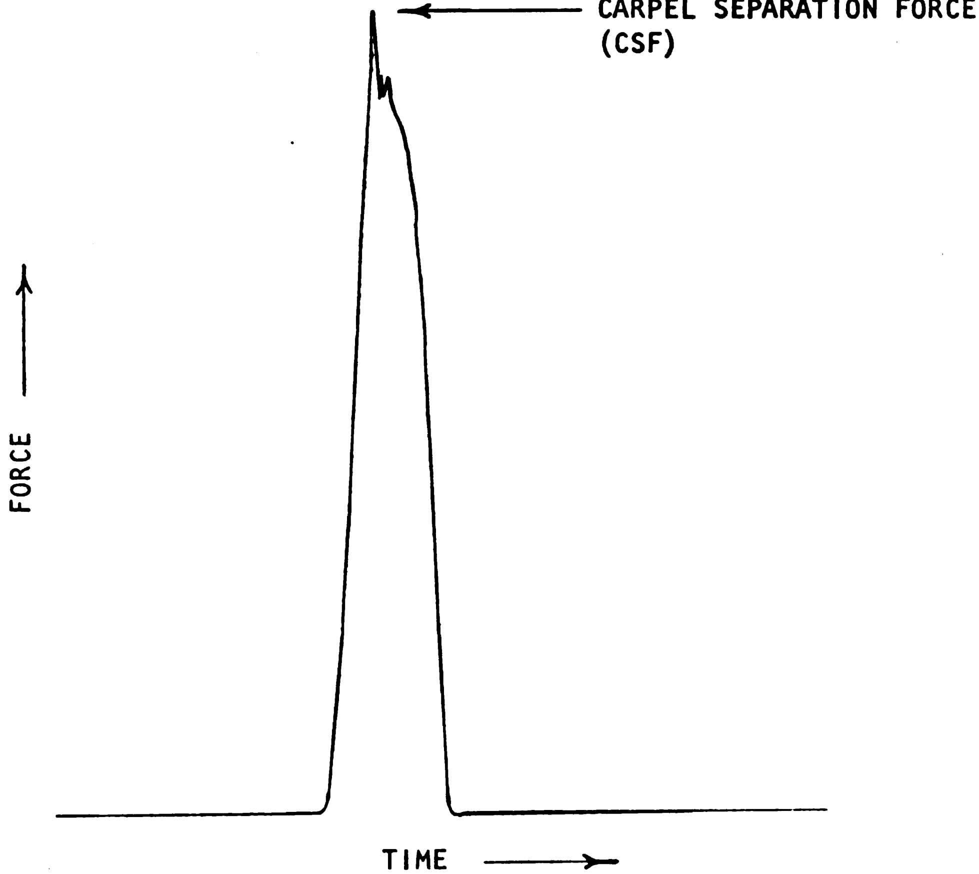

FIGURE 5 ILLUSTRATION OF A TYPICAL CURVE OBTAINED FROM THE CARPEL SEPARATION TEST SHOWING THE RESPONSE RECORDED.

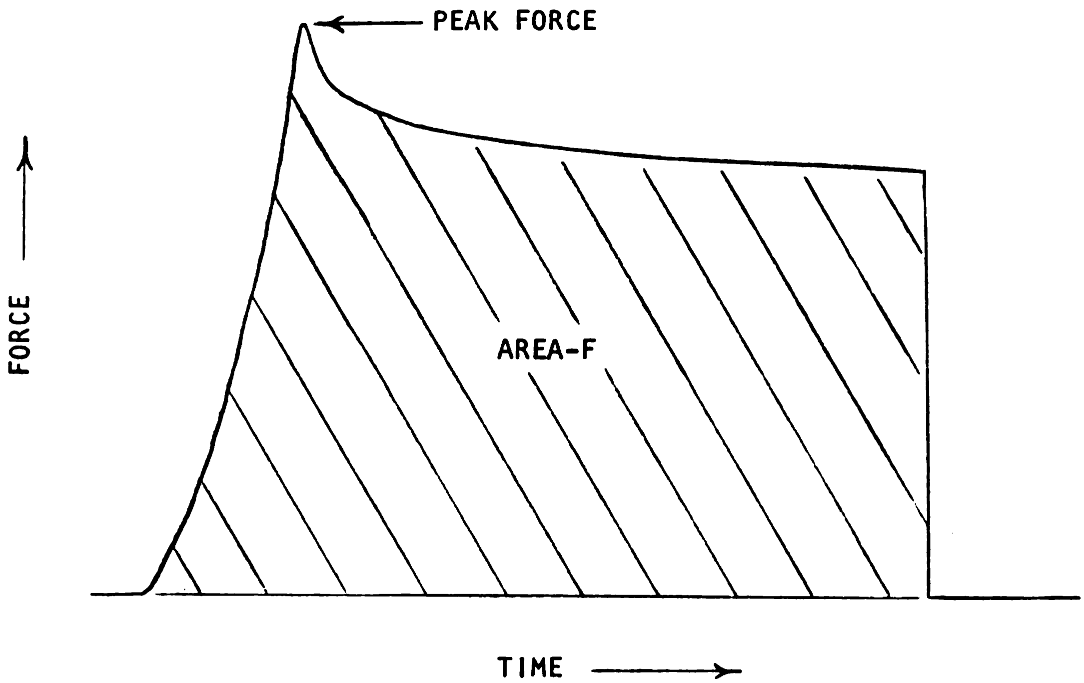

FIGURE 6 ILLUSTRATION OF A TYPICAL CURVE OBTAINED FROM THE DEFORMATION-RELAXATION TEST SHOWING THE RESPONSES RECORDED.

cucumber towards the blossom end was identified. At this position, the cucumber was cut cross-sectionally with a sharp knife. Three slices were then taken towards the stem end, each slice having a thickness of 0.25 in. The first slice was subjected to the carpel separation test; the second slice was used in the deformation-relaxation test; and the third slice was used in the force-relaxation test. The probe always approached the slice in a direction towards the stem end. The appropriate responses were recorded. Figure 8 shows the location of slices taken for a given carpel strength test.

There was no control over the harvest time or delivery of the cucumbers to the testing laboratory. Harvest times ranged from 8:00 A.M. to 4:00 P.M. and testing ranged from 1:00 P.M., the same day of harvest to 4:00 P.M., the day after harvest. All cucumbers were hand harvested and machine graded for size no. 3 (1.5 to 2.0 in. diameter).

Carpel strength measurements were taken on the following specific samples:

(1) Samples collected for impacting

(2) Pioneer variety; harvested on August 21, 1972; 25 cucumbers

(3) 601H variety; harvested on August 22, 1972; 25 cucumbers

(4) 381M variety; harvested on August 25, 1972; 25 cucumbers

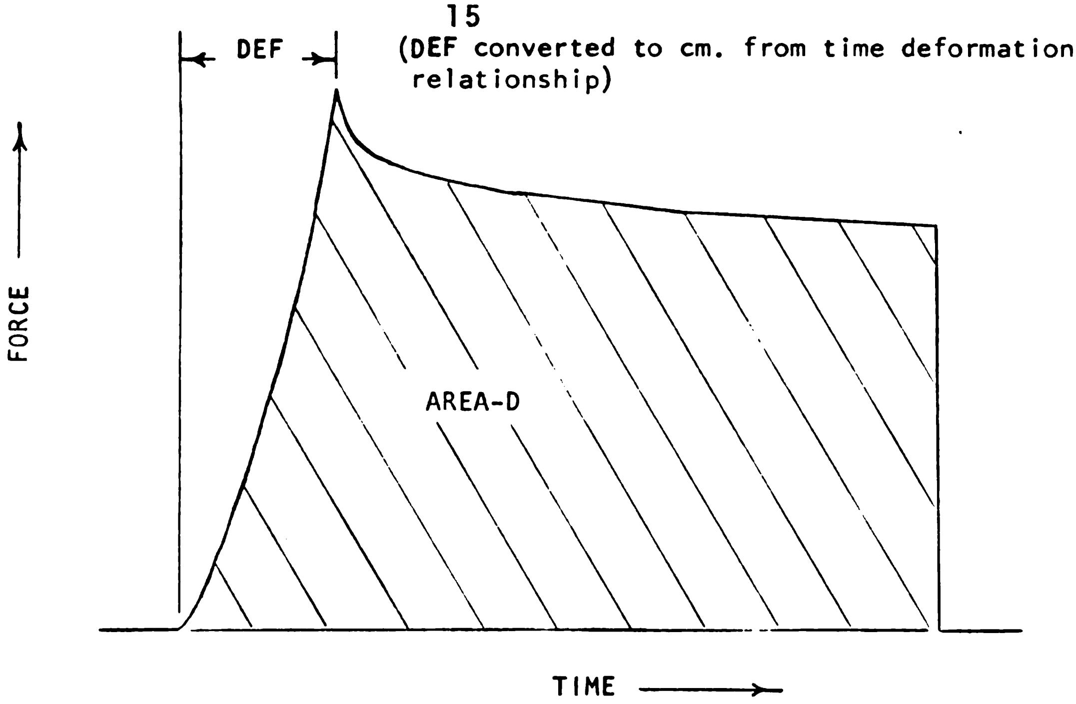

FIGURE 7 ILLUSTRATION OF A TYPICAL CURVE OBTAINED FROM THE FORCE-RELAXATION TEST SHOWING THE RESPONSES RECORDED.

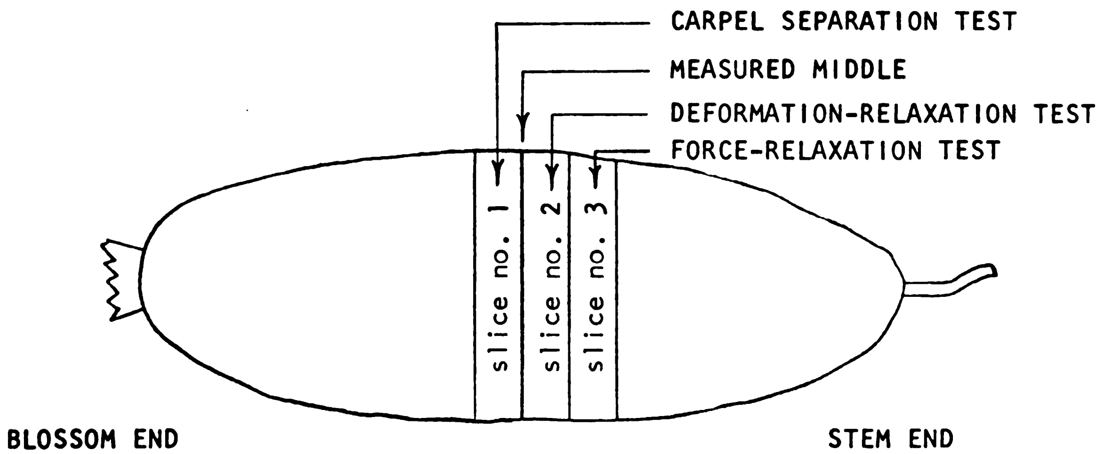

FIGURE 8 LOCATION OF SLICES FOR A GIVEN CARPEL STRENGTH TEST.

Samples 2 through 4 were harvested from the same field (Eaton Rapids, Mich.) and received no storage treatment (i.e. 50°F, 95% RH) prior to testing. Pioneer was a standard commercial hybrid variety and both 601H and 381M were monecious breeding lines.

Impact Experiments

All samples were hand harvested and brought to the laboratory for testing. Only size no. 3 cucumbers (1.5 to 2.0 in. diameter) were tested. The time of harvest was not controlled but each sample (with the exception of those harvested on September 11, 1972) received approximately 15 hours storage treatment in a 50°F, 95% RH room before being tested. The impact device is shown diagrammatically in Figure 9. Figure 10 shows the two types of impact examined. The impact procedure was as follows:

> The length and diameter was recorded for each cucumber. The cucumber was then coded with black indelible ink and placed on the force transducer (Model 912 quartz load cell with compression range of less than 1 lb. to 5000 lbs.). A circular flat impactor (1.125 in. diameter) with a total mass of 221.5 gm (including the impactor guide) was raised to a predetermined height with the position of the impactor being held by an electromagnet (power derived from Model 1020 D.C. Eico power supply). When the power to the

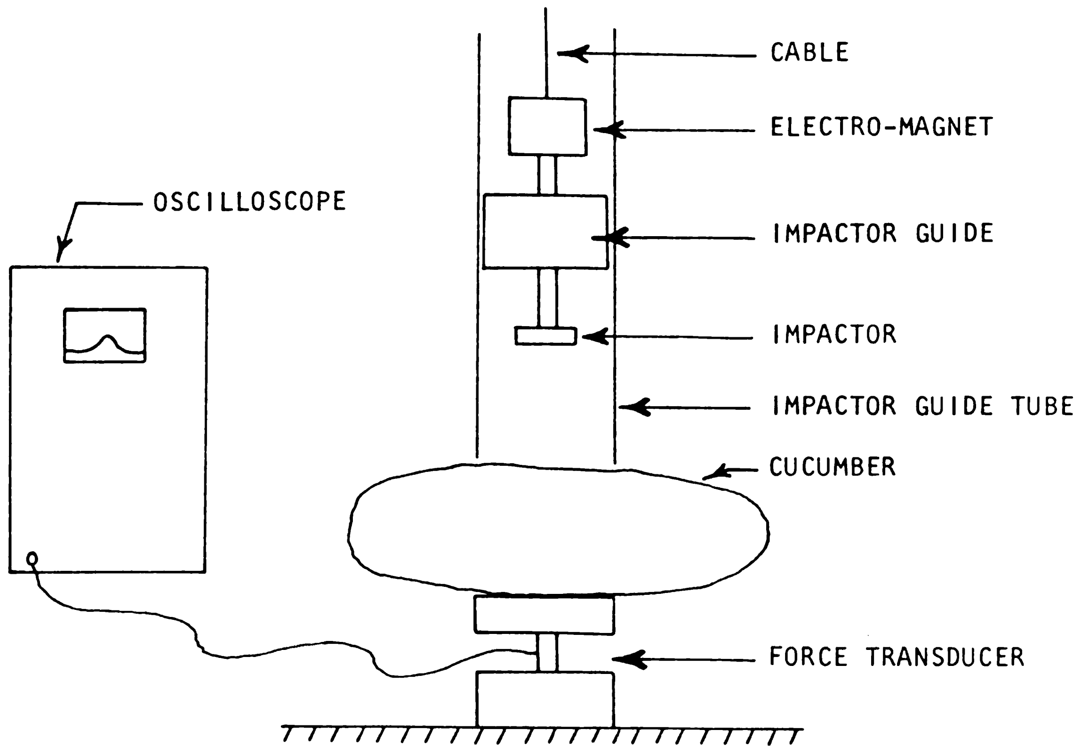

FIGURE 9 DIAGRAMMATICAL ILLUSTRATION OF THE IMPACT APPARATUS.

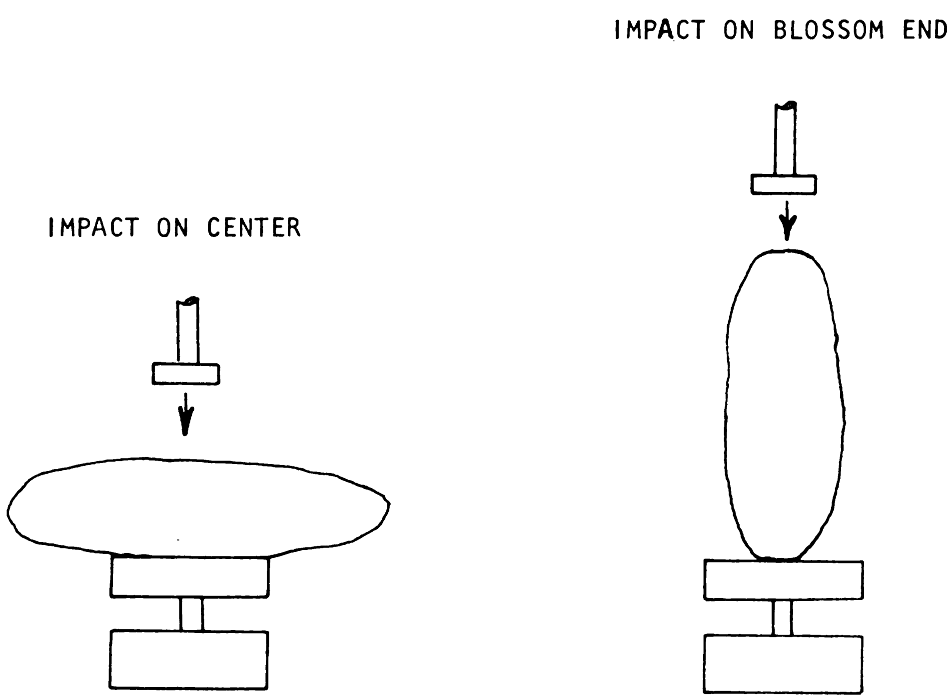

FIGURE 10 ILLUSTRATION OF THE TWO TYPES OF IMPACT EXAMINED.

electromagnet was cut, the impactor free fell until impact occurred. The force time curve was relayed to an oscilloscope (TEKRONIX type 599 storage oscilloscope) from which the peak impact force was recorded. The location of impact was identified by the code number. After impacting all cucumbers for a given sample, the cucumbers were either tested for green stock carpel strength, or placed in a 10 gallon polyethylene laboratory brine tank (13.5 in. diameter, 20.5 in. deep). The following description gives the specific experiments conducted:

EXPERIMENT NO. 1

(a) Pioneer variety; hand harvested and machine graded on August 21, 1972, Eaton Rapids, Mich.

(b) All cucumbers were tested for carpel strength.

(c) Drop heights were 5, 10, and 20 in. drops on center of cucumber.

(d) Ten cucumbers were tested at each drop height.

(e) Carpel strength was measured after all impacting was completed beginning with the first cucumber impacted.

EXPERIMENT No. 2

(a) Pioneer and 601H varieties; hand harvested and machine graded on September 8, 1972, Eaton Rapids, Mich.

(b) All cucumbers were brined.

(c) Drop heights were 0 in. drop (control). 20 in. drop on center, 15 in. and 20 in. drop on blossom end.

(d) Fifteen cucumbers were brined for each drop height for the 601H variety. 20 to 25 cucumbers were brined for each drop height for the Pioneer variety.

EXPERIMENT NO. 3

(a) Pioneer variety; hand harvested and machine graded on September 11, 1972, Eaton Rapids, Mich.

(b) Stored at 50°F, 95% RH and tested on September 13, 1972.

(c) All cucumbers were tested for carpel strength.

(d) Drop heights were 0 in. drop (control), 15 in. drop on center, and 15 in. drop on blossom end.

(e) Six cucumbers were tested for each drop height.

(f) Each cucumber impacted was immediately tested for carpel strength.

EXPERIMENT NO. 4

(a) Pioneer variety; hand harvested and hand graded on August 28, 1972, New Lothrup, Mich.

(b) Cucumbers were impacted and divided into two lots; one lot was brined and the other was tested for carpel strength.

(c) Drop heights were 0 in. drop (control), 5, 10, and 20 in. drop on center, 5 in. drop on center twice, and 10 in. drop on center twice.

(d) Forty cucumbers were impacted for each drop height: 20 were tested for carpel strength and 20 were brined.

(e) Carpel strength measurements were conducted after all cucumbers were impacted, beginning with the first cucumber impacted.

Experiments No. 1, 2, and 3 were conducted on cucumbers harvested from the same field.

Brining Procedure

After impacting a cucumber and identifying it with black indelible ink, it was carefully placed in a 10 gallon cylindrical polyethylene container. All cucumbers for a given Impact Experiment were brined in the same container. When the tank was full, a 20° Salometer brine was added until all cucumbers were submerged. Salometer is a measure of the degree of salt saturation and is defined as:

$$°s = (100.0) \times (\%\ \text{Salt in Solution})/26.5$$

Sufficient salt was added to account for the water lost by the cucumbers. A perforated polyethylene top kept the cucumbers below the surface of the brine.

The initial brine strength was maintained at 20°S until a total acid of 0.5%, measured as lactic acid, was achieved. The brine was circulated once per week with a varistaltic pump, being careful not to incorporate oxygen into the brine. As discussed by Etchells and Moore (1971), the desirable lactic acid bacteria tolerate very little oxygen (microaerophilic) and the undesirable gas-forming yeasts tolerate a wide range of oxygen concentrations.

Film yeasts were prevented from forming on the surface of the brine through the use of ultraviolet light. Figure 11 shows the brine tank setup with ultraviolet light.

After a total acid of 0.5% had been obtained, the salometer was increased 3°S per week with two salt additions per week until a salometer of approximately 45°S was obtained. The salometer was then increased 5°S per week until 60°S was obtained. After 60°S had been reached, the cucumbers were removed from the tank and evaluated for internal quality.

Brine Stock Evaluation

The only defects examined in the brine stock evaluation were lens bloat, balloon bloat, and fractures (both external and internal). A lens bloat was classified as a void area in the seed cavity. The major axis of small lens bloat was usually perpendicular to the longitudinal axis of the cucumber. A large lens bloat was a series of small lens bloat in which the membranes between the small bloats had been severed. The major axis of a large lens bloat was usually parallel to the longitudinal axis of the cucumber.

Balloon bloat was classified as a separation of the carpel suture. This type of bloat was always parallel to the longitudinal axis of the cucumber. In general a balloon bloat was larger than a lens bloat.

FIGURE 11 PHOTOGRAPH OF THE 10 GALLON BRINE TANKS WITH ULTRAVIOLET LIGHT.

Two types of fractures were evaluated. An external fracture was one in which the outer skin surface was broken. These fractures therefore encompassed from a surface break to a completely severed cucumber. An internal fracture was not visible externally. It was classified as an internal separation or break in which a bloat had not developed. Both lens and balloon bloat resulted in an internal void, whereas a fracture was simply a break or separation without signs of bloat. Figure 12 illustrates a balloon bloat, lens bloat, and enlarged lens bloat. The following procedure was used for the evaluation of each brine stock cucumber:

> The length and diameter of each cucumber was measured. Each cucumber was then cut longitudinally through the impact area and examined for internal defects (lens or balloon bloat) and fractures. The location of a defect was noted as occurring in either the blossom end, stem end, or center. The largest dimension (measured in cm) of a defect was the recorded size of that defect.

FIGURE 12 ILLUSTRATION OF A BALLOON, LENS, AND, ENLARGED LENS BLOAT.

CHAPTER IV

RESULTS AND DISCUSSION

Interest has evolved in the correlation between carpel strength and the potential for a cucumber to bloat during the brining process. It has been shown that varieties differ in their resistance to bloat (Jones *et al*. (1954)) and also in their carpel strength (Hooper *et al*. (1972b)). If carpel strength provides an indication of bloating potential for a variety, then changes in carpel strength due to impact should also provide an indication as to the effect of an impact on bloating potential. The correlation of carpel strength with impact severity would also enable one to evaluate the effect of a given handling system without exact knowledge of it.

Carpel Strength Evaluation for Impacted Samples

The carpel strength data collected for Impact Experiments No. 1, 3, and 4 are shown in Tables 1, 2, 3, and 4. The mean and standard deviation of observations collected for a given impact experiment are shown in Table A1 of Appendix A. PEAK FORCE (units of gmf) is the maximum force value obtained from the deformation-relaxation curve and AREA-F is a number from the integrator proportional to the area under the curve (see Figure 6). DEF (units of cm) is the deformation obtained from the force-relaxation curve and AREA-D is a number from the integrator proportional to the area under the curve (see Figure 7). The carpel separation force measurement is denoted by the symbol CSF (units of gmf) (see Figure 5). LSR is the smallest difference that can occur between two means of a given column for significant difference at the level indicated. This value was obtained using Tukey's w-procedure. The FMAX test which compares the maximum and minimum variances of the samples to be compared was employed to determine whether the set of samples were parametric or non-parametric. All parametric samples were compared using Tukey's w-procedure, and non-parametric samples were compared using the t test for comparing two means from non-parametric samples. These statistical tests are described and illustrated by Sokal and Rohlf (1969).

Table 1 shows the results of Impact Experiment No. 1. A significant difference between the 5 in. and 20 in. drop for both carpel strength tests was observed. The force-relaxation test revealed a significant difference at the .01 level between the 5 in. and 20 in. drop and between the 10 in. and 20 in. drop.

As seen from the data in Table 1, both PEAK FORCE and AREA-F decreased as impact levels increased. This indicated a weakening of the carpel. An example of deformation-relaxation curves for an impacted and non-impacted cucumber is shown in Figure 13. From the curve it is seen that PEAK FORCE and AREA-F are directly proportional.

Impact was also detected by the force-relaxation test. DEF increased and AREA-D decreased as drop height increased. Figure 14 shows an example of force-relaxation curves for an impacted and non-impacted cucumber.

From the statistical analysis of the data obtained from these two tests, this experiment indicated that the force-relaxation test was the most sensitive for detection of an impact.

The results of Impact Experiment No. 3 are summarized in Table 2. In this experiment, the carpel strength was examined immediately following impact. The results indicated significant difference, at the .01 level, between the following: (1) control and the 15 in. drop on center, and (2) 15 in. drop on the blossom end and 15 in. drop on center. This difference was revealed by both deformation-relaxation and force-relaxation tests. Since the samples for the carpel separation test were non-parametric, the t test was employed. Using this test, a significant difference at the .05 level was found only between the control and the 15 in. drop on center.

TABLE 1 CARPEL STRENGTH RESULTS FOR IMPACT EXPERIMENT NO. 1 (ALL IMPACTS ON CENTER).

DROP HEIGHT	PEAK FORCE (gmf)	AREA-F	DEF (cm)	AREA-D	NO. OF OBS.
5 in.	159.0	730.2	.324	702.2	10
10 in.	145.7	671.8	.344	692.8	10
20 in.	117.4	534.7	.467	674.0	9
$LSR_{.05}$	41.2	192.9	.073	14.0	-
$LSR_{.01}$	52.9	247.7	.094	18.0	-

AREA-F and AREA-D can be converted to actual area in units of gmf-sec upon multiplication by 6.0.

TABLE 2 CARPEL STRENGTH RESULTS FOR IMPACT EXPERIMENT NO. 3 (IMPACT EITHER ON BLOSSOM END (BE) OR ON CENTER (C)).

DROP HEIGHT	CSF (gmf)	PEAK FORCE (gmf)	AREA-F	DEF (cm)	AREA-D	NO. OF OBS.
0	355.5	163.2	770.8	.288	725.3	6
15 in. on BE	410.7	175.7	824.5	.283	724.3	6
15 in. on C	270.8	77.2	358.8	.495	669.7	6
$LSR_{.05}$	-	41.3	192.0	.101	24.3	-
$LSR_{.01}$	-	62.6	291.0	.153	36.8	-

AREA-F and AREA-D can be converted to actual area in units of gmf-sec upon multiplication by 6.0.

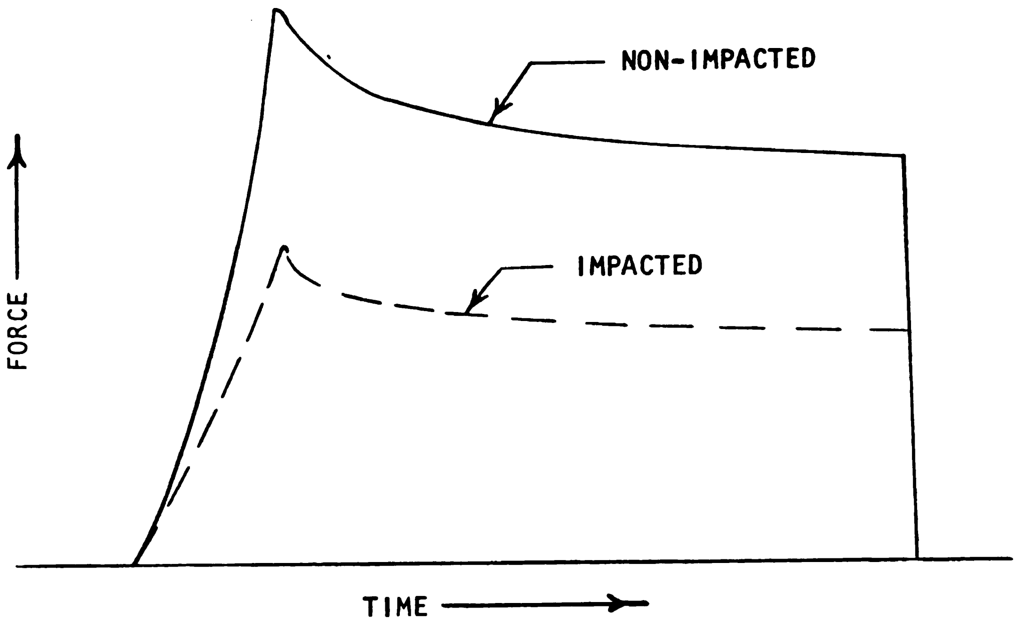

FIGURE 13 AN EXAMPLE OF DEFORMATION-RELAXATION CURVES FOR A NON-IMPACTED AND IMPACTED CUCUMBER (PIONEER VAR).

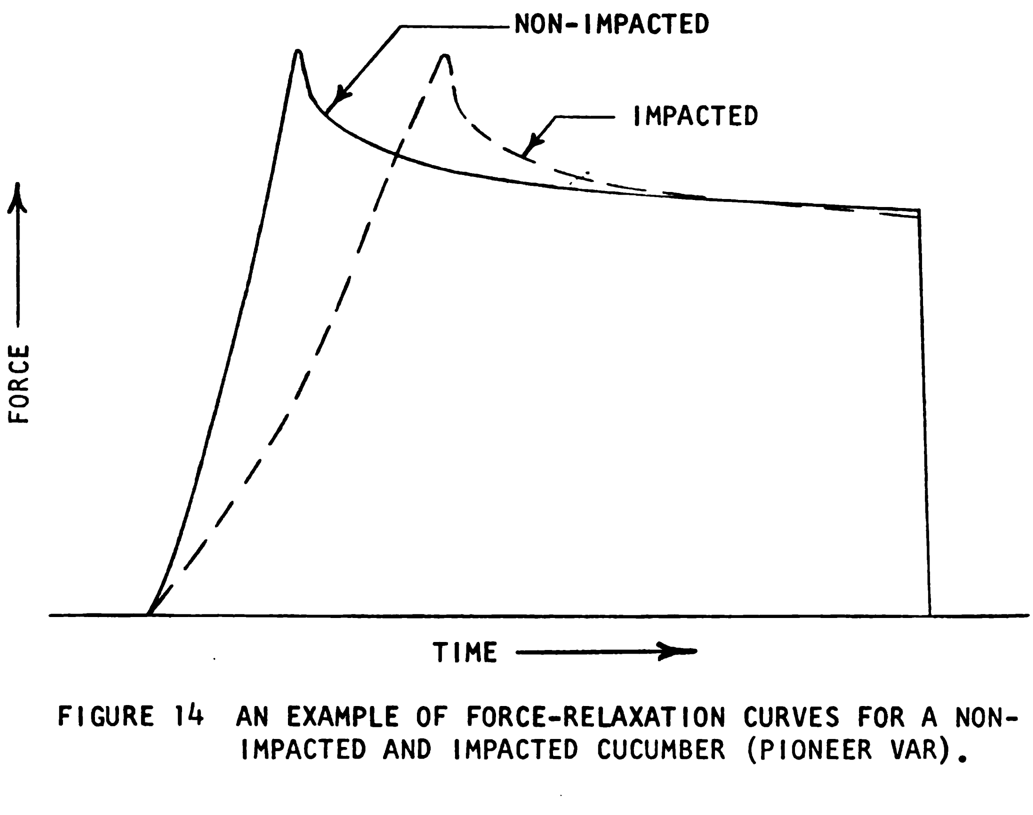

FIGURE 14 AN EXAMPLE OF FORCE-RELAXATION CURVES FOR A NON-IMPACTED AND IMPACTED CUCUMBER (PIONEER VAR).

Tables 3 and 4 show the results of Impact Experiment No. 4. The data was divided into two tables because, after impacting, half of the cucumbers were tested 1 to 3 hours after impact and the other half were stored an additional 20 hours (50°F, 95% RH) before being tested. The cucumbers were approaching oversize dimension (greater than 2 in. diameter) with an average diameter of 1.96 in.

Statistical analysis revealed a significant difference between the 5 and 20 in. drop on center at the .05 level. However, this difference was detected only by AREA-D from the force-relaxation test. In addition, this difference was only revealed by the tests performed 1 to 3 hours after impact. No significant difference between any means was found on the impacted samples stored an additional 20 hours.

At the bottom of each table is shown the maximum difference between the means for a given column. Comparison of these differences between Tables 3 and 4 shows a decreased ability to detect impact as time after impact increases. Although little significant difference was found in this experiment, the most sensitive test was, again, the force-relaxation test.

The results of the three experiments just discussed indicated that a certain amount of recovery in carpel strength occurred within the first few hours after impact. Although the impacts for Impact Experiments No. 1 and 3 are different, trends can be drawn from the results of the minimum

TABLE 3 CARPEL STRENGTH RESULTS 1 TO 3 HOURS AFTER IMPACT FOR IMPACT EXPERIMENT NO. 4 (ALL IMPACTS ON CENTER).

DROP HEIGHT	CSF (gmf)	PEAK FORCE (gmf)	AREA-F	DEF (cm)	AREA-D	NO. OF OBS.
0	295.7	147.4	687.3	.336	708.6	10
5 in.	318.2	164.0	762.5	.299	714.6	8
5 in. twice	248.1	142.2	657.7	.376	704.4	10
10 in.	295.9	153.0	684.2	.309	705.4	10
10 in. twice	266.9	140.7	652.6	.430	697.9	8
20 in.	255.5	121.8	558.4	.412	685.9	9
maximum difference	70.1	42.2	204.1	.104	28.7	-
$LSR_{.05}$	103.0	55.0	248.6	.132	27.6	-

AREA-F and AREA-D can be converted to actual area in units of gmf-sec upon multiplication by 6.0.

TABLE 4 CARPEL STRENGTH RESULTS AFTER 20 HOURS STORAGE FOR IMPACT EXPERIMENT NO. 4 (ALL IMPACTS ON CENTER).

DROP HEIGHT	CSF (gmf)	PEAK FORCE (gmf)	AREA- F	DEF (cm)	AREA-D	NO. OF OBS.
0	281.9	153.1	711.6	.314	712.6	8
5 in.	319.8	162.6	755.1	.285	722.6	10
5 in. twice	272.0	163.8	760.7	.286	718.6	10
10 in.	319.3	167.6	782.9	.284	728.1	9
10 in. twice	273.7	162.7	765.0	.294	724.4	9
20 in.	268.4	158.0	736.4	.331	710.0	10
maximum difference	51.4	14.5	71.3	.030	18.1	-
$LSR_{.05}$	99.6	68.4	309.8	.088	25.1	-

AREA-F and AREA-D can be converted to actual area in units of gmf-sec upon multiplication by 6.0.

and maximum impacts on center. Impact Experiment No. 3 (cucumbers evaluated immediately after impact) revealed a highly significant difference at the .01 level between the control and 15 in. drop on center (as measured by both relaxation tests). Impact Experiment No. 1 (cucumbers evaluated 1 to 3 hours after impact) was much closer to the cutoff point for significant difference between the 5 and 20 in. drop on center. The deformation-relaxation test revealed a significant difference only at the .05 level. In addition, Impact Experiment No. 4 showed significant difference between the control and 5 in. drop on center only for those cucumbers evaluated 1 to 3 hours after impact. No significant difference was found between impacts for those stored 20 hours before being tested.

Carpel Strength Evaluation by Variety

Evaluation of the impacted samples indicated that the force-relaxation test was the most sensitive in its ability to detect an impact (comparisons made on one variety only). The analysis of the carpel strength for three different varieties (381M, Pioneer, and 601H) is presented in Table 5. The mean and standard deviation of observations collected for each variety are given in Table A2 of Appendix A. These three varieties were known to exhibit weak, intermediate, and strong carpel strengths, respectively.

TABLE 5 CARPEL STRENGTH RESULTS FOR 3 VARIETIES OF PICKLING CUCUMBERS.

VARIETY	CSF (gmf)	PEAK FORCE (gmf)	AREA-F	DEF (cm)	AREA-D	NO. OF OBS.
381M	265.2	194.1	887.2	.258	710.6	21
Pioneer	274.1	169.0	780.4	.290	706.2	24
601H	406.4	161.4	737.0	.309	699.2	24
$LSR_{.05}$	-	26.1	117.7	.053	9.8	-
$LSR_{.01}$	-	32.9	148.2	.066	12.4	-

AREA-F and AREA-D can be converted to actual area with units of gmf-sec upon multiplication by 6.0.

As indicated in the impact evaluation, PEAK FORCE decreased and DEF increased as the carpel separation force (CSF) decreased. All three of these responses indicated decreasing carpel strength. Analysis of Table 5 shows that the strongest variety (601H) had the lowest PEAK FORCE and the largest DEF. The weakest variety (381M) had the largest PEAK FORCE and the lowest DEF. Apparently, internal varietal factors were significantly influencing the results of both relaxation tests. For analysis within a variety, the force-relaxation test seemed to be the best, but for comparison between varieties, the carpel separation test was the most objective. The one disadvantage of the carpel separation test was its degree of variability. In this case, it was again necessary to use the non-parametric t test for comparing two means. Using this test a significant difference at the .01 level was found between 381M and 601H, and between Pioneer and 601H.

A further possibility in the use of the relaxation tests for variety differentiation was the rate of relaxation. The theory behind this being the weaker the carpel, the faster the rate of relaxation. Figure 15 illustrates this theory. Several curves were examined for each variety subjected to the force-relaxation test. No difference was found in the rate of relaxation between the varieties.

The relaxation tests measured carpel strength on the basis of the rate of response to a given deformation or

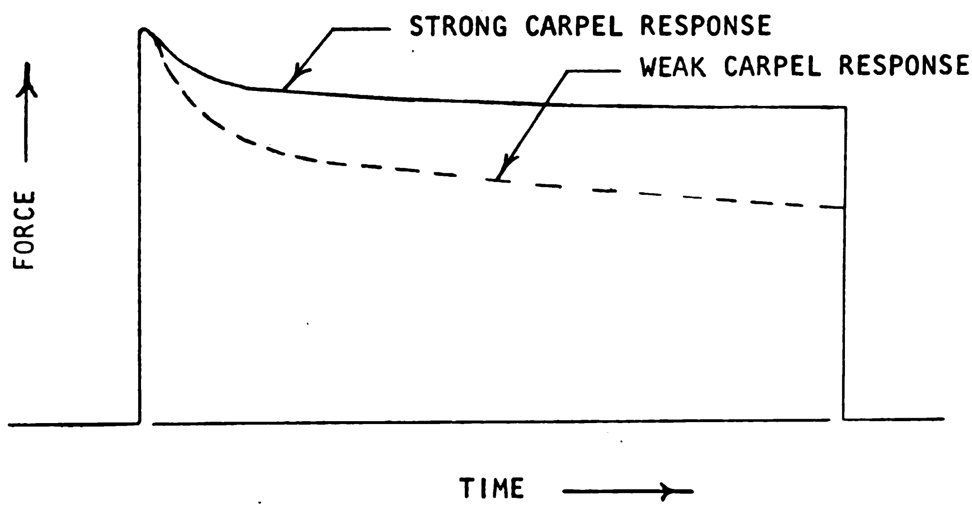

FIGURE 15 ILLUSTRATION OF THE EXPECTED CHANGE IN RELAXATION RATE FOR A STRONG AND WEAK CARPEL.

stress. The carpel separation test, on the other hand, measured only the total force required to separate the carpels. It might be possible for a variety to exhibit a rapid rate of response to a given deformation yet possess an overall weak carpel. In addition, it might be possible for a variety to exhibit a slow rate of response to a given deformation yet possess an overall strong carpel. This reasoning along with the results presented indicated that the relaxation tests were not suitable for the overall measurement of carpel strength between varieties.

Brine Stock Evaluation

From a design standpoint, it would be desirable to know the relationship between impacting and product damage. In the case of cucumbers, it would be desirable to know the effect of impact on the frequency and severity of bloating. Previous studies have shown that, as the handling stage progressed, the bloating frequency, both lens and balloon, also increased (Marshall *et al.* (1971)). Although, under controlled impact conditions, a correlation between impact and lens bloat has been found, no correlation has yet been found between impact severity and balloon bloat (Stout and Norris (1970); Segerlind and Moerdyke (1971)).

Figures 16 and 17 summarize the results of the brine stock analysis for Impact Experiments 2 and 4 (see procedures).

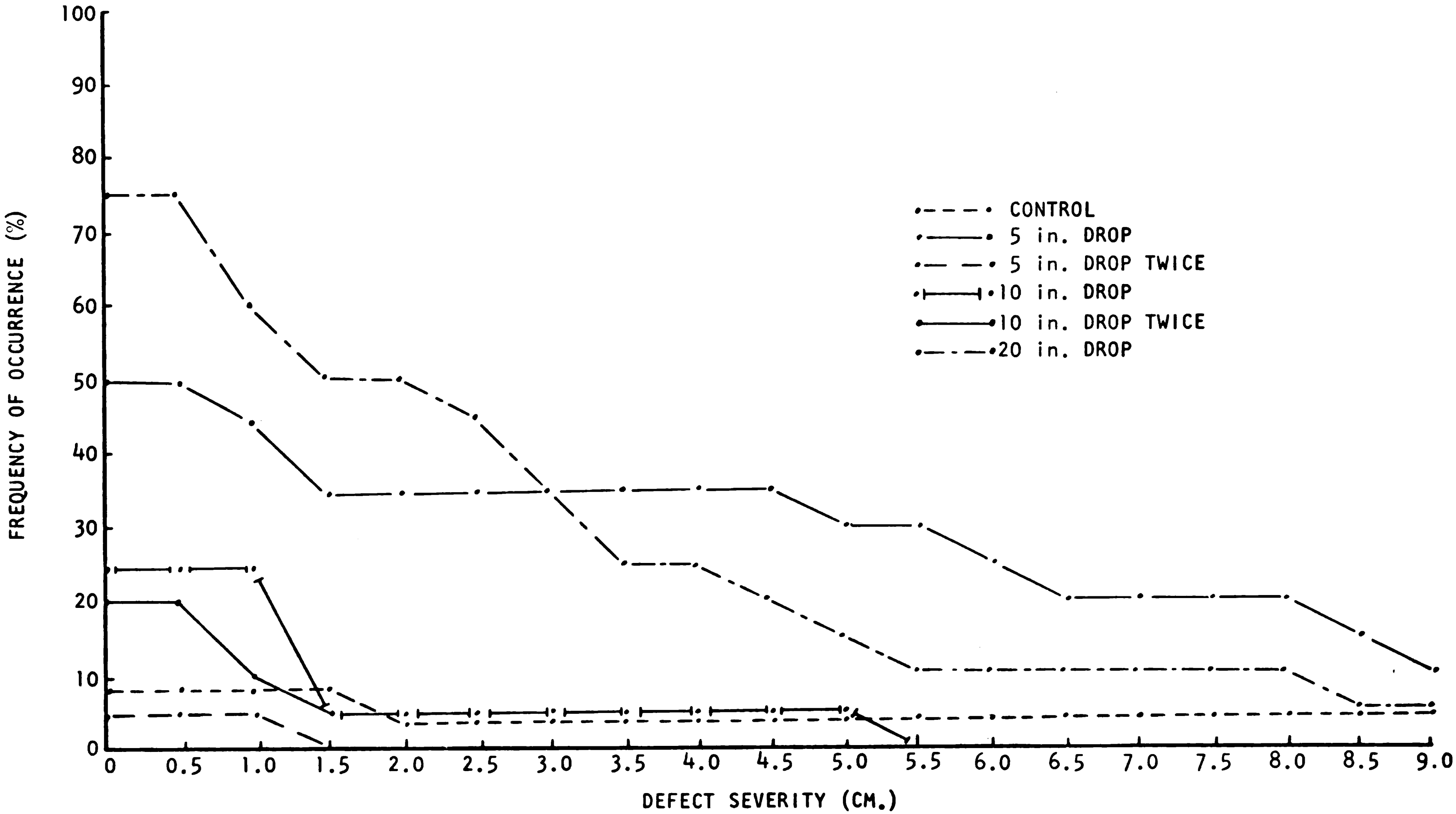

FIGURE 16 DEFECT FREQUENCY (LENS OR BALLOON BLOAT) FOR IMPACT HEIGHTS 0 TO 20 in. ON THE CENTER (IMPACT EXPERIMENT NO. 4).

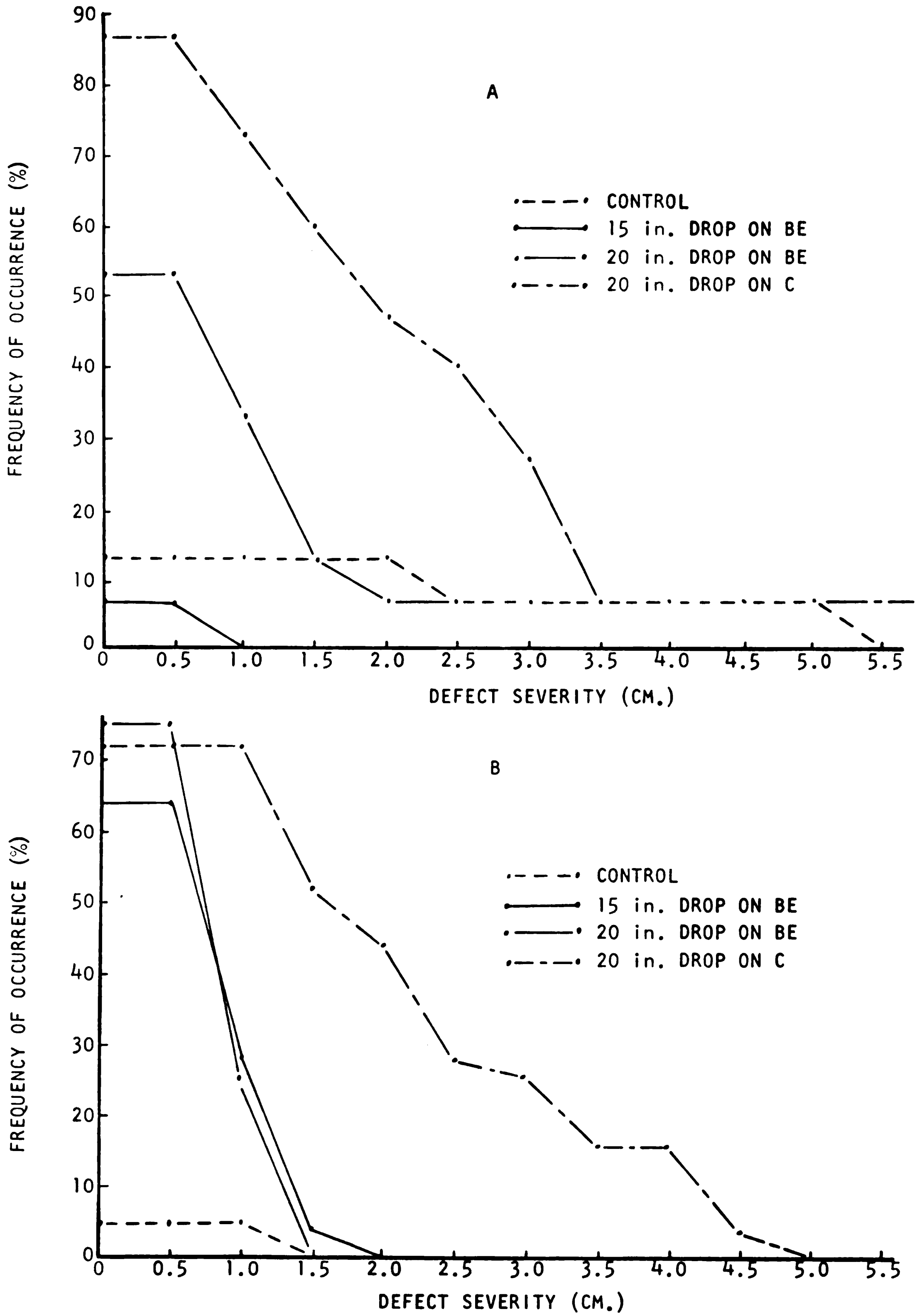

FIGURE 17 DEFECT FREQUENCY (LENS OR BALLOON BLOAT) FOR IMPACTS ON THE BLOSSOM END AND CENTER: A-601H VARIETY, B-PIONEER VARIETY (IMPACT EXPERIMENT NO. 2).

The largest dimension (to the nearest 0.5 cm) and location (either stem end, blossom end, or center) of a void was measured and recorded with the largest void for a cucumber being the only defect recorded for that cucumber. The horizontal axis of each graph shows the defect dimension of either balloon or lens bloat (fractures not included). The vertical axis gives the frequency of occurrence (in per cent) of a defect dimension that is greater than or equal to the value given on the horizontal axis.

As seen in all three graphs, a drop height of 20 in. on the center increased the occurrence of large voids quite significantly. Drop heights of 20 in. on the blossom end (Figure 17) increased only the frequency of small voids, all of which were classified as lens bloat. In Figure 16, the 10 in. drop height tended to increase the occurrence of small voids whereas the multiple 5 in. drop had no effect on defect severity or frequency. The data for the single 5 in. drop seemed to deviate from the other results. It was noted during evaluation that all the cucumbers with large defects for the single 5 in. drop sample were located at the top of the brine tank. No explanation, at this time, can be given for this occurrence.

Internal fractures (not visible externally) were not observed in any of the brine stock cucumbers examined. If an internal fracture had been present, it was apparently disguised by either balloon or lens bloating. The 20 in. drop on center did produce some external fractures ranging from breaks approximately 1/4 to 3/4 the diameter of the cucumber. No significant bloating was observed when an external fracture was present.

It was sometimes difficult to classify a void as either a lens or balloon bloat. These cases of difficulty arose when a void was balloon in shape with lens bloat merging along its boundary. The question then developed as to the origin of that bloat, or the amount that should be attributed to either lens or balloon bloating. The void or defect dimension that was most often in question was in the range of 2.5 to 4.0 cm.

With limitations on the data, general trends could be established. No lens bloat was recorded with a dimension greater than 3.0 cm and no balloon bloat was recorded with a dimension less than 3.0 cm. For analysis purposes, if the range of bloating, 2.5 to 4.0 cm, was omitted from the data, then the results could more confidently be expressed in terms of either lens or balloon bloating. These results are presented in Table 6. As before, there was still no explanation for the results of the single 5 in. drop on center.

In general, the results indicated that the frequency of lens bloat was increased due to impact. Blossom end impact seemed to cause only lens bloating. No significant conclusions could be drawn concerning balloon bloating. However, defects between 2.5 and 4.0 cm only developed for the 20 in. drop on center. This information indicated that

TABLE 6 SUMMARY OF BRINE STOCK EVALUATION CATEGORIZED AS EITHER LENS OR BALLOON BLOATING (IMPACTS OCCURRED EITHER ON THE BLOSSOM END (BE) OR ON CENTER (C)).

DROP HEIGHT	LENS BLOAT (%)	BALLOON BLOAT (%)	% NOT INCLUDED
0	4	4	0
5 in. on C	20	35	0
5 in. twice on. C	5	0	0
10 in. on C	20	5	0
10 in. twice on C	20	5	0
20 in. on C	40	20	25
Pioneer control	5	0	0
15 in. on BE	64	0	0
20 in. on BE	75	0	0
20 in. on C	48	5	24
601H control	7	7	0
15 in. on BE	7	0	0
20 in. on BE	47	7	0
20 in. on C	47	7	33

% NOT INCLUDED refers to defect sizes from 2.5 to 4.0 cm.

larger voids, whether they be classified as lens or balloon bloat, did occur for the greater impact levels. It would make little difference to a processor or consumer whether a defect, of a given dimension, was classified either as a lens or balloon bloat. The desirability or rather the lack of it would be the same.

A summary of the locations of defects for a given impact is shown in Table 7. For all impacts on the center, with the exception of the 5 in. drops, all defects recorded also occurred at the center. For impacts on the blossom end, the majority of defects occurred at the blossom end. However, occasionally a defect occurred at the center and 20 to 37% occurred at the stem end.

When analyzing the impacting apparatus, one sees that the cucumber was actually impacted on two surfaces; (1) the surface upon which it rested, and (2) the surface upon which the impactor contacted. Since a strong correlation existed between impact location and defect location, the fact that a cucumber was impacted on both the blossom and stem end would imply that defects would occur at both ends. As shown by Humphries (1968) the blossom end has the higher probability of incurring internal rupture than the stem end. Thus, one would expect more internal defects to be found in the blossom end than in the stem end.

TABLE 7 DEFECT LOCATION FOR A GIVEN IMPACT LEVEL (IMPACTS ON EITHER THE BLOSSOM END (BE) OR ON CENTER (C)).

DROP HEIGHT	% OCCURRENCE OF A DEFECT			SAMPLE SIZE
	BLO. END	STEM END	CENTER	
0	0	4	4	25
5 in. on C	10	0	45	20
5 in. twice on C	0	5	0	20
10 in. on C	0	0	20	20
10 in. twice on C	0	0	20	20
20 in. on C	0	0	75	20
Pioneer control	0	0	5	20
15 in. on BE	40	16	0	25
20 in. on BE	60	15	5	20
20 in. on C	0	0	72	25
601H control	7	0	7	15
15 in. on BE	6	0	0	15
20 in. on BE	33	20	7	15
20 in. on C	0	0	87	15

All defect sizes are included.

CHAPTER V

APPLICATION OF RESULTS

A relationship between the controlled impact and actual impacts which occur during handling was drawn. In general, for regular handling techniques, two types of impact occur. The first is an impact on a single product surface in which a non-supported product impacts another body. The easiest example to visualize for this case is a cucumber dropped on the floor. The second type of impact involves a simultaneous impact on two or more surfaces. This would involve a partially or fully supported product being impacted by another body. The impact would therefore occur on both the supported surface, and on the surface impacted by the body. The latter case was the type of impact examined in the previously discussed Impact Experiments.

In the Impact Experiments, there was no control to stop rebound impacts from occurring. Therefore, all subsequent rebound impacts were also recorded on the storage oscilloscope. Only the first rebound impact was of large enough magnitude to be recorded by the oscilloscope.

The following assumptions were made in correlating the controlled impact to the actual situation:

(1) The first impact was the one which caused all the damage.

(2) There was no loss in energy as the impactor approached the cucumber.

(3) The amount of energy returned to the impactor by the cucumber was equal to the initial total potential energy (PE) of the impactor times the ratio of the rebound peak impact force to the first peak impact force. Figure 18 illustrates this assumption.

(4) The impact surface in the real situation was of the same area and location as in the controlled impact situation.

(5) The mass and structure of any two cucumbers was indentical.

(6) Two cucumbers involved in an impact absorbed equal amounts of energy.

(7) The total mass of the cucumber was involved in the impact energy.

Only impacts on center were considered for the analogy between the controlled and actual situation. Table 8 shows the first peak impact force (F_1) and the rebound peak impact force (F_2) for the 10 and 20 in. drop on center (Impact Experiment No. 4). From this table the average ratio (R) of F_2/F_1 was determined. For the 10 in. drop R equaled 0.399 and for the 20 in. drop R equaled 0.358. The energy absorbed by the cucumber was therefore equal to $PE_{initial} \times (1 - R)$. For the 20 in. drop and an impactor mass of 0.2215 Kg:

$$PE=mgh=(0.2215 \text{ kg}) \times (9.807 \text{ m/sec}^2) \times (20.0 \text{ in.}) \times (0.0254 \text{ m/in.})$$

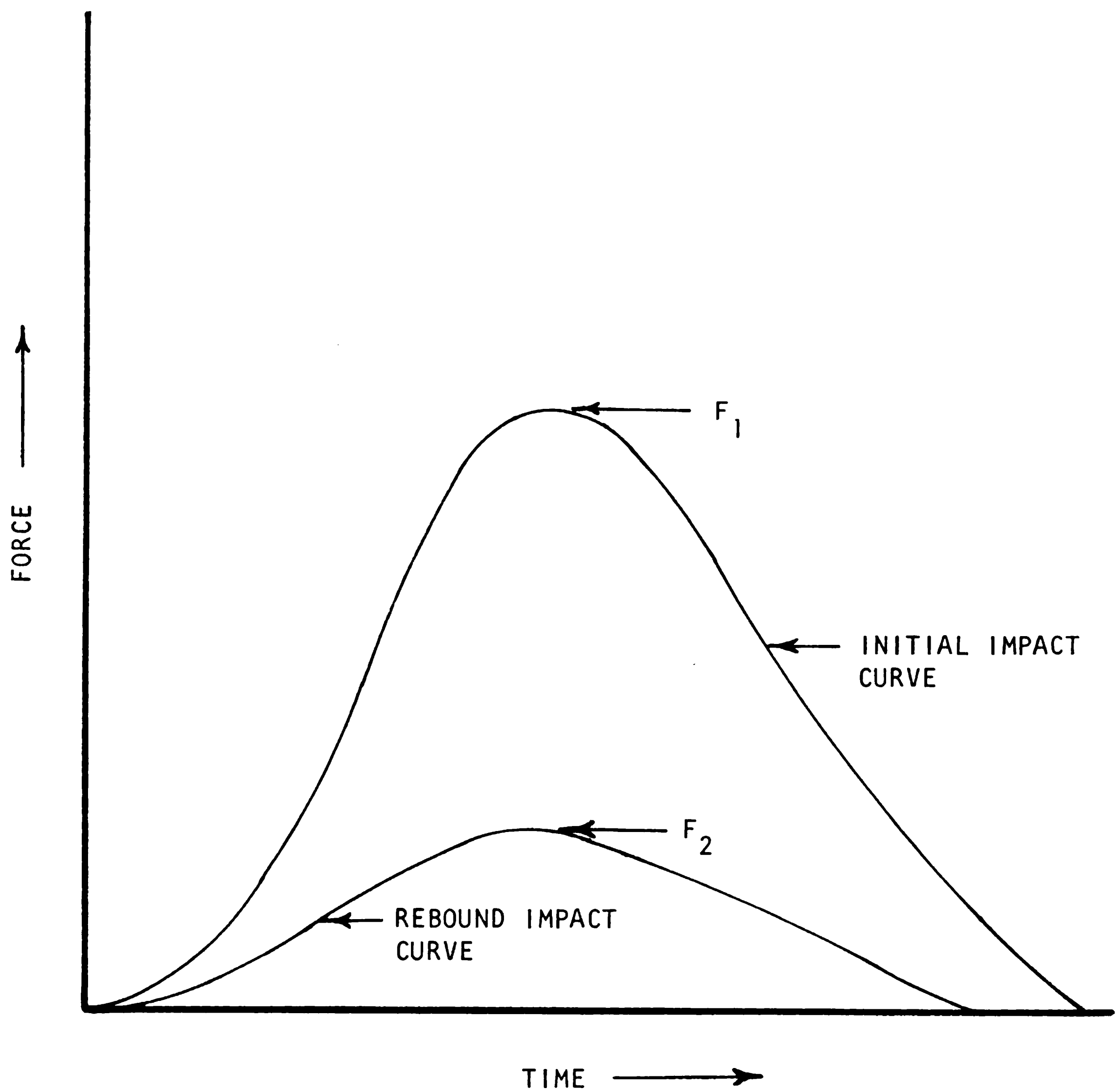

FIGURE 18 ILLUSTRATION OF INITIAL AND REBOUND IMPACT CURVES.

TABLE 8 INITIAL (F_1) AND REBOUND (F_2) PEAK IMPACT FORCE FOR THE 10 AND 20 in. DROP ON CENTER (IMPACT EXPERIMENT NO. 4).

10 in. DROP			20 in. DROP		
cucumber no.	F_1 (lbs)	F_2 (lbs)	cucumber no.	F_1 (lbs)	F_2 (lbs)
1	26	13	1	38	13
2	30	12	2	33	10
3	29	15	3	36	14
4	29	14	4	42	21
5	26	10	5	37	15
6	27	9	6	36	14
7	25	6	7	37	12
8	23	8	8	34	8
9	26	12	9	38	18
10	29	12	10	42	16
11	26	8	11	36	12
12	25	9	12	42	14
13	25	10	13	30	10
14	29	12	14	35	14
15	28	11	15	34	11
16	27	12	16	35	13
17	28	14	17	32	11
18	29	11	18	34	10
19	26	11	19	37	13
20	25	7	20	36	12

or: $$PE = 1.1035 \frac{Kg\ m^2}{sec^2}$$

The energy absorbed by the cucumber then equals:

$$PE_{absorbed} = (1 - .358) \times 1.1035 = .7084 \frac{Kg\ m^2}{sec^2}$$

An impact situation was considered where the impactor was simply replaced by another cucumber. The energy absorbed by each cucumber upon impact was assumed to be equal to 1/2 the initial potential energy. No. 3 cucumbers generally ranged between 150 to 200 gm in mass, therefore a cucumber mass of 175 gm was chosen for the energy calculation. To approximate the magnitude of damage caused by the controlled impact, the potential energy required for the real situation was set equal to twice the energy absorbed by the cucumber under controlled impact. From this, the height of the cucumber drop was calculated. For the 20 in. drop, the height equaled:

$$h = PE/mg = \frac{1.14168}{(.175) \times (9.807)} = .9255\ m = 32.5\ in.$$

Likewise for the 10 in. drop, following the same procedure:

$$h = 15.2\ in.$$

Brine stock results from Impact Experiment No. 4 with extrapolation to a cucumber on cucumber impact is shown in Figure 19. The horizontal axis gives the height

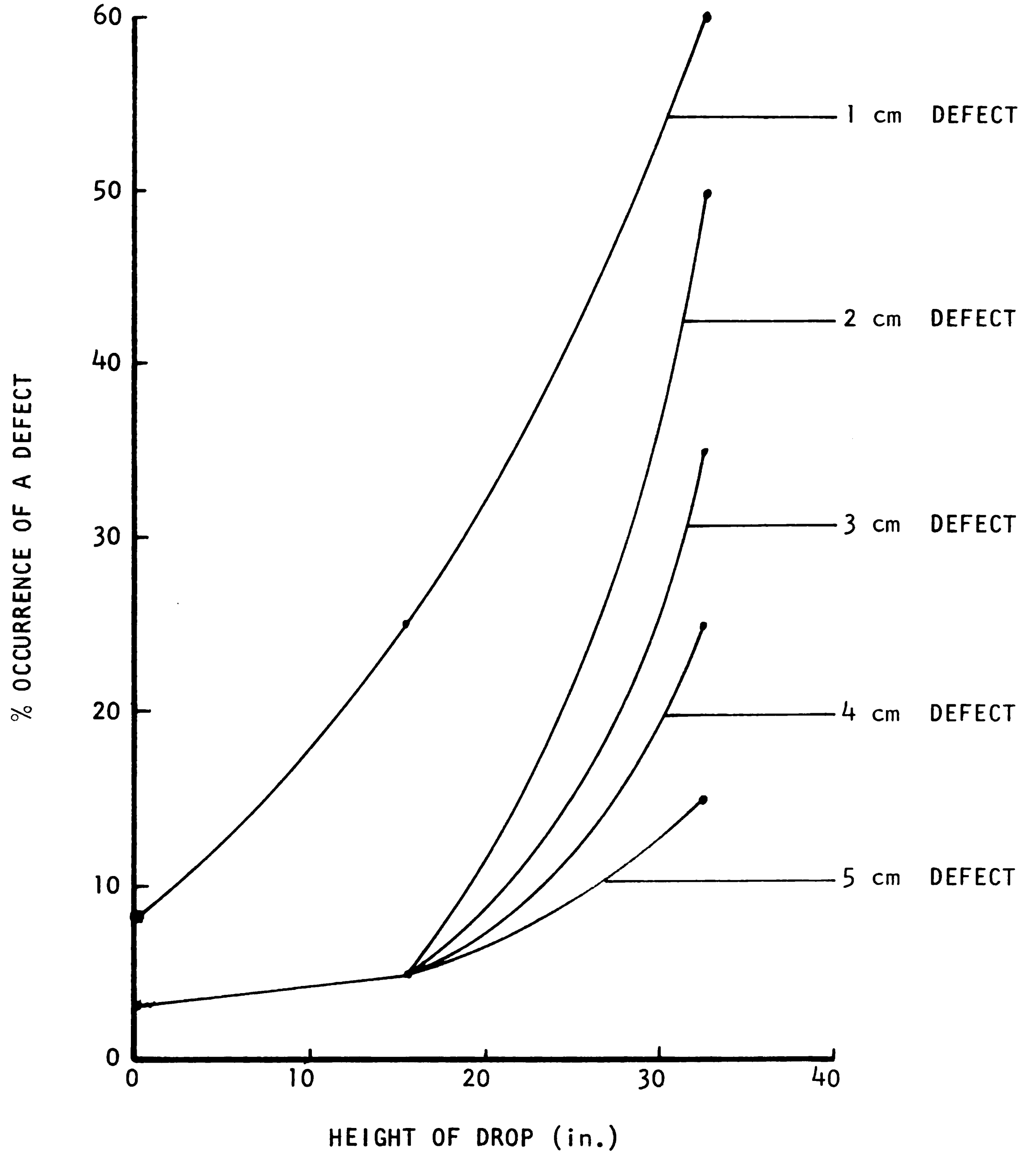

FIGURE 19 BRINE STOCK RESULTS EXTRAPOLATED FROM IMPACT EXPERIMENT NO. 4 FOR CUCUMBER ON CUCUMBER IMPACT.

of drop of one cucumber upon another. The vertical axis gives the % defects measured with a defect representing either a lens or balloon bloat. Each curve represents a defect size greater than or equal to the specified curve value. A 15.2 in. drop accounted for an increase in small defects but did not differ from the control for larger defects. A 32.5 in. drop tended to increase both the frequency and severity of defects.

From a design standpoint, if only single impacts of this type occurred, the designer could determine the appropriate handling requirements to remain within a given limit of damage. This analysis proposed a procedure for determining handling specifications. Product handling seems to have a direct relationship with both lens and balloon bloat (Marshall et al. (1971)). In addition, a weakening in carpel strength seems to increase the potential for balloon bloat (Hooper et al. (1972b)). High levels of single controlled impacts, however, revealed a correlation with only lens bloating, and, in addition, a recovery in carpel strength was observed. These observations indicate that a controlled single impact, regardless of severity, does not simulate the damage incurred through actual product handling. A single controlled impact provides an indication to the relationship between impact and product damage, but further information is required about the effect of multiple impacts and vibration.

CHAPTER VI

SUMMARY AND CONCLUSIONS

Three tests were utilized for determining the carpel strength of different varieties and for changes in carpel strength due to impact. An Instron Universal Testing Machine along with an area integrator was used for the measurement. All three tests involved a 3/16 in. diameter Magness-Taylor shape probe which was allowed to either pass through or simply deform a cross-sectional cucumber slice (0.25 in. thickness). The slice was supported on a 1.375 in. inside diameter slice support and the probe always made contact with the slice at the vertex of the tri-carpellate suture.

Specifically, the three tests were: (1) carpel separation test (probe was allowed to pass through the slice), (2) deformation-relaxation test (slice was deformed 0.3 cm and then allowed to relax), and (3) force-relaxation test (slice was deformed until a force level of 150 gmf was obtained, then allowed to relax).

Impacting was accomplished through use of a drop test. The whole cucumber was placed on a force transducer and then a flat circular impactor (221.5 gm, 1.125 in.

diameter) was dropped from a predetermined height unto the cucumber. The force-time curve of the first impact plus any measureable rebound impact was relayed to a storage oscilloscope. The following impacts were examined: (1) 5, 10, and 20 in. drop on center, (2) 5 in. drop twice and 10 in. drop twice on center, and (3) 15 in. and 20 in. drop on the blossom end.

Those cucumbers not tested for carpel strength were brined in 10 gallon cylindrical polyethylene tanks. A given brine stock cucumber was evaluated on the basis of classification and magnitude of the largest internal defect. The magnitude recorded was the largest dimension of the defect and the classification was either lens bloat, balloon bloat, internal fracture, or external fracture.

The following conclusions were obtained from this investigation:

(1) The force-relaxation test was the best test for measuring changes in carpel strength within a given variety.

(2) Both relaxation tests were unacceptable for carpel strength determination between varieties.

(3) The carpel separation test was quite variable but was the most acceptable for carpel strength determination between varieties.

(4) The ability to detect an impact tended to decrease as time after impact increased.

(5) Impacts on the center seemed to produce more severe brine stock defects than impacts on the blossom end.

(6) Brine stock quality generally decreased as the drop height increased.

(7) For the impacts examined, a positive association seemed to be present between impact and lens bloat whereas the relationship between impact and balloon bloat was not evident.

(8) An association seemed to be present between impact location and the resultant defect location.

BIBLIOGRAPHY

BIBLIOGRAPHY

Connor, L. J., 1969, Honey bee pollination requirements of hybrid cucumbers Cucumis sativus L., Thesis for M.S. Degree, Department of Entomology, Michigan State University, 6-9.

Costilow, R. N.; W. E. Ferguson, and S. Ray., 1955, Sorbic acid as a selective agent in cucumber fermentations. I. Effect of sorbic acid on microorganisms associated with cucumber fermentations. Applied Micro. 3: 341-345.

Costilow, R. N., 1957, Sorbic acid as a selective agent for cucumber fermentations. III. Evaluation of salt stock from sorbic acid treated cucumber fermentations, Food Tech. 11(2): 591-595.

Etchells, J. L.; A. F. Borg, and T. A. Bell, 1968, Bloater formation by gas-forming lactic acid bacteria in cucumber fermentations, Applied Micro. 16(7): 1029-1035.

Etchells, J. L. and W. R. Moore, 1971, Factors influencing the brining of pickling cucumbers--questions and answers, Pickle Pak Science, 1(1): 9.

Fluck, R. C., and E. M. Ahmed, 1972, Impact testing of fruits and vegetables, ASAE Paper No. 73-306.

Fridley, R. B., and P. A. Adrian, 1966, Mechanical properties of peaches, pears, apricots, and apples, Trans. of ASAE 9(1): 135-138, 142.

Hooper, A. W.; D. E. Marshall; L. R. Baker, and D. R. Heldman, 1972a, A method for measurement of carpel strength in pickling cucumbers, ASAE Paper No. 72-379.

Hooper, A. W.; L. R. Baker; D. E. Marshall, and D. R. Heldman, 1972b, Determination of force required to separate carpels of cucumber fruit slices, HortScience 7(3): 337 (Abstract).

Horsfield, B. C.; R. B. Fridley, and L. L. Claypool, Application of theory of elasticity to the design of fruit harvesting and handling equipment for minimum bruising, Trans. of ASAE, 15(4): 746-750.

Humphries, E. G., 1968, Cucumber impacts and structural damage, Pickle Pak, 28(3): 3-4.

Jones, I. D.; J. L. Etchells, and R. J. Monroe, 1954, Varietal differences in cucumbers for pickling, Food Tech. 8(9): 415-418.

Magness, J. R., and G. F. Taylor, 1925, An improved type of pressure tester for the determination of fruit maturity, U. S. Dept. of Agri. Circ. No. 350.

Marshall, D. E.; B. F. Cargill, and J. H. Levin, 1972, Physical and quality factors of pickling cucumbers as affected by mechanical harvesting, Trans. of ASAE, 15(4): 604-608, 612.

Marshall, D. E.; B. F. Cargill, and J. H. Levin, 1971, Mechanical harvesting and handling of pickling cucumbers--an evaluation of green stock and brine stock quality, ASAE Paper No. 71-348.

Mohsenin, N. N., 1970, Physical Properties of Plant and Animal Materials, Gordon and Breach Science Publishers, 123-143.

Nelson, C. W. and N. N. Mohsenin, 1968, Maximum allowable static and dynamic loads and effect of temperature for mechanical injury in apples, J. Agr. Eng. Res. 13(4): 305-317.

Park, D., 1963, The resistance of potatoes to mechanical damage caused by impact loading, J. Agr. Eng. Res. 8(2): 173-177.

Segerlind, L. J., and D. Moerdyke, 1971, Physical properties phase--1970 research project report on post harvest handling of cucumbers, National Pickle Growers' Assoc. Inc., Dept. of Agri. Eng. Mich. State Univ., and AERS USDA.

Sneed, F. D. and J. L. Bowers, 1970, Green fruit characteristics of cucumber as related to quality factors in brine stock, J. ASHS 95(4): 489-491.

Sokal, R. R. and F. J. Rohlf, 1969, Biometry, W. H. Freeman and Company, 237-238, 372, 374-375.

Stout, B. A. and E. R. Norris, 1970, Physical properties research--1969 research project report on post harvest handling of cucumbers, National Pickle Growers' Assoc. Inc., Dept. of Agri. Eng. Mich. State Univ., and AERS USDA.

APPENDIX

TABLE A1 MEAN AND STANDARD DEVIATION FOR IMPACTED SAMPLES.

DROP HEIGHT	EXP. NO.	CSF (gmf)	S. D.	PEAK FORCE (gmf)	S. D.	AREA-F	S. D.	DEF (cm)	S. D.	AREA-D	S. D.	NO. OF OBS.
5 in. on C	1	-	-	159.0	39.5	730.2	188.8	.323	.049	702.2	11.2	10
10 in. on C	1	-	-	145.7	30.0	671.8	137.8	.344	.044	692.8	10.7	10
20 in. on C	1	-	-	117.4	35.4	534.7	163.0	.467	.087	674.0	13.9	9
0	3	355.5	75.4	163.2	29.1	770.8	134.1	.288	.037	725.3	11.2	6
15 in. on BE	3	410.7	206.9	175.7	21.3	824.5	98.8	.283	.029	724.3	5.2	6
15 in. on C	3	270.8	19.9	77.2	12.0	358.8	59.8	.495	.078	669.7	18.6	6
0	4a*	295.7	71.4	147.4	39.2	687.3	178.5	.336	.089	708.6	15.0	10
5 in.	4a	318.2	97.7	164.0	49.4	762.5	227.0	.299	.057	714.6	9.2	8
5 in. twice	4a	248.1	49.6	142.2	41.7	657.7	191.9	.376	.128	704.0	19.3	10
10 in.	4a	295.9	61.3	153.0	31.4	684.2	118.6	.309	.041	705.4	28.7	8
10 in. twice	4a	266.9	52.5	140.7	26.4	652.6	123.6	.340	.055	697.9	19.3	10
20 in.	4a	255.5	79.8	121.8	29.1	558.4	134.9	.412	.119	685.9	14.8	8
0	4b	281.9	70.8	153.1	36.5	711.6	166.0	.314	.076	712.2	22.6	8
5 in.	4b	319.8	76.8	162.6	44.4	755.1	202.6	.285	.046	722.6	9.2	10
5 in. twice	4b	272.0	68.7	163.8	42.9	760.7	189.1	.286	.059	718.6	26.5	9
10 in.	4b	319.3	66.2	167.6	51.8	782.9	239.6	.284	.072	728.1	13.2	10
10 in. twice	4b	273.7	35.5	162.7	36.5	765.0	167.1	.294	.036	724.4	9.5	10
20 in.	4b	268.4	77.7	158.0	59.6	736.4	267.5	.330	.060	710.0	15.9	9

*a and b imply samples tested 1 to 3 and 20 hours after impact, respectively.

TABLE A2 MEAN AND STANDARD DEVIATION FOR PIONEER, 601H, AND 381M VARIETIES.

VARIETY	CSF (gmf)	S. D.	PEAK FORCE (gmf)	S. D.	AREA-F	S. D.	DEF (cm)	S. D.	AREA-D	S. D.	NO. OF OBS.
381M	265.2	59.3	194.1	41.6	887.2	180.6	.259	.088	710.6	11.4	21
Pioneer	274.1	104.8	169.0	27.2	780.4	128.3	.290	.070	706.2	12.2	24
601H	406.4	126.5	161.4	36.4	737.0	166.1	.309	.054	699.2	15.6	24