PAPER #88-6027

IMPACT PARAMETERS RELATED TO BRUISING IN SELECTED FRUITS

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Written for presentation at the 1988
International Summer Meeting of the
AMERICAN SOCIETY OF AGRICULTURAL ENGINEERS

Rushmore Plaza Civic Center
Rapid City, SD
June 26-29, 1988

SUMMARY:
Impact testing with an instrumented free-falling mass (50.4 g) device was applied to three varieties of pears and two varieties of apples, for increasing ripeness stages and impact energy - (2 to 20 cm drops). Impact parameters were studied in relation to bruise and to ripeness, establishing relations between them and with the different characteristics of the fruits.

KEYWORDS:

American Society of Agricultural Engineers

St. Joseph, MI 49085-9659

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IMPACT PARAMETERS RELATED TO BRUISING IN SELECTED FRUITS

C.GARCIA, M. RUIZ, P.CHEN

INTRODUCTION

An intensive research is being done in recent years to develop and apply impact testing in fruits and vegetables. The design of instrumented impact testers (Chen et al, 1985) makes it possible for researchers to conduct more indepth investigation into the mechanical parameters that explain the impact response of biological materials.

Impact is the most important cause of damage and losses in fruits during harvesting, handling and transporting operations. This impact damage problem is specially critical for apples and pears.

The response of fruits to impact can also be used as sorting criteria in the design of nondestructive automatic fruit-sorters (Delwiche, 1986, Nahir,1986). In these applications, knowledge of relevant impact parameters which describe the desired quality factor of fruits is needed. Fruits, being biological materials, vary greatly from one to the other. Most fruits have properties that change with varietal differences, with ripeness stage, and also with enviromental conditions. Extensive and systematic testing is needed to be able to arrive at conclusive results (Fitt, 1982; Topping and Lutton, 1986).

Mechanical models which have been used to analyze biological materials are the elastic, the viscoelastic and the elastoplastic. Given the short duration of impact (5-10 miliseconds) it appears reasonable to assume that viscoelastic influence is minimal in this type of testing. At least an important part of the response of fruits to impact has to be due to the elasticity of the cells as tissue components; the elasticity model is thus the first approach to calculate stresses and strains due to impact in fruits and vegetables. Other researchers have shown in the past that the elastic model could be used to predict fruit damage with fairly good results (Fridley et al, 1964; Horsfield et al, 1972; Chen et al, 1986; Hemmat and Murfitt, 1987; Hellebrand, 1988).

Nevertheless, important discrepancies still exist as to variations in the impact response, due to changes in the impact parameters and in fruit conditions (Ruiz et al, 1987; Chen et al 1987).

The presence of very apparent fractures in some materials when impacted with spherical tips (Chen et al, 1987) suggests that important differences exist in fruit mechanical properties which lead to very different ways of failure, even for the same materials; this is specially the case when testing fruits in different conditions or different varieties or fruit species.

OBJECTIVES

The objectives of this study are:

-- To develop a complete software batch to retrieve, analyze and display the data obtained from an accelerometer-based freefall impact tester.

-- To determine which parameters, measured or calculated, are relevant to detect differences in the response of fruits to impact.

-- To relate size and structure of the resulting bruises to those relevant impact parameters.

EXPERIMENTAL PROCEDURE

Development of the software.

The following programs were completed:

IMPACTO: Basic for all the following studies (Chen et al, 1985), it controls the retrieval of data of the impact tester, performs and displays all the calculations for the accelerometer readings; DATOS: calculates all parameters to be analyzed (see Table 2): maximun force and deformation; permanent deformation; total input energy and percentage of rebound energy; final velocity; mechanical impulse; optimun force/time and force/deformation slopes; total and final impact durations; times to maximun force and to maximun deformation; irregularities in the curve (i.e. bioyield points); TENSION, calculates aparent moduli of elasticity in impact; triaxial stresses, maximun shear stress and its depth (called "critical depth"); CALCULO and DIBUJO calculate and display graphics of any file as needed; MEDIAS calculates and stores average curves of any selected groups of impacts, after the suppression of outlayers if present. This software may be adapted to any similar data acquisition device designed for impact testing.

Materials and Methods

Fruits from two apple varieties ("Golden Delicious" and " Starking") and three pear varieties ("Blanquilla", "Decana de Comice" and "Limonera"), which are common in the European fresh market, were transported directly after harvest from growing fields in Lerida (Spain) into cold-storage chambers. Samples of about 150 kg of fruits were selected for testing. Pear samples were kept in polyethylene bags to prevent moisture losses. Tests were performed in 5 or 6 15-day periods, (i.e. 10-12 weeks of total testing time), and each weekly test included three testing dates: Monday, Wednesday and Friday which correspond to ripening times of 0, 48 and 96 hours respectively in ripening storage (20 °C) (See Table 1). All tests were made at room temperature (16-20 °C).

In each sample (10 fruits), impacts were applied with a 50.4 - g instrumented rod, which has a 19 mm diameter spherical tip (Chen et al. 1985); drops from 2,4,6,8,10,12 and 20 cm height were applied to each fruit. The resulting bruise was measured (depth and diameter, i.e. width) after cutting (Chen et al., 1987), and carefully inspected, both visually and with an estereoscopic microscope (NIKON SMZ-2T, 1-63xx). Cross-sectional slices were cut manually (.5-1 mm), and observed immediately using incident and transmitted illumination, and photographed when needed.

Other measurements

Other measurements include specific weight (by immersion of fresh cylindrical samples); radius of curvature for calculations; flesh firmness reading (using the Instron standard 8 mm diameter rod). Also shearing resistance of the flesh and other chemical ripeness indexes were performed for other purposes, not included in this report.

Statistical Analysis

A "correspondence factorial analysis" (Judez and Perez, 1987; program CORBE of the Politechnic Univ. Madrid) was applied to the data, including all parameter data listed in Table 2. In this type of analysis,a binary matrix is generated from any set of observations, characterized by a series of variables or qualitative modes; this matrix represents a N-dimensional space. The program selects some projections of the points of this space, in function of the most relevant axes , usually two or three. These axes are selected by minimum distance criteria, and they contain the significant modes or parameters on the grouping of the observations. The output is a large graphical representation of the selected projections, showing the relations of the parameters between themselves from the grouping of the points. This analysis procedure is best fitted to describe complex phenomena, which include many parameters and observations from which no previous relations are known, and its application to mechanical test data is very new.

A Grubbs test, as well as data description and multiple regression analyses on selected variables were performed, using the MSTAT (Michigan State Univ. Statistical Package,developed with the Agricultural Univ. of Norway).

RESULTS AND DISCUSSION

IMPACT PARAMETERS

Figure 1 shows an example of the variation of the average impact acceleration curves for 10 "Limonera" pears of different maturity.

Table 2 shows the relevant impact parameters analyzed in this study. Results obtained by the correspondence analysis show that, for all varieties tested, the distribution of the values of the impact parameters has a definite shape, with two changes in direction forming an inverted "V" or an "N" in the 3-dimensional space (see Figs. 2 and 3, for Golden Delicious) . This indicates that the phenomenon of the impact response of these fruits becomes different for increasing impact energy (height of fall from 2 to 20 cm) when using fruits of the same ripeness level. The energy levels at which the fruit changes in its mechanical response are, in these tests, 4-6 cm and 12 cm for all fruits, excluding "Limonera" pear.

Also, it is shown that the "distance" (i.e. difference) between the groups of observations is greater for specific drop-height increments, with variations for the different varieties.

When analyzing the data with elimination of the characteristic "drop height" (see Figs. 4 and 5 for "Limonera" pear) ripeness differences are responsible of the groupings; the data form a similar shape as was stated before. This indicates that increasing ripeness influences the grouping of the values of the parameters in a totally similar way as the increase in drop height.

According to this analysis, those parameters which evolve forming similar structures and remain near in their evolution are linearly related. Their groups are connected with straight lines, forming the directions of variation of the groups (see Figs. 7 and 8).

In those fruit varieties where ripeness differences are important, this characteristic (ripeness variation) combines with drop height, in the way shown in Fig.6 for "Limonera " pear; the drop-height related (not inverted) "Vs" shift orderly with increasing ripeness levels.

In all these analyses, the character named "ripeness" was defined just by the date of testing; only first week-day data were used. To verify objectively these ripeness changes, correlations between date of testing and Magness-Taylor firmness values were determined for all fruits; these show that both parameters are highly correlated (Table 3).

In most varieties and conditions tested, drop height of 4 cm showed the largest amplitude for ripeness differences (not shown in the included Figures). Therefore, impact of an energy equivalent to this 4 cm drop is postulated to be the best selection for detecting ripeness in an automatic device. Proper selection of the radius of curvature of the impacter would eliminate the negligible bruises observed in these tests.

When analyzing all data (including ripening room samples, see Table 1), it is shown that ripeness interferes completely with all drop-height related parameters; at the same time it associates linearly with some other parameters (see below). From this, it is established that a cuadratic relation exists with the mentioned drop height related parameters, being the rest of the parameters linearly related to ripeness. As an example, Fig 7 shows the distribution of impact-parameter values for "Blanquilla" pear: ripeness changes are distributed about the vertical axis trough the so-called "center of gravity"; drop-height related variables encircle them in the already shown inverted "V", suggesting a cuadratic distribution.

After these analyses, three categories of parameters can be established, depending on their relationship to drop-height of the impacter or to ripeness level of the fruits:

First group: Maximum deformation (DM); permanent deformation (DP); critical depth (PC); width of bruise (AM); depth of bruise (PM); maximum impulse (IM). These parameters always relate linearly with drop height and this relation is also shown by the regression analyses . The impulse, calculated by integration of the force-time curve is a very good measure of impact energy, showing a perfect linear relation with drop height, and being absolutely independent from ripeness level.

Second group: Maximum impact force (IF); optimum slope force/time (FT); coefficient (IF)*(FT); rebound velocity (VF). They show a close linear relation with drop height, although when the effect of ripeness becomes very important, they are affected by it. Percentage of elastic (rebound) energy (%E) is a strict "intermediate" parameter: Fig 8 shows the variation of this parameter (small circles) in the same pattern as the drop height-related parameters, but approaching ripeness variations; it relates consistantly with calculated elasticity modulus, as could be expected (triangles in Fig. 8).

Third group: Total impact duration (TT); final impact duration at v=0 (TF); increment (TT)-(TF);time to maximum force (TM), optimum slope force/deformation (FD); aparent dynamic modulus of elasticity (ME); maximum shear stress (EC). These parameters are linearly related with ripeness, some of them closer than others (Figure 7). A combination of a number of these parameters as a quality index could facilitate the detection of very small ripeness differences.

A significant result is that ripeness changes affect predominantly all time-related parameters. One such parameter (time to maximum force, TM) has been used previously for ripeness classification (Delwiche, 1987); the results of this study shows that the accuracy may be increased by using other time parameters. Another significant result is the better prediction of ripeness differences that can be accomplished by means of this impact testing than by the traditional penetrometer (Table 3, optimum slope force/deformation).

ELASTIC REBOUND

As has been shown (see above) the percentage of elastic energy decreases as drop height and ripeness level increase, showing an "intermediate" relationship with both characteristics; as with the rest of variables, an abrupt change appears, at 8 cm for apples and 6 cm for pears (from a %E of about 35% to about 10%). All this implies the presence of a significantly greater plastic deformation at these mentioned drop heights; being the tissue of the pear much more compact, with fewer air spaces (higher Poisson's coefficient) it reaches plastic failure stress earlier than the tissue of the apple, that contains a high percentage of air-space volume). Therefore, an important plastic deformation sets on at these mentioned energy levels and influences bruising, giving rise to significant differences in bruise structure and in bruise resistance (see below).

Ripeness changes influence the parameters in a similar way as drop height; we know that the resistant structure of the fruit tissue (lying in the cell walls and middle lamellae) modifies with increasing ripeness, causing a decrease in the elastic response, until complete plasticity is obtained with extremely advanced ripeness (especially so in pears).

There are two (calculated) parameters which do not behave in the same direction for drop-height increases and for ripeness increases: shear stress (EC), and critical depth (PC). EC increases with drop height, and, following elastic theory, decreases with ripeness; on the contrary, PC increases with drop height and <u>increases also with</u> ripeness; all this clearly explains the observed vaiations in bruise size.

BRUISE CHARACTERISTICS

Depth and width define size and shape of the bruises, different for the different varieties tested. The cross section is semi-elliptic (typically in apples) or semi-circular (typically in pears); one of the pear varieties ("Decana de Comice") shows long spikes extending radially into the fruit (Chen et al., 1987 made the same observation in Asian pears); they appear for drop heights over 6 cm, and firmness higher than 5.5 N (very soft).

The observed " critical point", as the depth of the initiation of fracture or discontinuity, is located between 1.8 mm and about 2.6 mm, varying broadly with ripeness level, drop height and fruit variety. The appearance and development of those discontinuities or fractures vary significantly (see Fig 9). In the case of "Decana de Comice" pear a clear evidence exists that a "fracture cone" is formed; this is traditionally related to shearing stresses. When comparing this "critical point" with calculated critical depths by application of the elastic contact, a difference of around 1 mm is observed, especially for 2 and 4 cm drops; it is postulated to be due to the presence of the skin, that adds to the measurement of the critical depth.

The presence of this type of fractures, only in some varieties and specific conditions, introduces a new factor of uncertainty in the results obtained by different researchers. Fracture is described as a "catastrophic" rupture, initiating when stress and strain surpass the resistance limit in a preexisting discontinuity in the microstructure; it propagates then uncontrollable through the material. It is established that a compact structure needs higher stresses to attain fracture in a certain "critical point", but, once established, this fracture propagates easier (Elices, 1986).

In apples, on the contrary, nearly horizontal discontinuities (not clearly fractures) turn up near the skin, and new ones form for higher energy impacts, and for increasing ripeness; due to the large number of small discontinuities between the cells, related to air spaces, failure of the structure is produced at the very beginning of indentor penetration, and new failure surfaces form as it penetrates into the fruit. It has been stated (Jowitt,1978), that a large quantity of deformation energy is dissipated in these failures, so that no high stresses are created in a determined "critical point", as is the case with "crisp" fruits. Jarimopas (1984) already showed this type of failures in apples. This type of failure may be better explained by deformation, or strain criterium, although, in the most recent studies on structural failure by fracture in solids, the distinction between strain or stress failure is minimized, as being not explanatory at all of the phenomenon.

Depth and width of bruises show not significant correlation with increasing ripeness, during a period of 10 or 12 weeks of cold storage (Fig 10). Only the variety "Limonera", with very important firmness decrease , shows some (not consistant) bruise size increase. This same figure shows the significant difference in bruise width between "Limonera","Blanquilla" and "Decana" pears, and both varieties of apples. No differences exist for depth of bruise when no spikes are formed (at 4 cm drops); they become highly significant for higher-energy impacts (Fig. 11).

CONCLUSIONS

It is shown that the impact device, instrumented in the present study is very reliable and accurate for impact testing of fruits and similar materials; it is efficient and fast for determining all possible parameters involved in the mechanical response to a free-falling mass. From the parameters studied, some are closely related to drop height and independent from ripeness changes in the fruits, like maximum and permanent deformation (DM and DP); some are closely dependent on ripeness, like duration of impact and times to maximum force or maximum deformation (TT,TF and TM); and some show an intermediate relationship, like percentage of elastic (rebound) energy (%E).

Plastic deformation increases highly with increasing drop height and ripeness, with abrupt changes in the overall impact response, that turns from nearly elastic to predominantly plastic.

Fruits with a dense , juicy pulp and low air-space volume are more susceptible to deep bruises; these may develop cone-shaped and radial fractures when impacted. Fruits with a high volume of air spaces between the cells develop bruises in width, closer to the skin. Size of bruises depends predominantly on total applied impact energy, for a fixed indentor, and for the ripeness variation and the varieties considered in this study; in some materials, and in selected conditions, however, spikes may appear which increase significantly the depth of bruises; this is the case of dense and "crisp" fruits, with low air-space in the tissue.

ACKNOWLEDGEMENTS

The financial support of the U.S.-Spain Joint Commitee for Scientific and Technological Cooperation (Project No. CCA 8411012) is gratefully acknowledged. The cooperation of the Cold Storage Institute from the CSIC (Scientific Research Council) in Madrid is also gratefully appreciated.

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	Fruit variety	Harvesting date	Firmness Interval (N)	Testing dates	Total no. of fruits	Height (cm)
PEARS	Blanquilla	10-Sept.87	45,8-15,3	Sept. 21-23-25 Oct. 5-7-9-19-21-23 Nov. 2-4-6-16-18-20	150	2,4,6,8,10 and 12 (Sept.21-Oct.9) 2,4,6,8,10,12 and 20 (Oct.19-Nov.20)
	Decana de Comice	11-Sept.87	38,8-5,1	Sept. 21-23-25 Oct. 5-7-9-19-21-23 Nov. 2-4-6-16-18-20	150	2,4,6,8,10 and 12 (Sept.21-Oct.9) 2,4,6,8,10,12 and 20 (Oct.19-Nov. 20)
	Limonera	26-July-87	70,8-8,38	Aug. 3-5-7-10-12-14-24-26-28 Sept. 7-9-11-21-23-25 Oct. 5-7-9	180	4,6,8,10 and 12
APPLES	Golden Delicious	12-Oct.87	29,2-16,5	Oct. 19-21-23 Nov. 2-4-6-16-18-20-30 Dec. 2-4-14-16-18	150	2,4,6,8,10,12 and 20
	Starking	9-Oct.87	32,4-18	Oct. 19-21-23 Nov. 2-4-6-16-18 20-30 Dic. 2-4-14-16-18	150	2,4,6,8,10,12 and 20

Table 1.- Summary of tests and testing conditions (Free-falling impacter of 50.4 gr).

Name of parameter	S.I. Units	Symbol
Maximum deformation	mm	DM
Permanent deformation	mm	DP
Critical depth (maximum shear stress location Hertz model)	mm	PC
Maximum mechanical impulse	N x s	IM
Maximum bruise depth	mm	PM
Maximum bruise width	mm	AM
Percentage of rebound energy	%	%E
Maximum impact force	N	IF
Optimum slope force/time	N/s	FT
Calculated coefficient	N^2/s	IF x FT
Rebound velocity	m/s	VF
Total impact duration	ms	TT
Final impact duration	ms	TF
Time to maximum force	ms	TM
Increment TT-TF	ms	IT
Optimum slope force/deformation	N/m	FD
Aparent dynamic modulus of elasticity	Pa	ME
Maximum shear stress	Pa	EC

Table 2.- Summary of impact parameters studied.

Parameter	Correlated with	Correlation coefficient		Variety and storage conditions
Bruise width (A.M)	Drop height	0,744	(n = 300)	Limonera Pear cold storage
Bruise width (A.M)	Drop height	0,685	(n = 150)	Limonera Pear ripening room 3rd week test
Bruise depth (P.M)	Drop height	0,733	(n = 300)	Limonera Pear cold storage
Bruise depth (P.M)	Drop height	0,678	(n = 150)	Limonera Pear ripening room 3rd week test
Testing date	Maximum Magness Taylor force	- 0,780	(n = 60)	Limonera Pear cold storage
Testing date	Maximum Magness Taylor force	- 0,702	(n = 30)	Limonera Pear ripening storage
Testing date	Optimum slope Force/ deformation	- 0,865	(n = 60)	Limonera Pear cold storage
Testing date	Optimum slope Force/ deformation	- 0,723	(n = 30)	Limonera Pear ripening storage
Bruise width (A.M)	Drop height	0,895	(n = 1050)	Golden Delicious apple all testing impacts
Bruise depth (P.M)	Drop height	0,911	(n = 1050)	Golden Delicious apple all testing impacts

Table 3.- Values of most significant correlation coefficients for selected parameters.

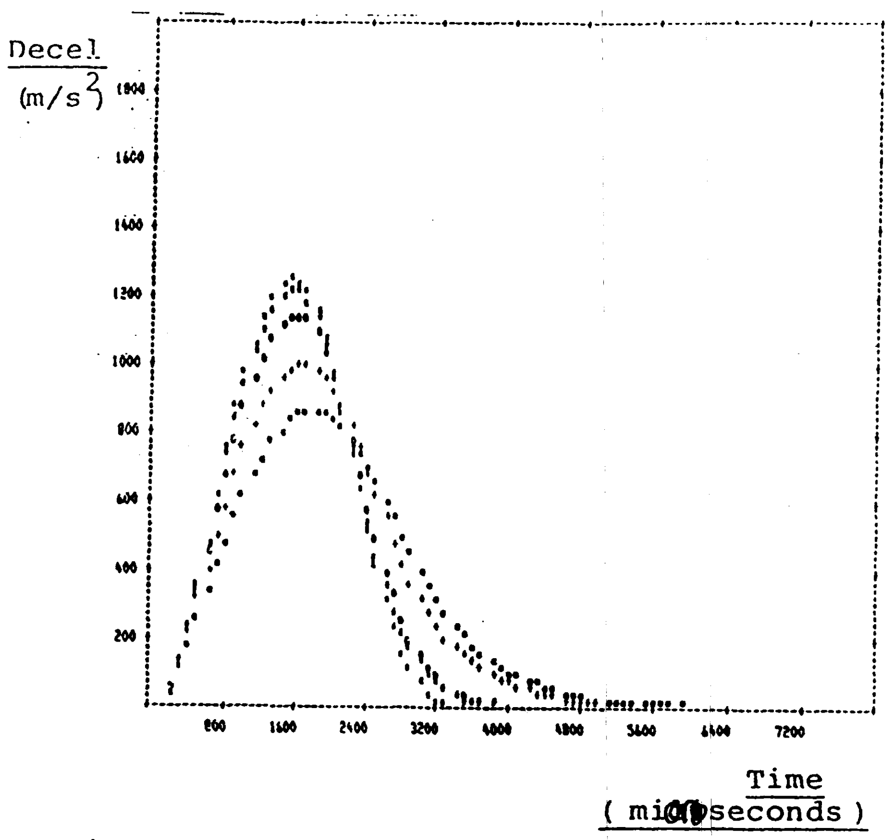


Figure 1. Average impact curves for different ripeness levels in "Limonera" pear.(▮)=3 Aug.87 (*)=10 Aug., (o)=24 Aug., (+)=7 Sept.,(⊕)=21 Sept.

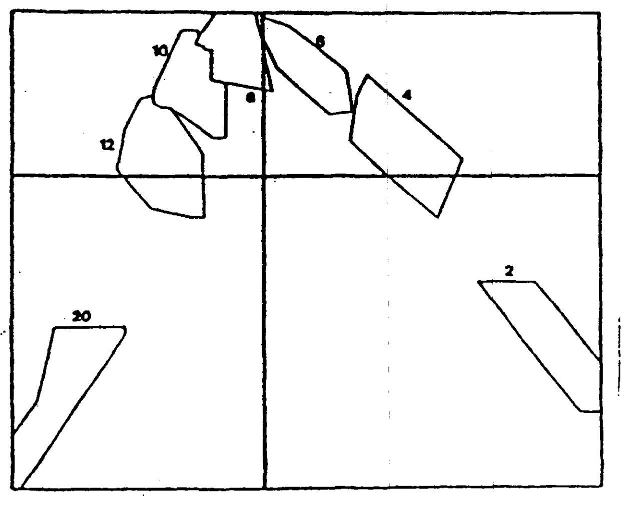


Figure 2. Factorial projection (axes 1-2)of impact data for all 0-day ripening tests. Numbers are height of drop. The areas represent point clusters, associated with each drop height. " Golden Delicious" apple.

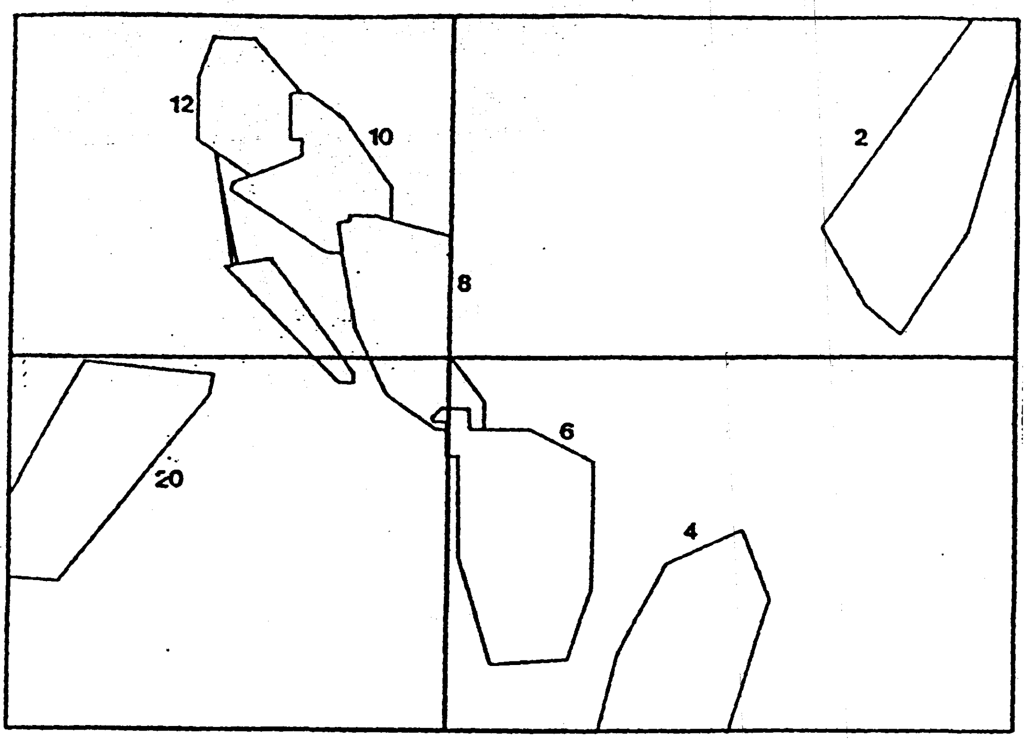


Figure 3. Same data as Fig. 2, axes 1-3.

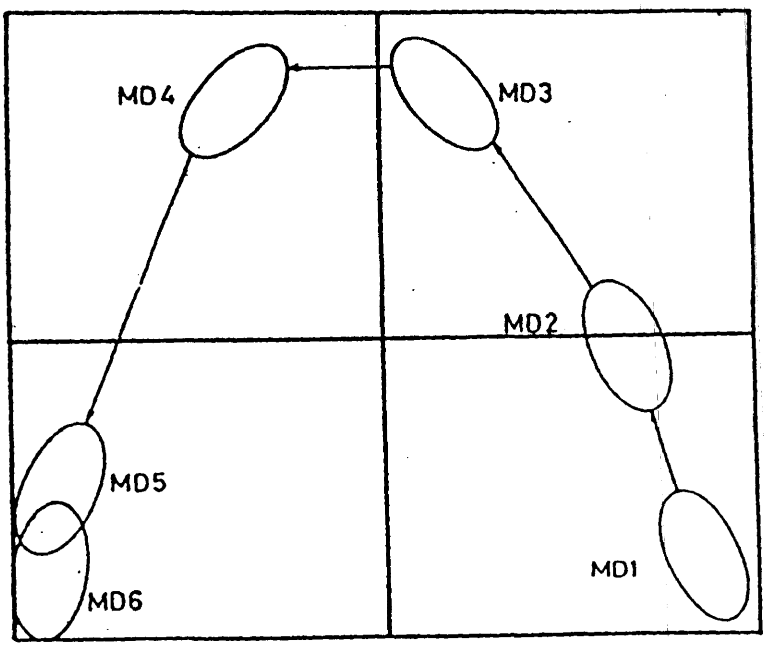


Figure 4. "Limonera" pear. Factorial plane 1-2, 0 days ripening; 6 cm drop. Ellipses represent point clusters, being MD1 to MD6 increasing ripeness.

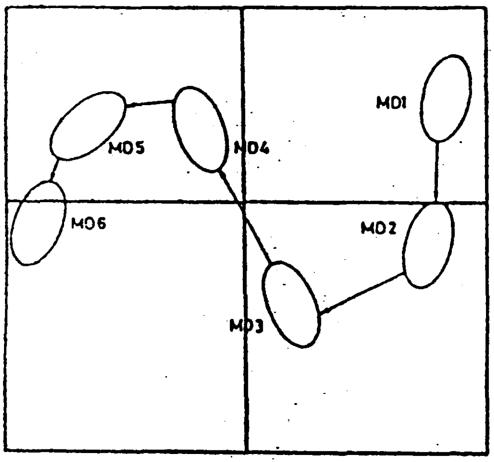


Figure 5. "Limonera" pear. See Fig. 5. Plane 1-3

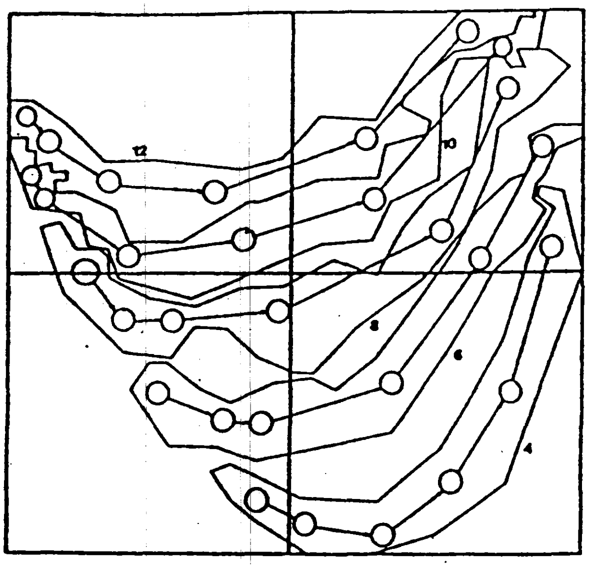


Figure 6. "Limonera". Plane 1-2; All data 0 days ripening. 4-12: drop heights; circles and arrows represent increasing-ripeness clusters of points.

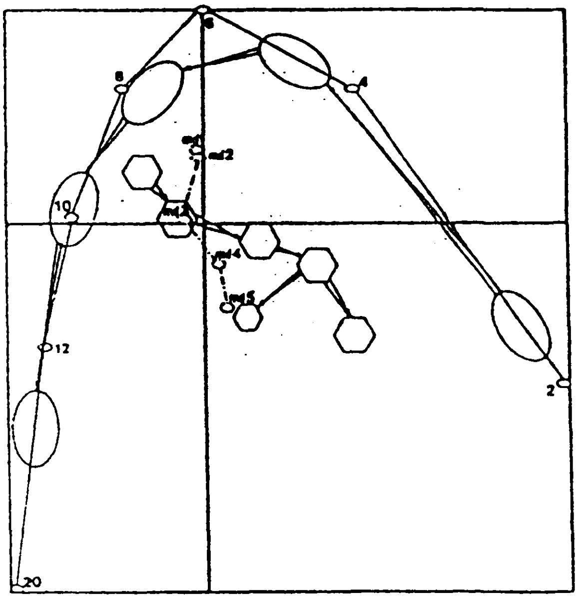


Figure 7. "Blanquilla" pear. Plane 1-2 for all 0-days ripen. data. Ellipses: clusters of height-related parameters; hexagons: clusters of ripeness-related parameters

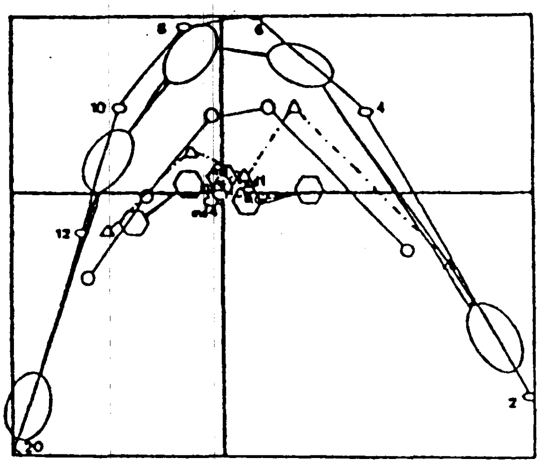


Figure 8. Plane 1-2."Starking" apple (see Fig.7).Triangles: (ME); circles: (%E).

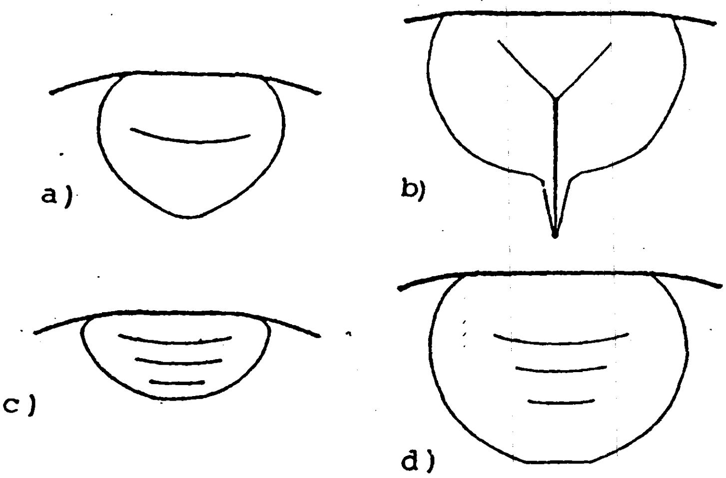


Figure 9. Types of bruises and failures/ fractures in all varieties tested. 12 cm drops. a) "Limonera"; b) "Decana"; c) both apple varieties; d) "Blanquilla".

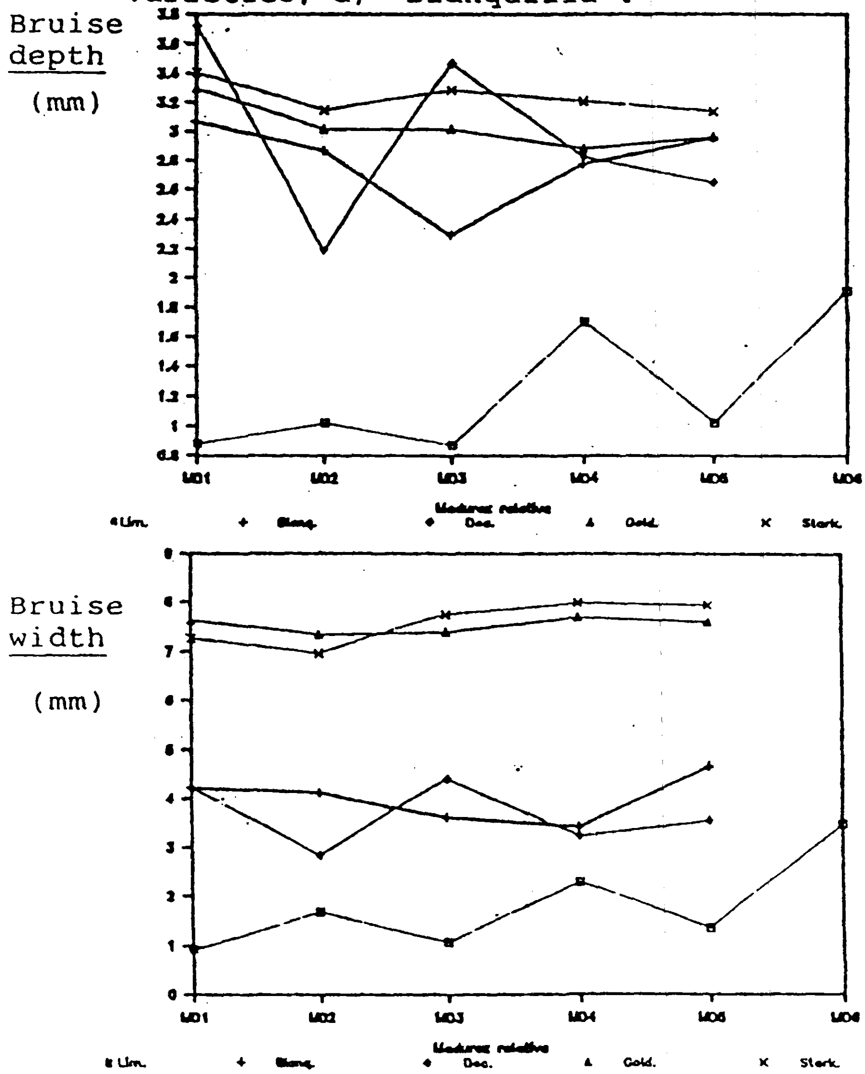
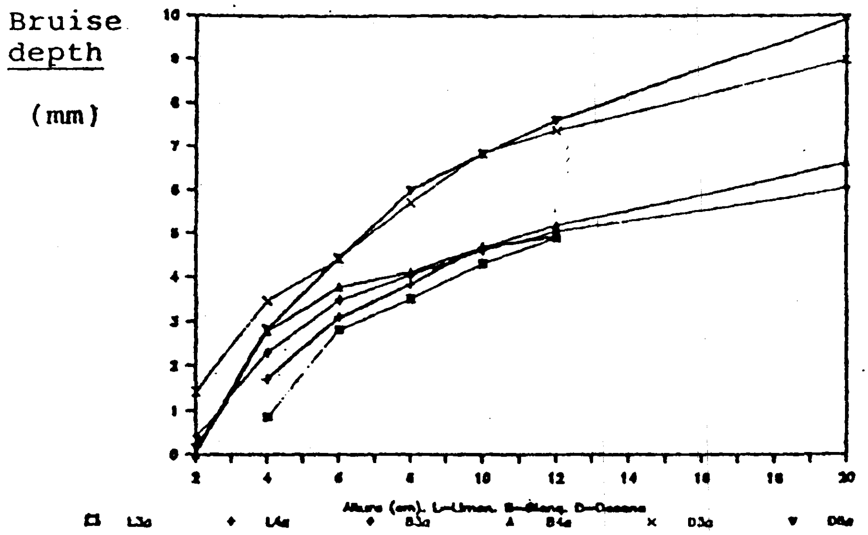


Figure 10. Depth and width of bruise, for all varieties; 4 cm drops; MD1 to MD6: increasing ripeness (0 hrs.ripe.).



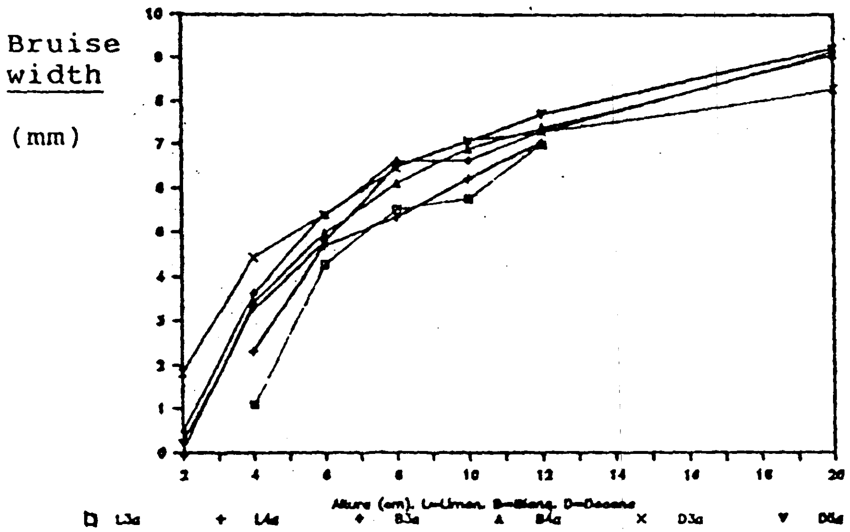


Figure 11. Depth and width of bruise in relation to impact severity (2 to 20 cm drops);pears, 6th and 8th weeks of cold storage,0 days ripening.
L: "Limonera" B:"Blanquilla D: "Decana".
3a: 6th week ; 4a: 8th week.

Name of parameter	S.I. Units	Symbol
Maximum deformation	mm	DM
Permanent deformation	mm	DP
Critical depth (maximum shear stress location Hertz model)	mm	PC
Maximum mechanical impulse	N x s	IM
Maximum bruise depth	mm	PM
Maximum bruise width	mm	AM
Percentage of rebound energy	%	%E
Maximum impact force	N	IF
Optimum slope force/time	N/s	FT
Calculated coefficient	N^2/s	IF x FT
Rebound velocity	m/s	VF
Total impact duration	ms	TT
Final impact duration	ms	TF
Time to maximum force	ms	TM
Increment TT-TF	ms	IT
Optimum slope force/deformation	N/m	FD
Aparent dynamic modulus of elasticity	Pa	ME
Maximum shear stress	Pa	EC

Table 2.- Summary of impact parameters studied.

Parameter	Correlated with	Correlation coefficient	Variety and storage conditions
Bruise width (A.M)	Drop height	0,744 (n = 300)	Limonera Pear cold storage
Bruise width (A.M)	Drop height	0,685 (n = 150)	Limonera Pear ripening room 3rd week test
Bruise depth (P.M)	Drop height	0,733 (n = 300)	Limonera Pear cold storage
Bruise depth (P.M)	Drop height	0,678 (n = 150)	Limonera Pear ripening room 3rd week test
Testing date	Maximum Magness Taylor force	- 0,780 (n = 60)	Limonera Pear cold storage
Testing date	Maximum Magness Taylor force	- 0,702 (n = 30)	Limonera Pear ripening storage
Testing date	Optimum slope Force/ deformation	- 0,865 (n = 60)	Limonera Pear cold storage
Testing date	Optimum slope Force/ deformation	- 0,723 (n = 30)	Limonera Pear ripening storage
Bruise width (A.M)	Drop height	0,895 (n = 1050)	Golden Delicious apple all testing impacts
Bruise depth (P.M)	Drop height	0,911 (n = 1050)	Golden Delicious apple all testing impacts

Table 3.- Values of most significant correlation coefficients for selected parameters.

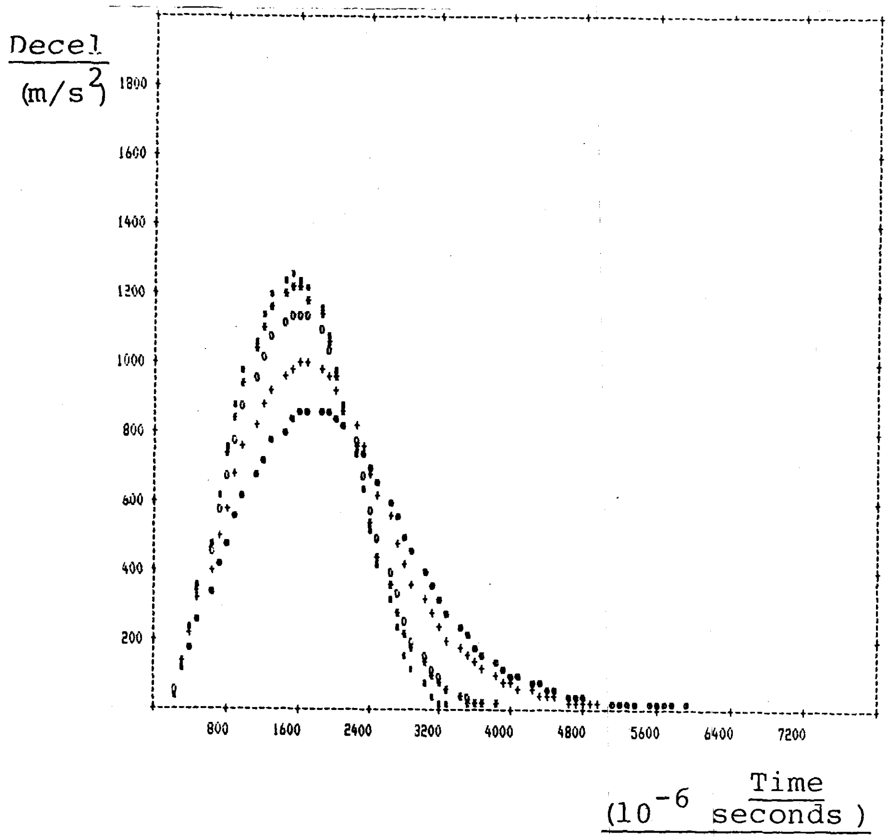


Figure 1. Average impact curves for different ripeness levels in "Limonera" pear.(▮)=3 Aug.87 (✱)=10 Aug., (o)=24 Aug., (+)=7 Sept.,(Ф)=21 Sept.

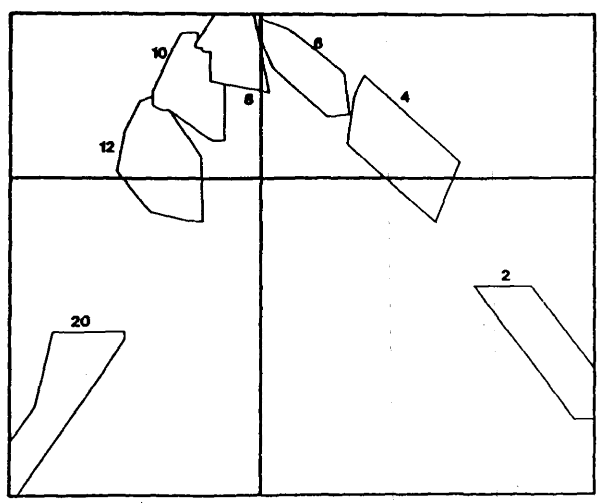


Figure 2. Factorial projection (axes 1-2)of impact data for all 0-day ripening tests. Numbers are height of drop. The areas represent point clusters, associated with each drop height. " Golden Delicious" apple.

	Fruit variety	Harvesting date	Firmness Interval (N)	Testing dates	Total no. of fruits	Height (cm)
PEARS	Blanquilla	10-Sept.87	45,8-15,3	Sept. 21-23-25 Oct. 5-7-9-19-21-23 Nov. 2-4-6-16-18-20	150	2,4,6,8,10 and 12 (Sept.21-Oct.9) 2,4,6,8,10,12 and 20 (Oct.19-Nov.20)
	Decana de Comice	11-Sept.87	38,8-5,1	Sept. 21-23-25 Oct. 5-7-9-19-21-23 Nov. 2-4-6-16-18-20	150	2,4,6,8,10 and 12 (Sept.21-Oct.9) 2,4,6,8,10,12 and 20 (Oct.19-Nov. 20)
	Limonera	26-July-87	70,8-8,38	Aug. 3-5-7-10-12-14-24-26-28 Sept. 7-9-11-21-23-25 Oct. 5-7-9	180	4,6,8,10 and 12
APPLES	Golden Delicious	12-Oct.87	29,2-16,5	Oct. 19-21-23 Nov. 2-4-6-16-18-20-30 Dec. 2-4-14-16-18	150	2,4,6,8,10,12 and 20
	Starking	9-Oct.87	32,4-18	Oct. 19-21-23 Nov. 2-4-6-16-18 20-30 Dic. 2-4-14-16-18	150	2,4,6,8,10,12 and 20

Table 1.- Summary of tests and testing conditions (Free-falling impacter of 50.4 gr).

Table 1.- Summary of impact parameters studied.

Name of parameter	S.I. Units	Symbol
Maximum deformation	mm	DM
Permanent deformation	mm	DP
Critical depth (maximum shear stress location Hertz model)	mm	PC
Maximum mechanical impulse	N x s	IM
Maximum bruise depth	mm	PM
Maximum bruise width	mm	AM
Percentage of rebound energy	%	%E
Maximum impact force	N	FM
Optimum slope force/time	N/s	F/T
Calculated coefficient	N^2/s	IF x F/T
Rebound velocity	m/s	VF
Total impact duration	ms	T
Final impact duration	ms	TF
Time to maximum force	ms	TM
Increment TT-TF	ms	IT
Optimum slope force/deformation	N/m	FD
Aparent dynamic modulus of elasticity	Pa	ME
Maximum shear stress	Pa	EC

Table 2.- Values of most significant correlation coefficients for selected parameters.

Parameter	Correlated with	Correlation coefficient r	no. obs.	Variety and storage conditions
Bruise width (A.M)	Drop height	0,744	(n = 300)	Limonera Pear, cold storage
Bruise width (A.M)	Drop height	0,685	(n = 150)	Limonera Pear, ripening room, 3rd week test
Bruise depth (P.M)	Drop height	0,733	(n = 300)	Limonera Pear, cold storage
Bruise depth (P.M)	Drop height	0,678	(n = 150)	Limonera Pear, ripening room, 3rd week test
Testing date	Maximum Magness Taylor force	- 0,78	(n = 60)	Limonera Pear cold storage
Testing date	Maximum Magness Taylor force	- 0,702	(n = 30)	Limonera Pear ripening storage
Testing date	Optimum slope Force/ deformation	- 0,865	(n = 60)	Limonera Pear cold storage
Testing date	Optimum slope Force/ deformation	- 0,723	(n = 30)	Limonera Pear ripening storage
Bruise width (A.M)	Drop height	0,895	(n = 1050)	Golden Delicious apple, all tests
Bruise depth (P.M)	Drop height	0,911	(n = 1050)	Golden Delicious apple, all tests