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thesis entitled

CARBON DIOXIDE EVOLUTION AS A MEARUSE OF DAMAGE TO FRESH APPLES HANDLED IN CORRUGATED SHIPPING CONTAINERS

presented by

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has been accepted towards fulfillment of the requirements for

M. S. degree in PACKAGING

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Date 10/1/85

CARBON DIOXIDE EVOLUTION AS A MEASURE OF DAMAGE TO FRESH APPLES HANDLED IN CORRUGATED SHIPPING CONTAINERS

by

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A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

School of Packaging

1985

ABSTRACT

CARBON DIOXIDE AS A MEASURE OF DAMAGE TO FRESH APPLES HANDLED IN CORRUGATED SHIPPING CONTAINERS

by

James Michael Brown

An objective, non-destructive method for determining the level of damage to horticultural commodities would be valuable for evaluating the peformance of produce shipping containers. Previous research has indicated that mechanically damaged apples show enhanced CO_2 output when compared to non-damaged fruit.[1/]

Apples (Malus domestica Borkh., cv. 'Empire') were packaged in two types of corrugated shipping containers. Three forces (impact by dropping, compression and vibration) with all combinations of packing and forces were applied to the shipping containers. The apples were removed from the shipping containers and placed in air-tight plastic buckets where carbon dioxide evolution was measured 1, 2, 3, 4 and 5 hours post treatment. Later, a visible rating of mechanical injury was given to the apples.

Visible injury scores positively correlated with the CO_2 evolution of mechanically damaged apples at 99% confidence limits. The type of 1) force(s) applied, 2) packaging, and 3) fruit position within a container caused significant differences in CO_2 output and visible injury scores. A method was developed where the change in CO_2 output of damaged apples can be measured for determining the protective characteristics of shipping containers.

1/ Klein, J. D. 1983. Physiological causes for changes in carbon dioxide and ethylene production by bruised apple fruit tissues. Ph.D. dissertation, Michigan State University, East Lansing.

ACKNOWLEDGMENTS

I would like to thank J. Lee, my major professor and the other members on my committee, A. C. Cameron and R. Brandenburg; and, D. H. Dewey, who provided me with encouragement and support throughout my undergraduate and graduate programs at Michigan State University.

I would also like to thank Weyerhaeuser Company, who supported the completion of my thesis while I was employed in their Shipping Container Division. Especially, R. S. Ernsberger, Manager of Technology, Shipping Container Division, and S. K. Kaluzny, Unit Manager, Statistics and Applied Math.

Portions of this research were sponsored by American-Israel Binational Agricultural Research Fund, Project No. I-118-80, administered jointly by Drs. D. H. Dewey and K. Peleg.

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LIST OF SYMBOLS AND ABBREVIATIONS

CO_2	carbon dioxide
cm	centimeter
cv	cultivar
C_2H_4	ethylene
gm	gram
g	gravity
hr	hour
hz	hertz
in.	inch
m	meter
μℓ or μL	microliters
mℓ or mL	milliliter
N	Newton
O_2	oxygen
lbf	pounds of force
r.h.	relative humidity
*	significant at 5% level of probability
**	significant at 1% level of probability

INTRODUCTION

During distribution, fresh fruit and vegetables are susceptible to physical damage, causing major post-harvest losses at all levels of marketing. Produce packaged in shipping containers is likely to encounter various handling hazards, such as dropping, compressive loads and vibration inputs. Before the performance of a produce shipping container can be determined, individual fruit must be inspected and assigned a subjective rating of physical damage. An objective, nondestructive method for readily assessing damage would be useful for evaluating the effects of transit forces on fresh produce packaged in shipping containers.

Many horticultural crops respond to injury by changes in carbon dioxide output. Work by Klein (15) and unpublished results by Dewey and Parker[1/] have suggested that the increased carbon dioxide output of damaged apples, tomatoes and oranges is related to the level of visible bruising on these crops. A method by which this change in carbon dioxide production could be captured and measured after damage to fruits might provide an objective, rapid index of injury.

[1/] D. H. Dewey, Ph.D., Professor Emeritus and Michael L. Parker, Graduate Student, Michigan State University, East Lansing, MI 48824.

Therefore, the purpose of this thesis is fourfold: 1) to determine how the change in CO_2 output of bruised apples correlates to a subjective rating of visible damage, 2) to examine the effects of various simulated transit inputs (impact by dropping, vibration, compression and combinations thereof) and fruit position within a container on CO_2 output and visual injury scores of apples, 3) determine whether the change in carbon dioxide evolution of apples can be used to evaluate the protective characteristics of shipping containers, 4) to provide a method by which the change in CO_2 output of apples after damage can be measured and utilized as an objective method for determining the protective characteristics of shipping containers.

LITERATURE REVIEW

PHYSIOLOGICAL RESPONSES OF INJURED FRUITS

Many studies have focused on the enhanced CO_2 or ethylene production of crops after mechanical damage. Tomato (1,15,17,21,22), apple (22), banana (19), cantaloupe (20), cherry (26) and citrus (6,14,31) show enhanced CO_2 output following injury. Similarly, enhanced ethylene following injury has been observed in apple (5,22,27), avocado (33), cantaloupe (20), citrus (36) and tomato (17,22).

MacLeod et al. (17) reported higher levels of CO_2 production within 24 hours for tomatoes after bruising by impact. Additionally, an increase in the number of drops correlated with higher levels of CO_2 and ethylene production. Six days after damage, increased CO_2 production could not be detected.

Nakamura and Ito (21,22) found an increase in respiration rate of tomato fruit after vibration. The increase in respiration was observed after vibrating fruit at 1 and 2 g at specified durations from 30 minutes to 5 hours. When vibration times were short, there was a proportional increase in CO_2 production with respect to the acceleration level.

Other studies have shown that harder surfaces, higher compressive loads and higher vibration accelerations increased the production of CO_2 in citrus (6). Vines et al. (36) reported higher respiration rates and ethylene levels in grapefruit after fruit was dropped from a height of 4 and 6 feet onto a hard surface. The grapefruit returned to normal respiration rates with time. They concluded that C_2H_4 after damage was a stress symptom and not a normal metabolic product in citrus.

Information regarding the biochemical changes that take place in damaged fruit is limited. Many studies refer to the increase in CO_2 production of bruised fruit as enhanced respiratory activity. Pollack and Hills (27) observed that following bruising of red tart cherries, "the increase in carbon dioxide output greatly exceeded the increase in oxygen utilization". Oxygen consumption increased 50%, while CO_2 output increased 126%. Hyodo et al. (14) observed almost twice the CO_2 output as compared to O_2 uptake during the first 5 hours post-treatment after Satsuma mandarin fruit were dropped. Later O_2 uptake and CO_2 evolution were similar. Robitaille and Janick (28) suggested that an increase in CO_2 production after bruising of apples was not the result of increased respiration.

Klein (15) demonstrated that excess CO_2 after dropping apple fruit "came exclusively from the bruised tissue." He found cortical tissues .5 cm below the epidermis produced 77 $\mu\ell/g{\cdot}hr$ at the bruise site and 35 $\mu\ell/g{\cdot}hr^{-1}$ at the control site on the fruit. Additionally, excised bruised tissues displayed a greater response to damage than whole fruit. Klein concluded that "the increase in CO_2 evolution from apples after bruising is not due to enhanced aerobic or anaerobic respiratory activity, but rather due to decarboxylation of malic acid in cortical tissues at the bruise site," but gave litle evidence for this statement.

Whatever the cause of increased CO_2 evolution of damaged fruit is, the preceding studies have shown that enhanced CO_2 output occurred from damaged fruits when compared to nondamaged fruits, and increasing the level of damage by increasing the impact force, number of impacts, and the duration or magnitude of vibration resulted in a proportionally increased CO_2 evolution in these fruits.

SIMULATED TRANSIT TESTING OF SHIPPING CONTAINERS

A simulated transportation environment can be designed in one of two ways: 1) to record transit vibrations and reproduce them with a servo hydraulic vibrator, or 2) to reproduce the damage observed in the transportation environment by trial and error with arbitrarily chosen impacts and vibrations (8,10). A knowledge of the transportation environment is necessary to develop meaningful tests; however, no one simulated transit test can be used to determine the performance of a container (12,13,37). The design of tests to simulate the transportation environment and to subsequently reproduce the damage in the laboratory basically consists of three types of forces: impact by dropping, vibration and compression.

IMPACT BY DROPPING

Ostrem and Godshall (25) have indicated that impact damage caused by dropping is affected by the size, weight, contents and shape of the container. During distribution, container bottoms will receive 70% of all drops; the remaining 30% of drops will occur on container sides, edges or tops (25). Edge and corner drops occur from greater heights than flat drops. Most containers will be dropped at low levels numerous times, and will experience few drops from high levels. There is a direct correlation between drop height, weight and the size of a container; the heavier and larger the package, the lower the drop height. Palletized loads experience lower and fewer drops than nonpalletized loads.

Many studies have focused on predicting the level of injury to crops within packages with mathematical expressions after impact (12,31,34,35). These mathematical expressions are capable of predicting the level of damaged fruit based on drop height, number of drops, fruit variety and package type. However, in addition to drops, produce containers experience compressive loads and vibration inputs; therefore, these equations fall short of predicting how a particular package system would provide protection from all the hazards experienced in a transportation environment.

Guillou et al. (10) recommends using 50 two-inch flat drops in the laboratory to simulate impact damage to produce containers. Schoorl (30) dropped apple packs from heights of 6" and 12" (1, 3, 9 and 27 times), 18" (1, 3 and 9 times), 24" (1 and 3 times) and 48" (1 time). American Society for Testing Materials D-4169, Performance Testing of Shipping Containers and Systems (3), suggests 4 drops on each base edge of the container from a height of 3", 6" or 9" (depending on the assurance level chosen) to simulate damage to a palletized truckload.

VIBRATION

Frequencies encountered in the transportation are primarily below 25 Hertz, with 3-15 Hertz being most prevalent (7,9). Vibration inputs are usually from .2 to .8 g at 3 to 10 Hertz for rail transportation and from .1 to .8 g at 3 to 20 Hertz for trucks (7). In a study of the causes of fruit damage on transport trucks, it was shown that frequencies can range from 3 to 20 Hertz with accelerations less than .1 g to slightly higher than 1 g (24).

According to O'Brien (23), the vibration of fruit within containers depends on: 1) the depth of the container, 2) the tightness of fill, 3) type of suspension system used in the truck, 4) the magnitude of force exerted to the truck from the roadbed, 5) the vibrating characteristics of the fruit species. Fruit in the upper layers of containers experience greater injury (9,24) since this fruit receives higher levels of acceleration during distribution.

Guillou reported that a test of 12 Hertz at 1 g for 30 minutes satisfactorily reproduced damage in the laboratory to produce in shipping containers (10). ASTM D-4169 (3) recommends testing packages from 5-15 minutes (depending on assurance level chosen) at the resonant frequency of the package system at .5 g to simulate truck transport and .25 g to simulate railroad transport at each possible shipping position of the container, up to four positions.

COMPRESSION/LOAD FORCES

Fruits within containers are subject to compression bruises when a corrugated shipping container collapses and the fruit is required to carry the weight from other containers (29). Shipping containers are usually tested empty under standard conditions of 23°C and 50% R.H. at deformation rate of 1/2" per minute (2). Ultimately, the load a container can support in the distribution environment is dependent on several factors: moisture content of the board, the way the load is applied, length and rate at which the load is applied, previous handling of the package (29), length of time in storage, vibration during transport and stacking pattern (2). Additionally, the failure of containers in storage is primarily related to the creep characteristics of the material (8).

The reaction of a stacked load to vibration can produce forces to lower container's useful strength more than the dead-load weight of a stack. Therefore, Godshall (7) recommends utilizing a single container to represent the bottom container with a dead-load mass on top to represent the other containers in a stack. Godshall simulated vertical dynamic loading with dead loads from 10 to 70% of the compressive strength of the container and applied acceleration inputs from .2 to .8 g at increments of .1 g with frequencies of 4, 6, 8 and 10 Hertz for 1-1/2 hours. With these vibration inputs, it was determined that containers could be loaded to 70% of their compressive strength and survive the effects of vertical dynamic loading experienced during distribution.

ASTM D-4169 (3) recommends loading containers utilizing the following equation to simulate loads during transport and storage.

$$L = W \frac{(H-h)}{(h)} \times F$$

where:

L = minimum required load, lbf or N
W = weight of one shipping unit or individual container, lbf or N
h = height of shipping unit or individual container, in or m
F = a factor to account for the combined effect of the individual factors described above

Balodis (4) suggested the following schedule for compression testing produce containers to simulate the storage environment: two weeks in a cool store with each pack under a 400-lb. load; two days in a conditioned room under 300 lb.; five days in a cool store under a 300-lb. load; and one day in a conditioned room under a 200-lb. load. The conditioned rooms could be set at 20°C and 65% RH for moderate testing or 30°C and 85% RH to simulate tropical markets.

CARBON DIOXIDE RESPONSE OF APPLES DAMAGED IN CORRUGATED SHIPPING CONTAINERS

MATERIALS AND METHODS

Apples (Malus domestica Borkh., cv. 'Empire') without apparent bruises and defects and relatively uniform in size (2 3/4" in diameter) were taken out of controlled atmosphere storage from the upper layers of fruit orchard bins during April of 1984. The apples were placed in foam trays and corrugated shipping containers and stored under refrigeration at 0°C for later use.

Twenty-four hours before conducting each block, fruits were removed from cold storage and repacked into the test containers. This allowed sufficient time for the apples to equilibrate to test temperature and for the possible handling effect of increased CO_2 output to subside before testing.

Apples in one-bushel boxes having internal dimensions of 19 3/4" x 11 1/2" x 12" were subjected to various drop, vibration and compressive inputs. After treatment, entire apple boxes were placed in airtight containers having internal dimensions of 20 1/4" x 13 5/8" x 12 3/4". The airtight containers had sampling ports on diagonally opposite sides where gas measurements were taken hourly. There was no significant difference between damaged and nondamaged fruit CO_2 responses. It was hypothesized that the CO_2 response of the damaged fruit was not detected because the CO_2 within the airtight containers was diluted since all the fruit within the corrugated boxes was not damaged. Therefore, an alternate method where individual sample fruits from damaged corrugated boxes were placed in small airtight buckets was used in this study, and is discussed below.

Before placing the sample fruit in the shipping containers to be tested, they were labeled individually with a permanent ink marker. A total of 60 fruits, 20 for the top, middle and lower layers of the test containers, was labeled (see Figure 1). There were 5 layers of fruit in each container, 125 apples per container. Carbon dioxide response and visible injury scores were taken only from fruit in the top, middle and bottom layers. Sixteen shipping containers was prepared for one replication, and three forces were applied to two types of containers: drop, compression and vibration, with all combinations of packages and forces applied. In total, four replications were run.

Two package types were tested, both of full telescope half-slotted design: 1) tray-pack having internal dimensions of 19-3/4" x 11-1/2" x 12", the top and bottom corrugated combined board were of 42/33/42 and 69/33/69 construction, respectively; and 2) one-bushel boxes having internal dimensions of 19-7/16" x 11-5/8" x 10-1/4", the top and bottom corrugated combined board were of 42/26/42 and 69/26/69 construction, respectively. The numbers that describe the construction of the corrugated board refer to the weight of the liners and medium in pounds per 1000 square feet. Containers without fruit were allowed to condition at approximately 50% R.H. and 20°C for one week prior to being tested.

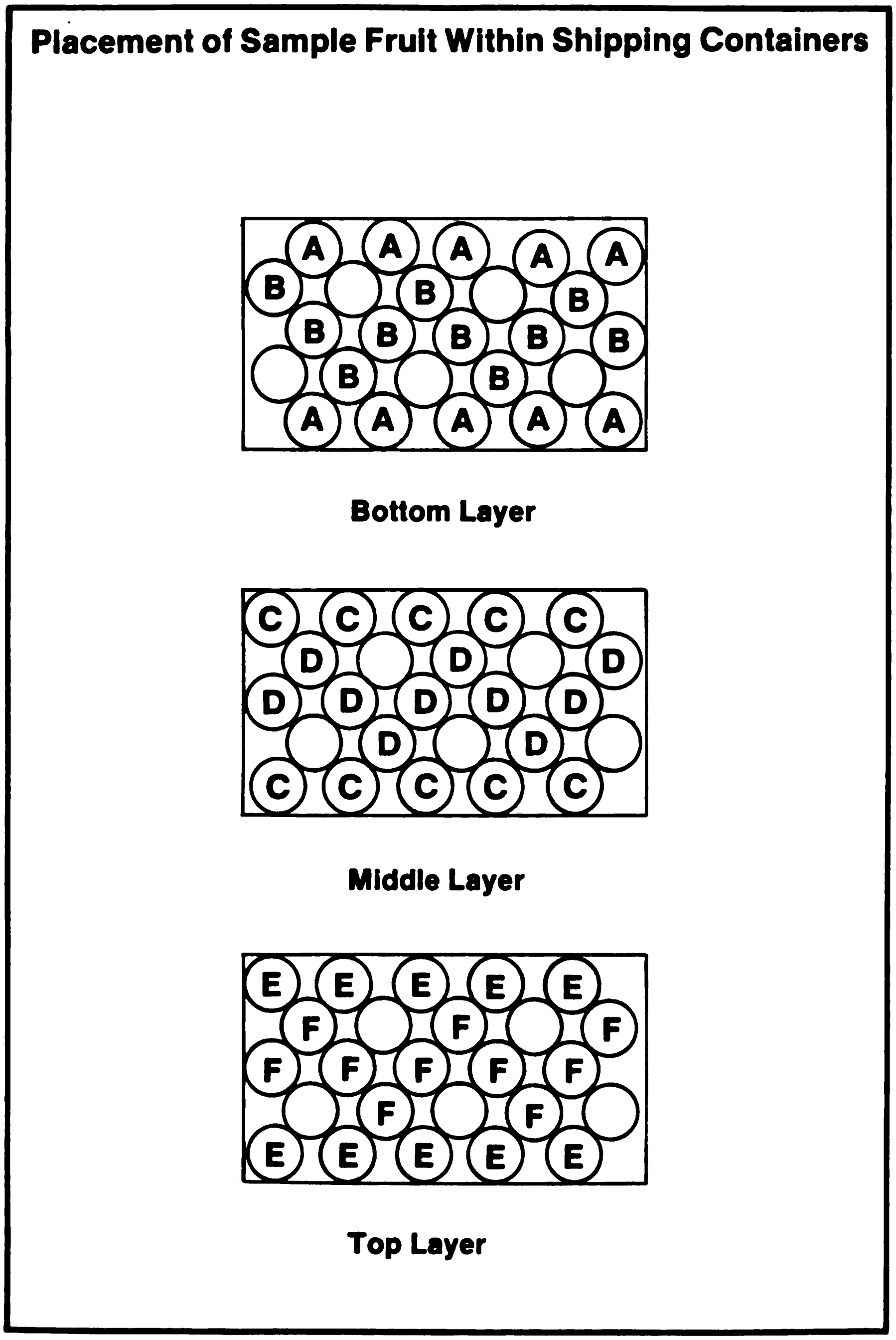


Figure 1. Placement of sample fruit in shipping containers.

The compressive strength of the two types of containers was determined in accordance with ASTM D-642 (2), Compression Test For Shipping Containers. The pulp spring cushion trays used in the tray packs were capable of holding 25 fruit each, for a total of 125 fruit per container. The one-bushel boxes were hand pattern packed using a pulp tray in the bottom to aid in producing the pattern of successive layers of fruit by the K.P. system (26).

The lengthy period of time required to apply the treatments prevented all 16 treatment combinations and replications from being performed on the same day. Therefore, the treatments were split into two blocks (see Table 1).

Since the 16 treatment combinations were split into two blocks, the Drop x Vibrate x Compression x Package (tray) interaction was confounded due to incomplete blocks by day. Four variables were studied: drop, vibrate, compression and package type each having two levels. With time all 16 treatment combinations ($2^4 = 16$) were replicated 4 times. Additionally, each container was sampled at 6 positions within each container. Therefore, the experimental design was a split plot with main plot treatments represented by the 2^4 factorial and subplot treatments by position.

Force treatments were applied first by dropping followed by vibration and then compressing. Drops were performed with an MTS (MTS Systems Co., Minneapolis, MN) shock machine which had a guided table and a 2 ms impact programmer to produce a repeatable shock which was transmitted to the package on the table. Dropping consisted of two 25 cm flat drops. To ensure reproducibility, containers were securely fastened to the table.

Table 1. Application of force treatments by incomplete blocks on K.P. and tray-pack shipping containers with cv. 'Empire' apples.

Time 1

Treatment	Type of Force	Package Type
1	None	K.P.
2	Compress	Tray
3	Vibrate	Tray
4	Vibrate x Compress	K.P.
5	Drop	Tray
6	Drop x Compress	K.P.
7	Drop x Vibrate	Tray
8	Drop x Vibrate x Compress	Tray (confounded)

Time 2

Treatment	Type of Force	Package Type
9	Drop	K.P.
10	Drop x Compress	Tray
11	Drop x Vibrate	Tray
12	Drop x Vibrate x Compress	K.P.
13	None	Tray
14	Compress	K.P.
15	Vibrate	K.P.
16	Vibrate x Compress	Tray

Compression testing was performed with a Baldwin-Emery compression tester. The load was applied in accordance with ASTM D-642 (2) with a continuous motion of .5 + .1 in./min. to 1600 lbs.

Vibration testing was performed on a MTS servo hydraulic vibration table. Shipping containers were securely fastened to the table with two 3/8" steel rods which screwed into the table and a 1" x 1" piece of wood. Vibration testing consisted of brining the table up sinusoidally from 3 Hertz to 9.5 Hertz at a constant g level of .8 g and maintaining the vibration level at .8 g and 9.5 Hz for 30 minutes. All simulated transit testing was performed at 50% R.H. and 23°C.

After the treatments had been applied, fruit samples were removed from the packages and placed in plastic 6000 mℓ buckets. Ten fruit were placed in each bucket, equaling two buckets per layer and six buckets per corrugated container. The lids for the buckets were modified with two 1/4" holes where gas samples could be taken at 1, 2, 3, 4 and 5 hours post treatment. The tubs were closed and sealed with airtight lids in the same order and time sequence at which CO_2 samples were obtained. The gas samples were taken with an ADC (Analytical Development Company) analyzer utilizing an infrared detector with a built in recirculating pump and digital percentage readout. Gas samples were taken by inserting the two needles of the analyzer through the lid holes covered with gas-proof tape. Fifteen to 20 seconds were required to obtain a stable CO_2 reading. After each reading, a fresh piece of tape was immediately placed over the holes to prevent the escape of the atmosphere from the bucket.

After the fifth-hour reading, lids were removed from each bucket and the fruit was weighed. The apples were then held 4 days at 20°C and rated for visible damage. A rating system of from 1 to 5 was utilized: 1 = no damage; 2 = slight but noticeable; 3 = moderate, affects marketing; 4 = severe, reduces value; 5 = very severe, unmarketable.

The microliters of CO_2 evolved per gram of fruit per hour were calculated as follows:

$$CO_2\ (\mu\ell/\mathrm{gm}\cdot\mathrm{hr}) = \frac{(CO_2)(.01)(\Delta\mathrm{volume})}{(\mathrm{fruit\ weight})(\mathrm{time})}$$

CO_2 = reading from analyzer

Δvolume = gross volume of containers (mℓ) - fruit weight (grams)

time = length of time the tubs were sealed (hourly reading)

RESULTS

RELATIONSHIP BETWEEN CO_2 µℓ/gm·hr AND INJURY SCORES OF 'EMPIRE' APPLES

The highly significant positive correlation of CO_2 evolution of the apples at the fourth hour following treatment to the subsequently measured injury scores is shown in Figure 2. These 4th-hour CO_2 readings yielded the highest r-square value to the injury scores and the 1st-hour readings the lowest (Table 2). Therefore, only the 4th-hour CO_2 readings are presented in the results and discussion sections of the text. The CO_2 reading for all other hours (1, 2, 3 and 5) are tabulated in the appendix.

Each variable tested (drop, compress, vibrate, package type and position) correlated at 99% confidence limits with the visual injury scores of the apples. However, r-square values varied from a high of .6039 for Position F to a low of .2801 for dropping (Table 3); the overall r-square value for the 4th-hour reading was .4568.

SPLIT-PLOT ANALYSIS OF VARIANCE

The data were analyzed two ways: 1) as a split plot by factorial effects where all 6 variables were included (drop, vibrate, compress, package type, position and replication (blocks) - see Tables 4 and 5), and 2) as a split plot by treatment combination where 16 treatments (2 drop x 2 vibrate x 2 compress x 2 package type = 16) with the CO_2 output and injury scores for the 6 positions within each container grouped together as one mean.

Table 2. Relationship between CO_2 production and injury score rating of 'Empire' apples at 1, 2, 3, 4 and 5 hours post treatment

Hour	r-square	F
1	.3335	191.18**
2	.4521	315.23**
3	.4472	309.02**
4	.4568	321.22**
5	.4528	316.06**

Table 3. Relationship between CO_2 production, treatment and injury score rating of 'Empire' apples 4 hours post treatment

Treatment	r-square	F
Drop	.2801	73.93**
Vibrate	.4648	164.98**
Compress	.3957	124.39**
Package Type	.5440	226.66**
Position	-	
A	.5611	79.28**
B	.4099	43.07**
C	.3735	36.96**
D	.3448	32.63**
E	.5903	89.32**
F	.6039	94.54**

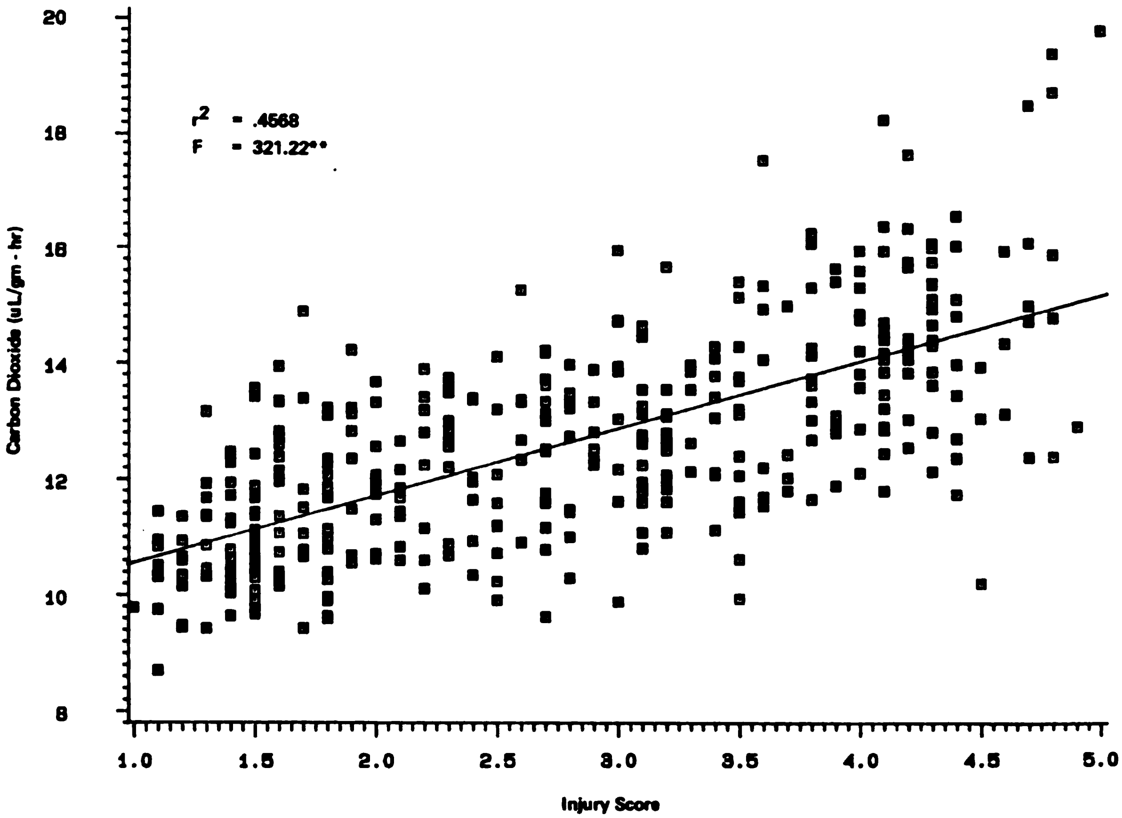


Figure 2. The relationship between CO_2 evolution and injury scores of 'Empire' apples at 4 hours post treatment.

Table 4. Split plot by factorial effects for CO_2 μℓ/gm·hr - hour 4 of cv. 'Empire' apples damaged in corrugated shipping containers

Source	DF	Anova SS	F Value	PR>F
BLOCK	3	27.21	2.19	.1019
TREATMENT	15	390.97	6.30	.0001**
DROP	1	102.61	24.81	.0001**
VIBRATE	1	151.28	36.58	.0001**
COMPRESS	1	10.25	2.48	.1224
PACKAGE	1	2.22	0.54	.4672
DROPxVIBRATE	1	4.17	1.01	.3208
DROPxCOMPRESS	1	8.40	2.03	.1609
DROPxPACKAGE	1	0.49	0.12	.7322
VIBRATExCOMPRESS	1	4.49	1.09	.3030
VIBRATExPACKAGE	1	36.90	8.92	.0045**
COMPRESSxPACKAGE	1	13.94	3.37	.0730
DROPxVIBRATExCOMPRESS	1	23.00	5.56	.0228*
DROPxVIBRATExPACKAGE	1	0.72	0.17	.6786
DROPxCOMPRESSxPACKAGE	1	22.34	5.40	.0247*
VIBRATExCOMPRESSxPACKAGE	1	4.36	1.05	.3102
DROPxVIBRATExCOMPRESSxPACKAGE	1	5.80	1.40	.2424
BLOCKxTREATMENT (Error 1)	45	186.08	4.43	.0001**
POSITION	5	55.00	11.77	.0001**
DROPxPOSITION	5	53.04	11.35	.0001**
VIBRATExPOSITION	5	112.87	24.16	.0001**
COMPRESSxPOSITION	5	6.37	1.36	.2401
PACKAGExPOSITION	5	78.74	16.85	.0001**
DROPxVIBRATExPOSITION	5	7.73	1.65	.1475
DROPxCOMPxPOSITION	5	4.81	1.03	.4005
DROPxPACKAGExPOSITION	5	30.19	6.46	.0001**
VIBRATExPACKAGExPOSITION	5	4.30	0.92	.4686
VIBRATExPACKAGExPOSITION	5	79.66	17.05	.0001**
COMPRESSxPACKAGExPOSITION	5	8.81	1.89	.0967
DROPxVIBRATExCOMPRESSxPOSITION	5	3.76	0.80	.5506
DROPxVIBRATExPACKAGExPOSITION	5	0.50	0.11	.9900
DROPxCOMPRESSxPACKAGExPOSITION	5	4.72	1.01	.4124
VIBRATExCOMPRESSxPACKAGExPOSITION	5	8.25	1.77	.1197
DROPxVIBRATExCOMPRxPACKxPOSITION	5	5.68	1.22	.3003
(Error 2)	240	224.24		
TOTAL	383			

Table 5. Split plot by factorial effects for injury scores of cv. 'Empire' apples damaged in corrugated shipping containers

Source	DF	Anova SS	F Value	PR>F
BLOCK	3	1.17	1.43	.2456
TREATMENT	15	276.34	151.63	.0001**
DROP	1	161.20	591.23	.0001**
VIBRATE	1	44.15	161.91	.0001**
COMPRESS	1	10.21	37.43	.0001**
PACKAGE	1	17.68	64.85	.0001**
DROPxVIBRATE	1	1.58	5.78	.0204*
DROPxCOMPRESS	1	4.46	16.37	.0002**
DROPxPACKAGE	1	7.26	26.63	.0001**
VIBRATExCOMPRESS	1	0.92	3.38	.0728
VIBRATExPACKAGE	1	14.81	54.30	.0001**
COMPRESSxPACKAGE	1	8.46	31.03	.0001**
DROPxVIBRATExCOMPRESS	1	1.04	3.82	.0569
DROPxVIBRATExPACKAGE	1	0.08	0.28	.6003
DROPxCOMPRESSxPACKAGE	1	4.13	15.13	.0003**
VIBRATExCOMPRESSxPACKAGE	1	0.09	0.34	.5605
DROPxVIBRATExCOMPRESSxPACKAGE	1	0.28	1.03	.3149
BLOCKxTREATMENT (Error 1)	45	12.27	2.24	.0001**
POSITION	5	2.07	3.40	.0056**
DROPxPOSITION	5	42.33	69.68	.0001**
VIBRATExPOSITION	5	33.49	55.12	.0001**
COMPRESSxPOSITION	5	1.52	2.50	.0314*
PACKAGExPOSITION	5	18.29	30.11	.0001**
DROPxVIBRATExPOSITION	5	0.72	1.19	.3147
DROPxCOMPxPOSITION	5	1.40	2.30	.0457
DROPxPACKAGExPOSITION	5	0.64	1.05	.3890
VIBRATExPACKAGExPOSITION	5	1.61	2.65	.0236*
VIBRATExPACKAGExPOSITION	5	23.94	39.41	.0001**
COMPRESSxPACKAGExPOSITION	5	2.12	3.49	.0046
DROPxVIBRATExCOMPRESSxPOSITION	5	0.93	1.53	.1811
DROPxVIBRATExPACKAGExPOSITION	5	0.46	0.76	.5794
DROPxCOMPRESSxPACKAGExPOSITION	5	0.37	0.61	.6923
VIBRATExCOMPRESSxPACKAGExPOSITION	5	0.31	0.51	.7686
DROPxVIBRATExCOMPRxPACKxPOSITION	5	0.14	0.23	.9492
(Error 2)	240	29.16		
TOTAL	383			

Split Plot by Factorial Effects - Main Effects

The variables drop, vibrate and position had a statistically significant effect on CO_2 evolution, Table 6. Vibration had the greatest effect on CO_2 $\mu\ell$/gm·hr, followed by position, dropping, compression and package type, respectively. Dropping had the greatest effect on injury scores, followed by vibration, package type, compression, and position, respectively.

Dropping

Dropping containers significantly enhanced CO_2 evolution by 1.03 $\mu\ell$/gm·hr and injury scores by 1.30 units compared to not dropping containers. The significant increase in CO_2 evolution for dropped fruit amounted to 9% over that of fruit which was not dropped but otherwise exposed to all other treatments; the increase in visible damage was 61%.

Vibrating

Vibrating containers significantly enhanced CO_2 evolution by 1.26 $\mu\ell$/gm·hr and injury scores by .68 unit compared to not vibrating containers. The significant increase in CO_2 evolution for vibrated fruit amounted to 10% over that of fruit which was not vibrated but otherwise exposed to all other treatments; the increase in visible damage was 28%.

Table 6. Comparison of treatment main effects on CO_2 production and injury scores for cv. 'Empire' apples damaged in corrugated shipping containers

Treatment (Variable)		N	CO_2 Evolution µℓ/gm·hr		Injury Score Rating	
			Mean	Duncan Grouping	Mean	Duncan Grouping
Dropping	(+)	192	13.17	A	3.44	A
	(-)	192	12.13	B	2.14	B
Vibrating	(+)	192	13.28	A	3.13	A
	(-)	192	12.02	B	2.45	B
Compressing	(+)	192	12.81	A	2.95	A
	(-)	192	12.49	A	2.62	B
Package Type	(tray)	192	12.73	A	3.00	A
	(K.P.)	192	12.57	A	2.57	B
Position:						
Top Layer	a	64	12.42	C	2.79	ABC
	b	64	12.51	C	2.85	A
Middle Layer	c	64	12.29	C	2.71	BC
	d	64	12.37	C	2.81	AB
Bottom Layer	e	64	12.95	B	2.68	C
	f	64	13.35	A	2.88	A

Means with the same letter are not significantly different at α=.05.

Compressing

Compressed containers did not significantly enhance CO_2 evolution of the apples; however, injury scores were significantly increased .33 unit compared to non-compressed containers. The increase in CO_2 evolution for compressed fruit amounted to 3% over that fruit which was not compressed but otherwise exposed to all other treatments; the increase in visible damage was 13%.

Package Type

CO_2 evolution was higher for apples in the K.P. container; however, there was no significant difference between the two types of containers tested. Injury scores were significantly higher by .43 unit for apples in the K.P. container.

Position

The position of apples in a package had a significant effect on their CO_2 output and injury scores. Positions E and F in the top layer yielded significantly higher CO_2 values than one another and positions A, B, C and D, while positions A, B, C and D were not significantly different from one another with respect to CO_2 output. Positions A, B, D and F did not produce significantly different injury scores than each other, but damage to apples in these positions was significantly higher than in positions C (middle layer) and E (top layer).

Split Plot by Factorial Effect - Significant Two-way Interactions

The highly statistically significant interactions of Drop x Position, Vibrate x Package, Vibrate x Position, and Package x Position on CO_2 µℓ/gm·hr and injury scores are presented in Figures 3 through 10. Additionally, Drop x Vibrate, Drop x Compress, Drop x Package, Compress x Package and Compress x Position were significant treatment interactions for injury scores but not CO_2 evolution.

Drop x Position (Figures 3 and 4 and Table 7)

When containers were not dropped, CO_2 evolution was the lowest for positions A and B (bottom layer) followed by positions C, D, E and F, see Figure 3. Injury scores for non-dropped containers followed a similar trend, see Figure 4 and Table 7. When containers were dropped, position D (middle layer) had the lowest CO_2 output, followed by positions C, E, A, B and F - fruit in the middle of the container had the lowest CO_2 output.

Apples in positions A, B, C and D when dropped had a higher CO_2 output when compared to non-dropped apples. Carbon dioxide evolution for positions E and F, both located in the upper layer of the containers, were least affected by dropping. Injury scores for fruit in dropped containers were the highest for apples in the bottom of containers, followed by those in the middle and top, respectively. Injury scores for all of the positions were significantly affected by dropping except positions E and F (top layer). Therefore, when containers were dropped, apples located near the bottom of the containers were injured most, and apples located near the top, the least.

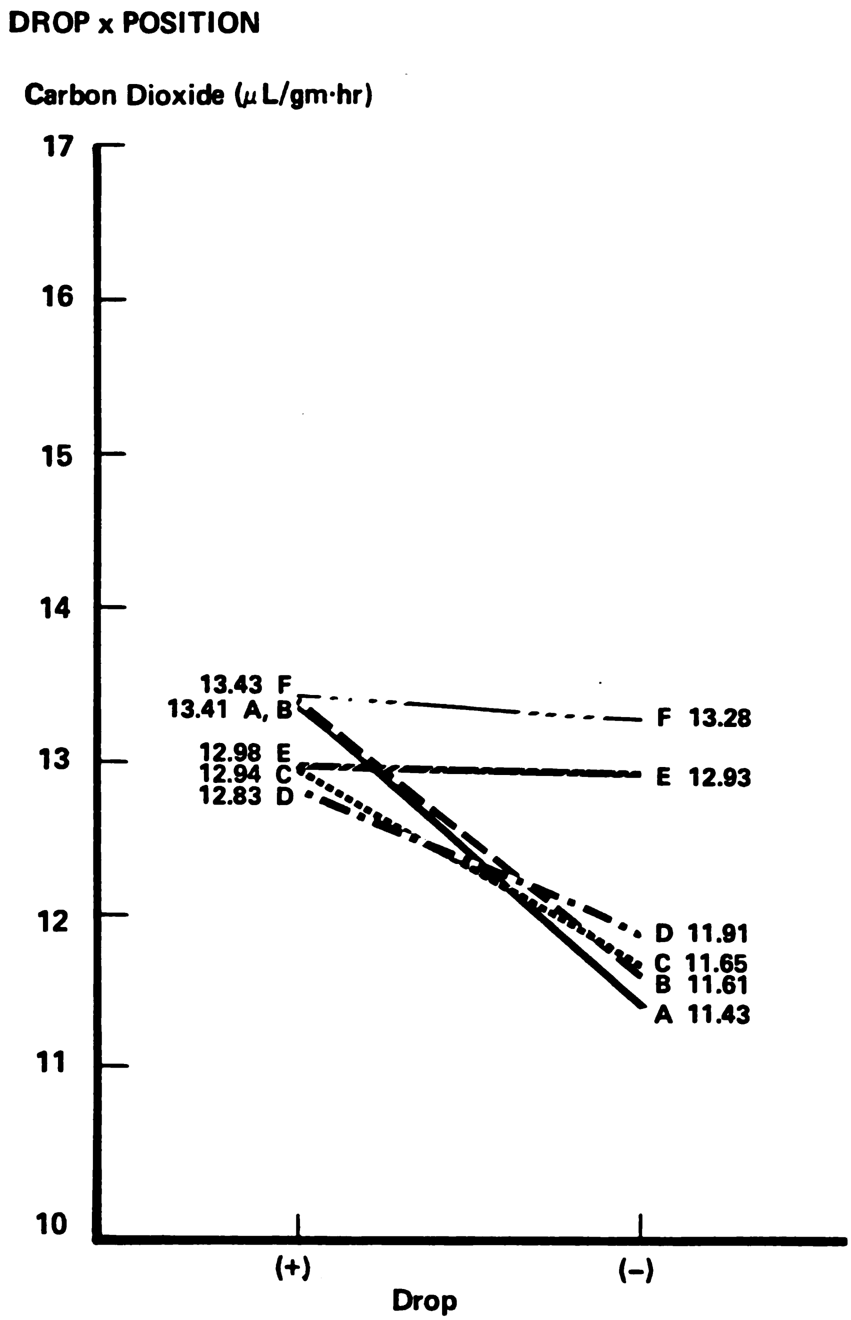


Figure 3. Interaction effect between dropping and position on CO_2 μℓ/gm·hr evolved from 'Empire' apples measured 4 hours post treatment.

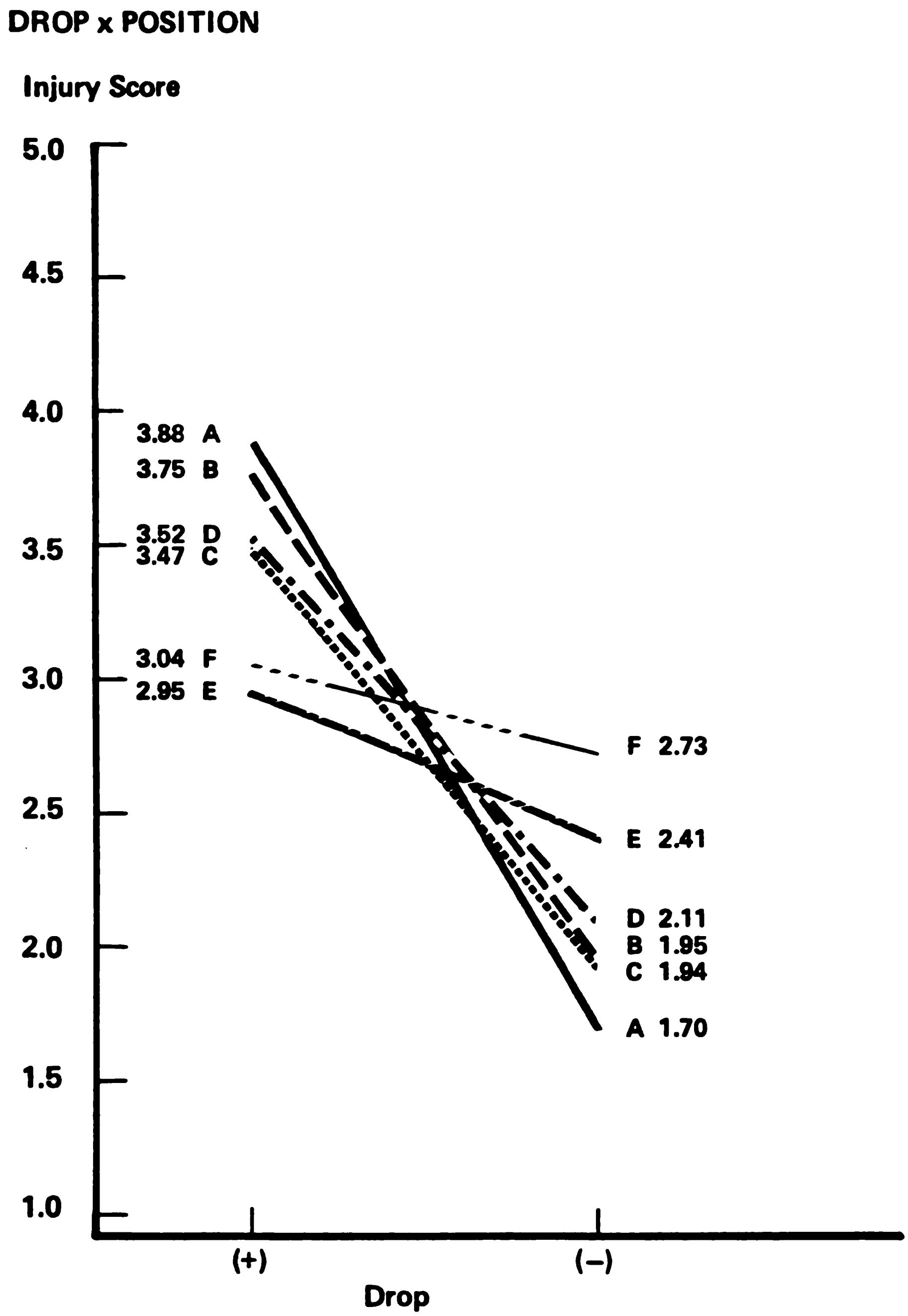


Figure 4. Interaction effect between dropping and position on injury score of 'Empire' apples.

Table 7 Treatment comparisons within the drop x position treatment interaction on CO_2 production and injury scores for cv. 'Empire' apples damaged in corrugated shipping containers.

Treatment Comparison	Mean Diff. CO_2 $\mu\ell$/gm·hr	F	Mean Diff. Injury Score	F
(d^-, $position^A$) vs (d^+, $position^A$)	1.98	3.89**	1.82	13.94**
(d^-, $position^B$) vs (d^+, $position^B$)	1.80	3.54**	1.80	13.79**
(d^-, $position^C$) vs (d^+, $position^C$)	1.29	2.54**	1.53	11.72**
(d^-, $position^D$) vs (d^+, $position^D$)	.92	1.81**	1.41	10.80**
(d^-, $position^E$) vs (d^+, $position^E$)	.05	0.10	.54	4.14
(d^-, $position^F$) vs (d^+, $position^F$)	.15	.30	.31	2.37

<u>Vibrate x Package Type</u> (Figures 5 and 6 and Table 8)

Vibration increased CO_2 output in the tray containers by 1.87 µℓ/gm·hr (16%) and injury scores by 1.07 units (52%). Vibrating K.P. containers increased CO_2 output by .63 µℓ/gm·hr (5%) and injury scores by .28 unit (10%). When containers were not vibrated, the K.P. container had a higher CO_2 and injury score reading; however, when containers were vibrated, the tray-pack container had a higher CO_2 output and a similar injury score reading when compared to the K.P. container. Therefore, the effect of vibrating was greater for tray-pack containers than for K.P. containers.

<u>Vibrate x Position</u> (Figures 7 and 8 and Table 9)

Vibration resulted in the highest CO_2 output and injury scores in the top layer of the shipping containers, positions E and F. Vibration caused no significant effect on CO_2 output or injury scores for fruit in positions A and B, located in the bottom layer of the containers but did significantly increase CO_2 evolution for apples located in the top (positions E and F). Non-vibrated containers displayed higher CO_2 output and injury scores for fruit located toward the bottom and middle of the containers.

<u>Package Type x Position</u> (Figures 9 and 10 and Table 10)

Positions E and F (top layer) in the tray-pack container had the highest CO_2 output, while positions A and B (bottom layer) had the highest CO_2 output for the K.P. container.

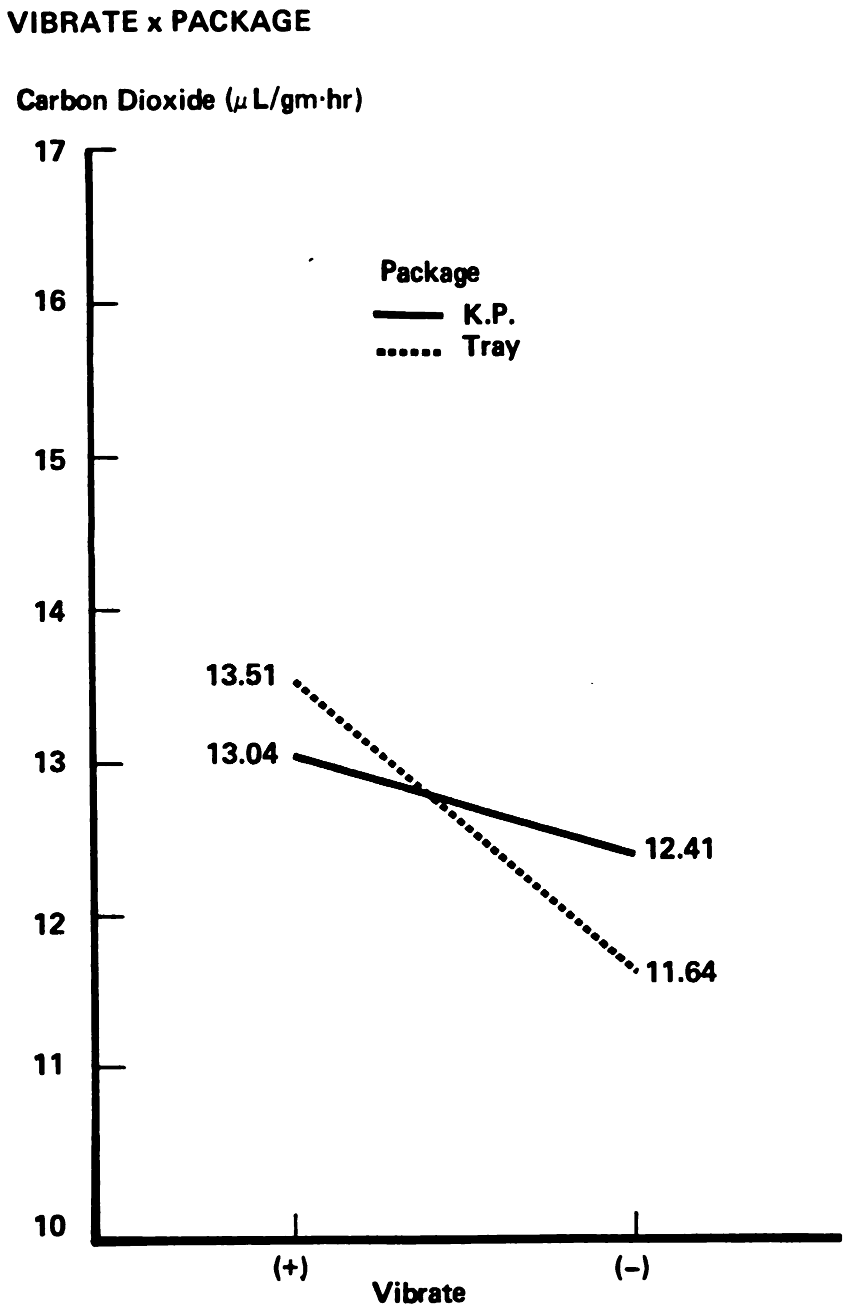


Figure 5. Interaction effect between vibrating and package type on CO_2 μℓ/gm·hr evolved from 'Empire' apples measured 4 hours post treatment.

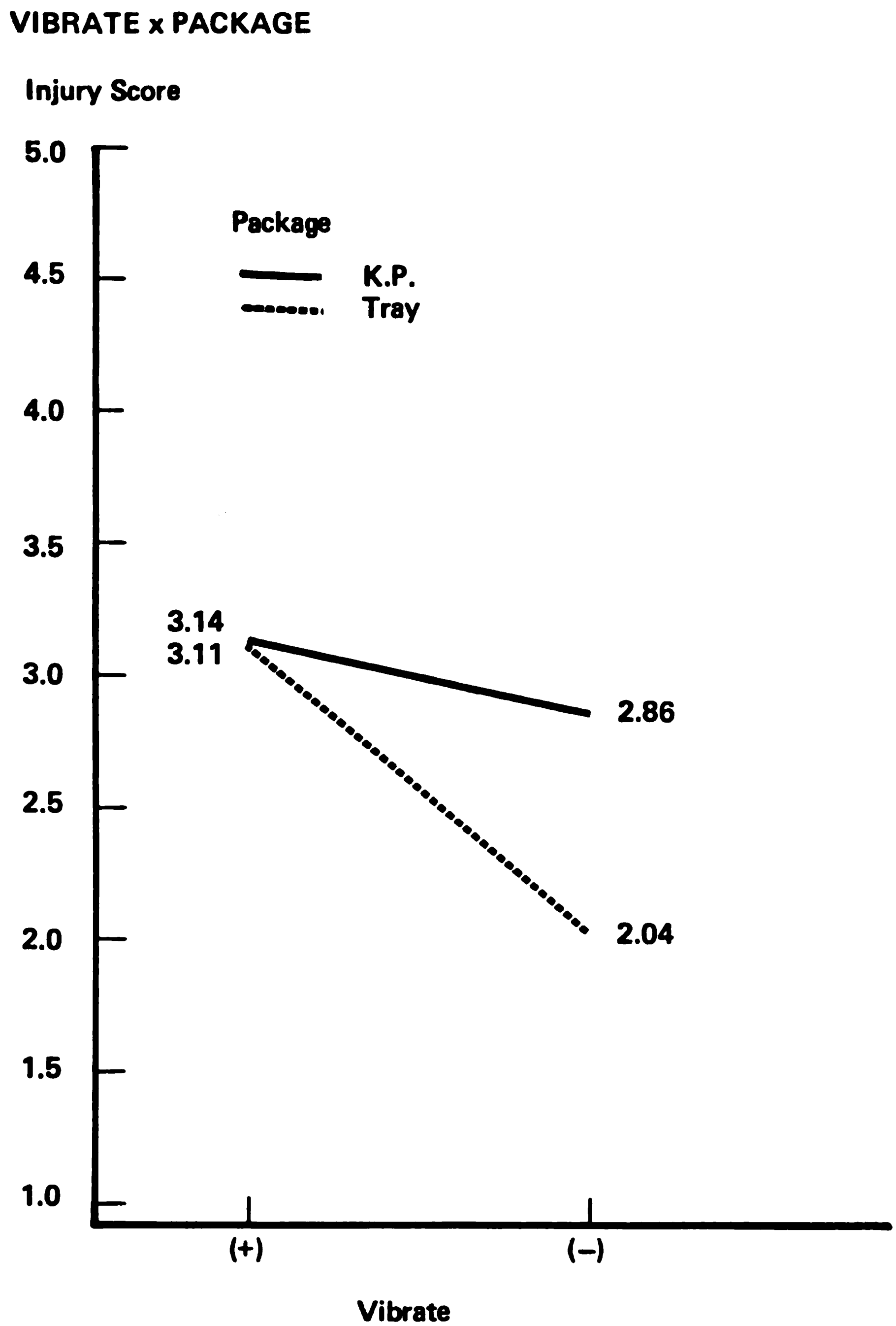


Figure 6. Interaction effect between vibrating and package type on injury score of 'Empire' apples.

Table 8. Treatment comparisons within the vibrate x package type treatment interaction on CO_2 production and injury scores for cv. 'Empire' apples damaged in corrugated shipping containers.

Treatment Comparison	Mean Diff. CO_2 $\mu\ell$/gm·hr	F	Mean Diff. Injury Score	F
(v^-, p^{tray}) vs (v^+, p^{tray})	1.87	6.37**	1.07	14.20**
(v^-, p^{tray}) vs $(v^+, p^{K.P.})$	1.4	4.77*	1.10	14.60**
(v^-, p^{tray}) vs $(v^-, p^{K.P.})$	0.77	2.62	0.82	10.88**
$(v^-, p^{K.P.})$ vs (v^+, p^{tray})	1.10	3.75	0.25	3.32
$(v^-, p^{K.P.})$ vs $(v^+, p^{K.P.})$	0.63	2.15	0.28	3.72
(v^+, p^{tray}) vs $(v^+, p^{K.P.})$	0.47	1.60	0.03	.40

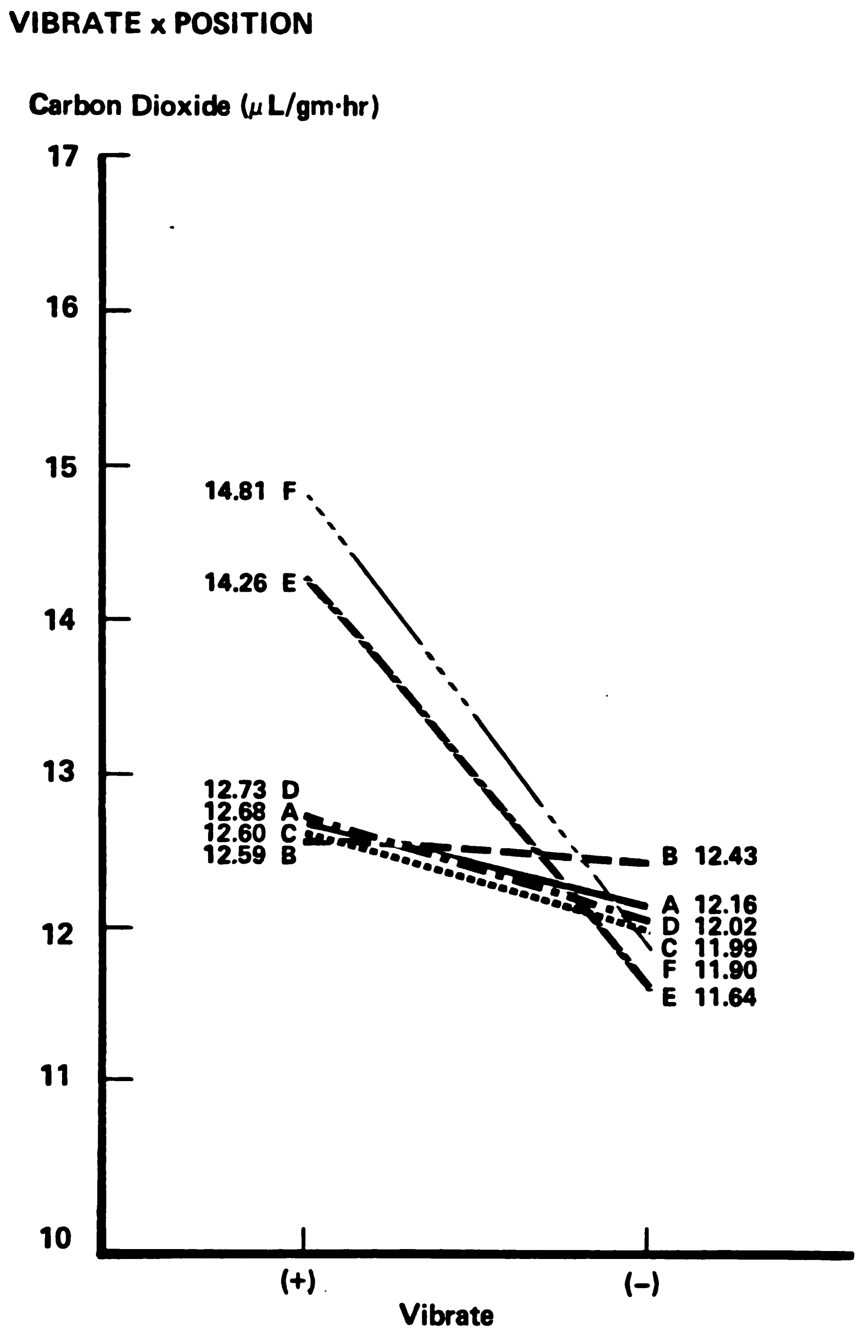


Figure 7. Interaction effect between vibrating and position on CO_2 μℓ/gm·hr evolved from 'Empire' apples measured 4 hours after treatment.

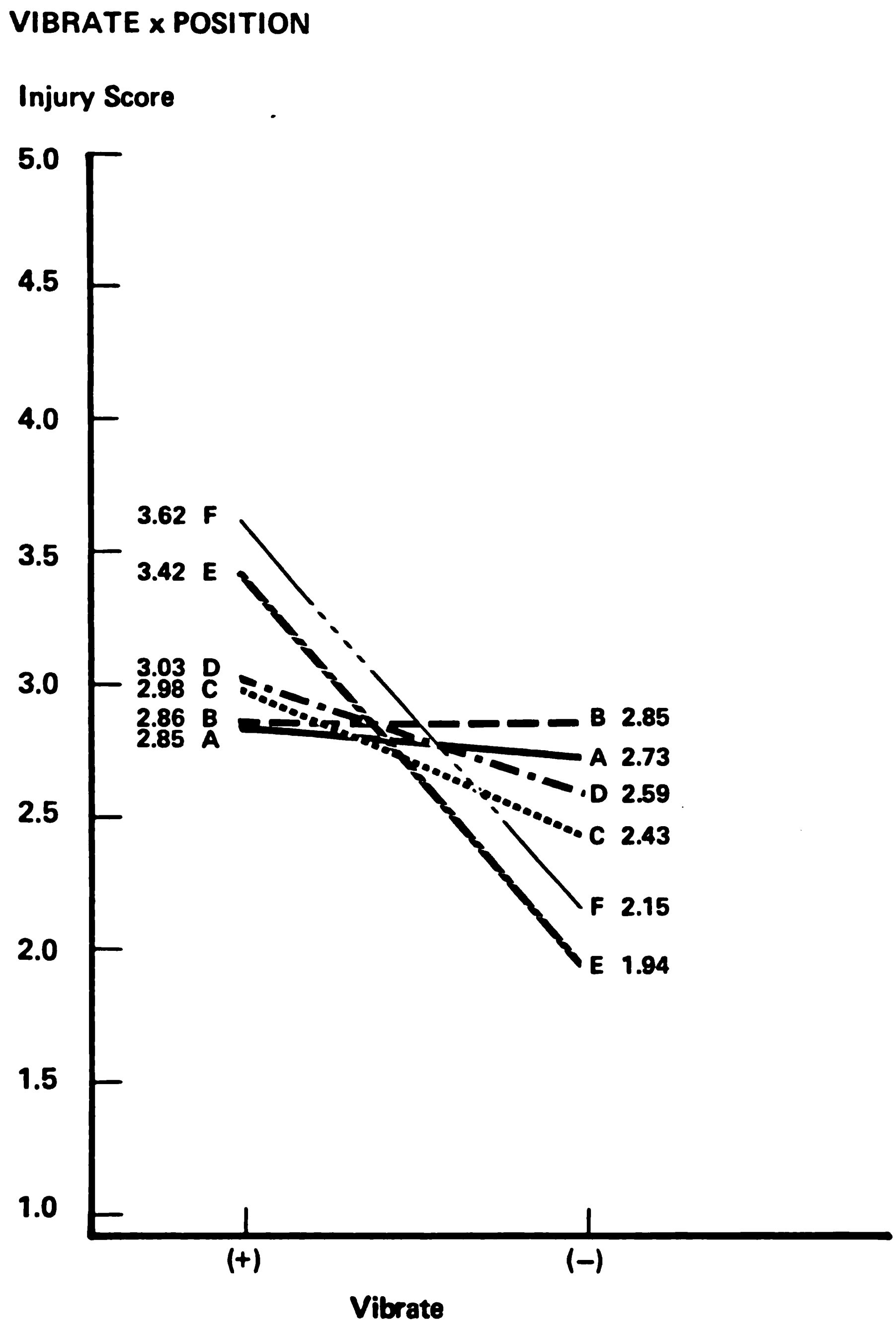


Figure 8. Interaction effect between vibrating and position on injury score of 'Empire' apples.

Table 9. Treatment comparisons within the vibrate x position treatment interaction on CO_2 production and injury scores for cv. 'Empire' apples damaged in corrugated shipping containers.

Treatment Comparison	Mean Diff. CO_2 $\mu\ell$/gm·hr	F	Mean Diff. Injury Score	F
(v^-, position^A) vs (v^+, position^A)	.52	1.02	.12	.92
(v^-, position^B) vs (v^+, position^B)	.16	.31	.01	.08
(v^-, position^C) vs (v^+, position^C)	.61	1.20	.55	4.21*
(v^-, position^D) vs (v^+, position^D)	.71	1.40	.44	3.37
(v^-, position^E) vs (v^+, position^E)	2.62	5.15*	1.48	11.34**
(v^-, position^F) vs (v^+, position^F)	2.91	5.72*	1.47	11.26**

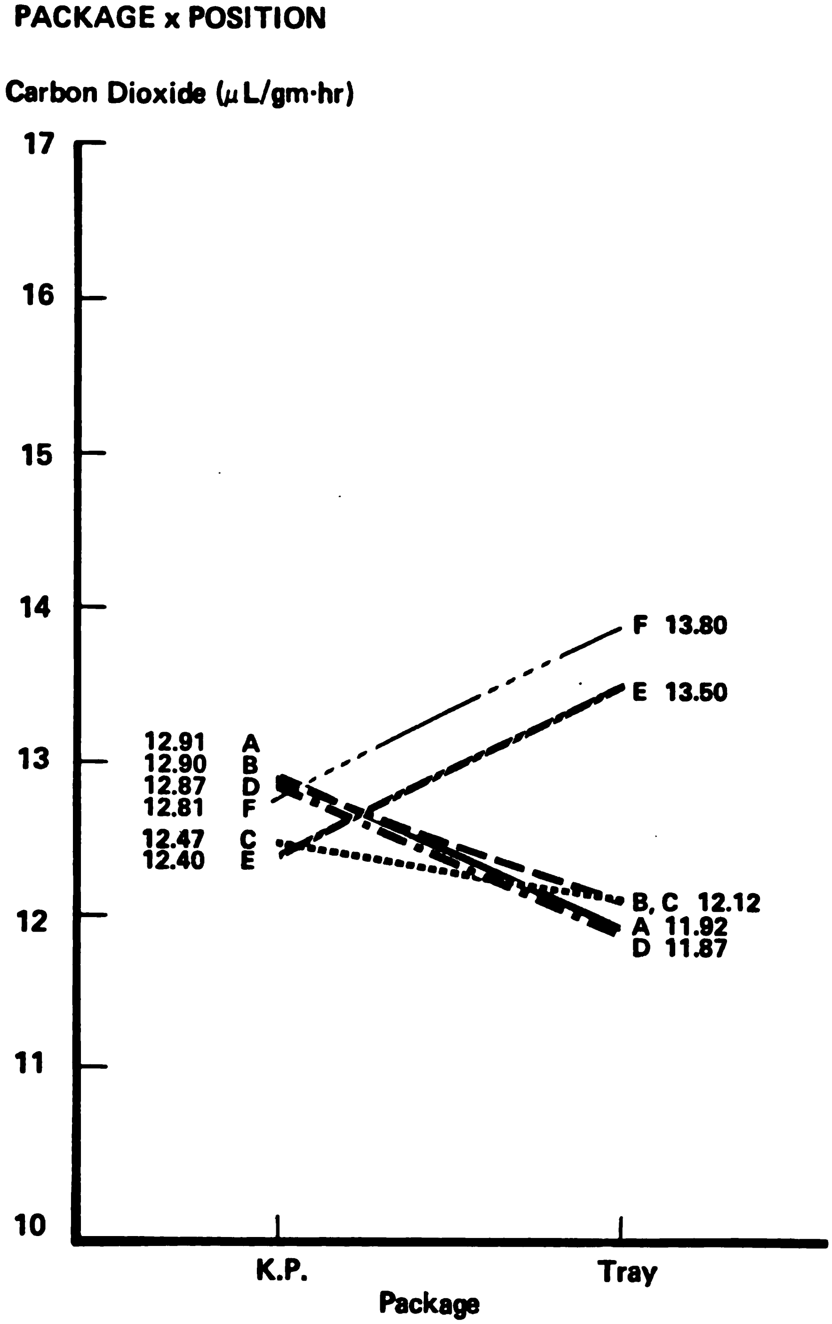


Figure 9. Interaction effect between package type and position on CO_2 μℓ/gm·hr evolved from 'Empire' apples measured 4 hours after treatment.

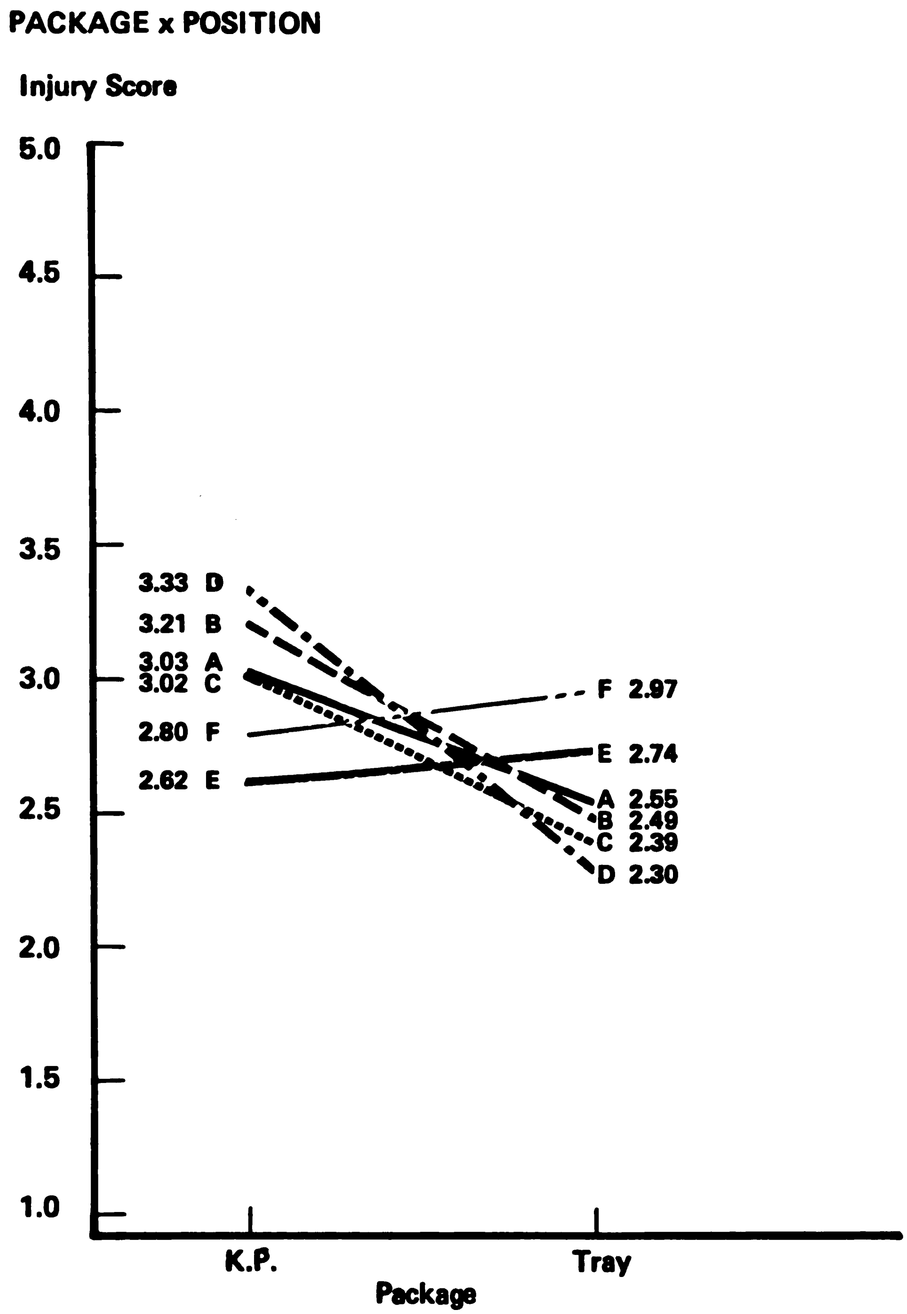


Figure 10. Interaction effect between package type and position on injury score of 'Empire' apples.

Table 10 Treatment comparisons within the package type x position treatment interaction on CO_2 production and injury scores for cv. 'Empire' apples damaged in corrugated shipping containers.

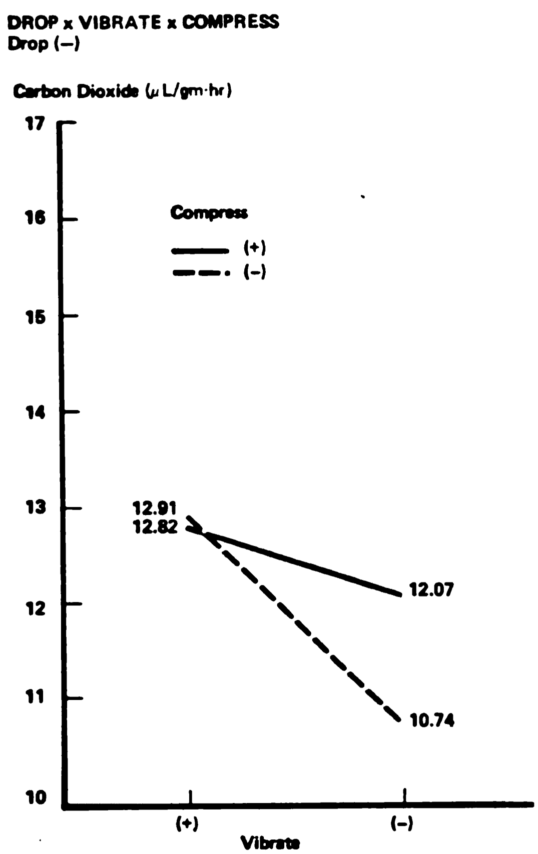
Treatment Comparison	Mean Diff. CO_2 µℓ/gm·hr	F	Mean Diff. Injury Score	F
($p^{K.P.}$, $pos.^{A}$) vs (p^{tray}, $pos.^{A}$)	0.99	1.95	0.48	3.68
($p^{K.P.}$, $pos.^{B}$) vs (p^{tray}, $pos.^{B}$)	0.78	1.53	0.72	5.52*
($p^{K.P.}$, $pos.^{C}$) vs (p^{tray}, $pos.^{C}$)	0.35	0.69	0.63	4.83*
($p^{K.P.}$, $pos.^{D}$) vs (p^{tray}, $pos.^{D}$)	1.0	1.97	1.03	7.89**
($p^{K.P.}$, $pos.^{E}$) vs (p^{tray}, $pos.^{E}$)	1.1	2.16	.12	.92
($p^{K.P.}$, $pos.^{F}$) vs (p^{tray}, $pos.^{F}$)	1.08	2.12	.17	1.30

Split Plot by Factorial Effects - Significant Three-way Interactions

The Drop x Compress x Package and the Vibrate x Package x Position three-way interactions were significant for CO_2 evolution and injury scores, while the Drop x Vibrate x Compress and the Drop x Package x Position three-way interactions were significant for CO_2 evolution but not for injury scores; and the Vibrate x Compress x Position and the Compress x Package x Position were signficant for injury scores but not for CO_2 evolution.

Drop x Vibrate x Compress (Figures 11-12)

The effect of vibrating on fruit CO_2 output when containers were not dropped or compressed was to increase CO_2 by 2.17 µℓ/gm·hr (20%) and to increase injury scores 1.01 units (74%). The effect of vibrating containers that were compressed and dropped was to increase CO_2 1.32 (11%) µℓ/gm·hr and injury scores .56 unit (17%). The effect of dropping on CO_2 output when containers were not vibrated or compressed was to increase CO_2 by 2.02 µℓ/gm·hr (19%) and injury scores by 1.75 units (129%). The effect of dropping when containers were vibrated and compressed was to increase CO_2 1.02 µℓ/gm·hr (8%) and injury scores by 1.06 units (39%). The effect of compressing when containers were not dropped or vibrated was to increase CO_2 1.33 µℓ/gm·hr (12%) and injury scores .75 unit (55%). The effect of compressing when containers were dropped and vibrated was to increase CO_2 by .30 µℓ/gm·hr (2%) and injury scores .12 unit (3%). Containers dropped, not vibrated and not compressed had .24 higher CO_2 µℓ/gm·hr (2%) than containers dropped, not vibrated and compressed.



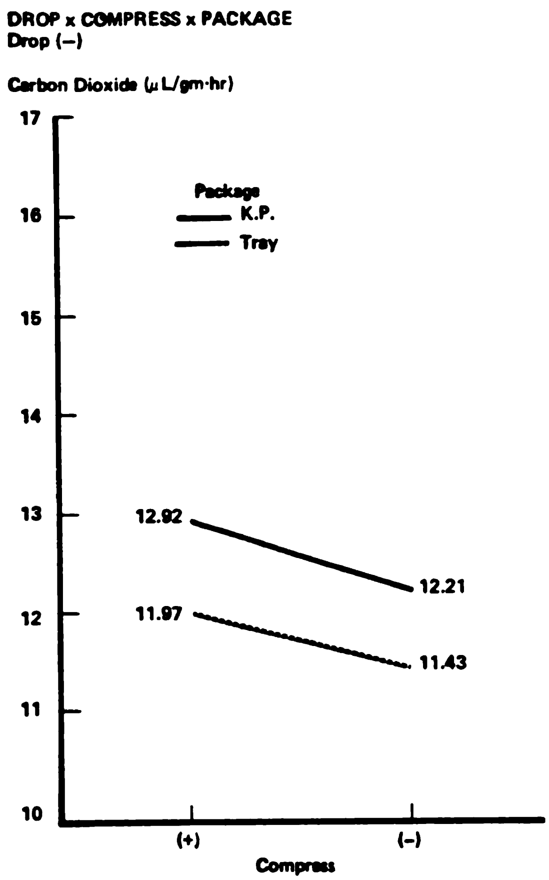
Figures 11 and 12. Interaction effect between dropping, vibrating and compressing on CO_2 μℓ/gm·hr evolved from 'Empire' apples measured 4 hours post treatment.

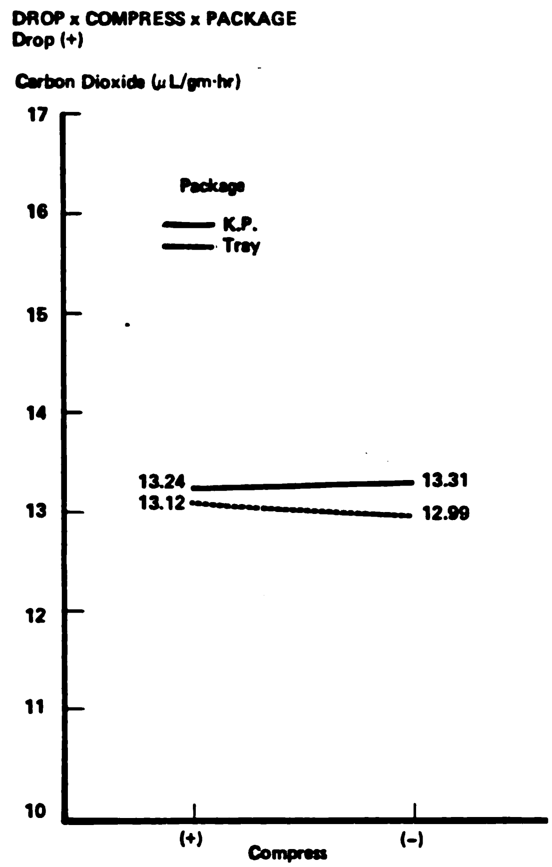
<u>Drop x Compress x Package Type</u> (Figures 13-16)

When containers were dropped and compressed, the K.P. package had .12 CO_2 μℓ/gm·hr (1%) and .80 (26%) injury score unit higher than the tray-pack container. K.P. containers compressed and not dropped had .95 CO_2 μℓ/gm·hr (8%) and .66 (32%) injury score unit higher than the tray-pack container. Tray-pack containers dropped and not compressed had .32 CO_2 μℓ/gm·hr (2%) and .62 (20%) injury score unit lower than K.P. containers. Therefore, the combined effect of dropping and compressing was greater for the K.P. than the tray-pack container on CO_2 output and injury scores.

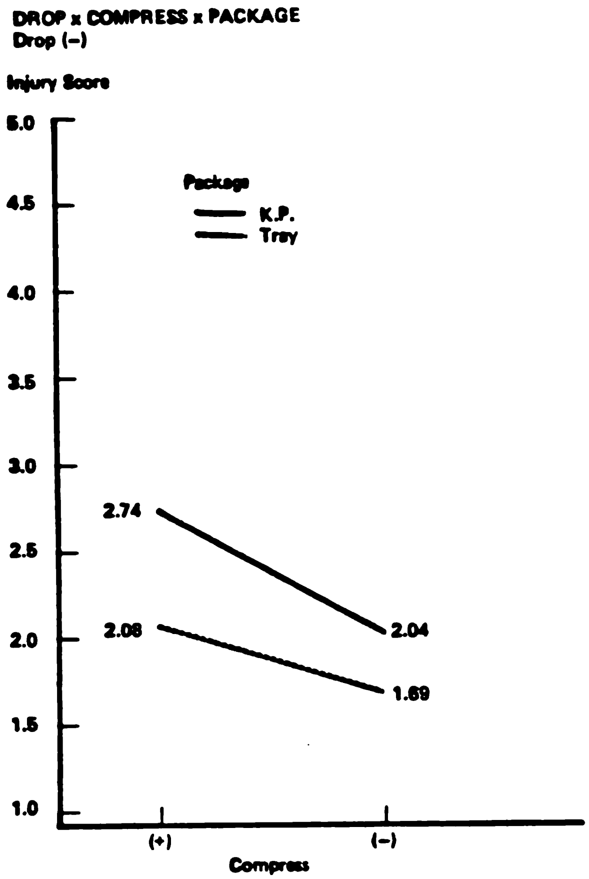
<u>Drop x Package Type x Position</u> (Figures 17-18)

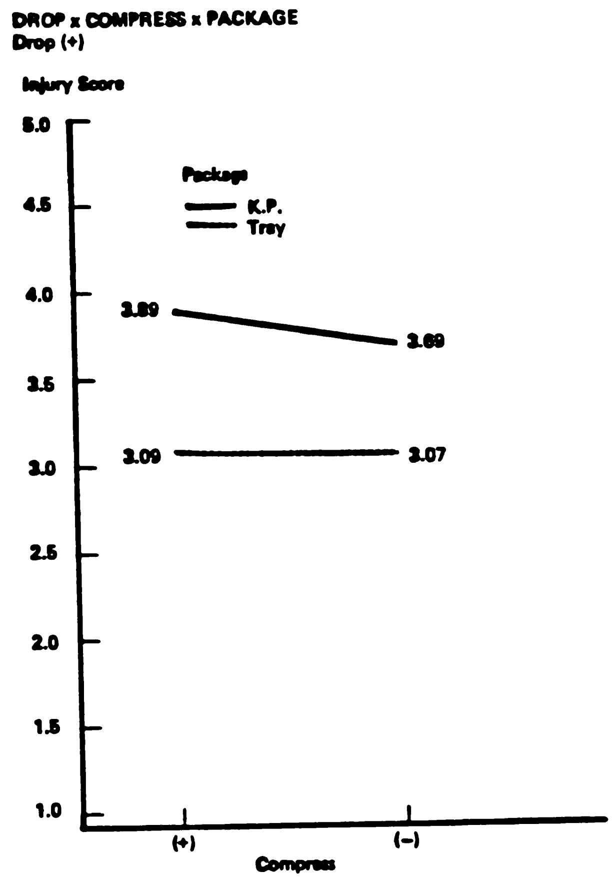
In the K.P. containers that were not dropped, fruit in positions A and B (bottom layer) evolved the lowest CO_2, or 2.56 CO_2 μℓ/gm·hr lower than in K.P. containers that were dropped. Top-layer fruit (positions E and F) evolved the highest CO_2 in K.P. containers that were not dropped and the lowest CO_2 in containers that were dropped. Positions C and D (middle layer) in the K.P. container evolved moderate levels of CO_2 for both dropped and not dropped containers. Positions E and F evolved the highest CO_2 in the tray-pack containers whether they were dropped or not dropped. Positions A and D evolved the lowest CO_2 in the tray-pack containers whether the containers were dropped or not dropped. Therefore, dropping affected the ordering of the positions in the K.P. containers more than in tray-pack containers.



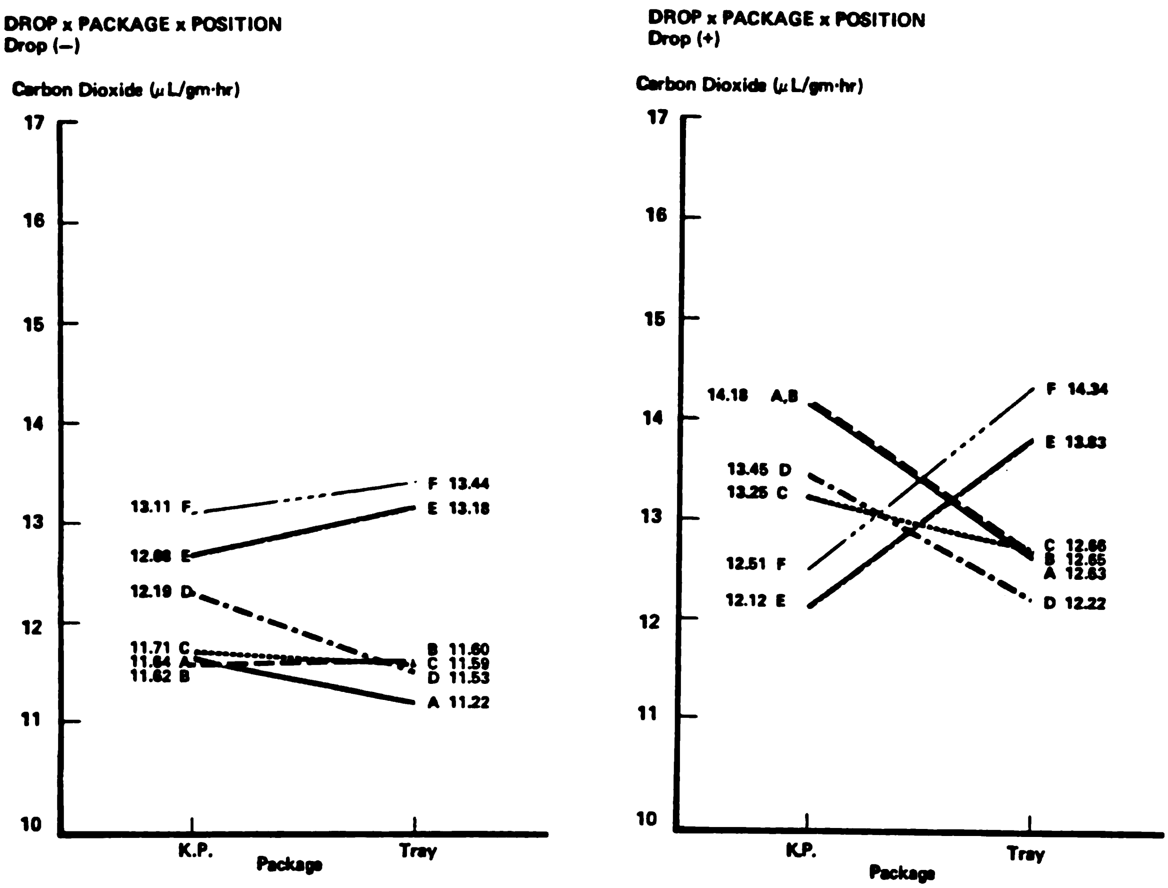


Figures 13 and 14. Interaction effect between dropping, compressing and package type on CO_2 µℓ/gm·hr evolved from 'Empire' apples measured 4 hours post treatment.





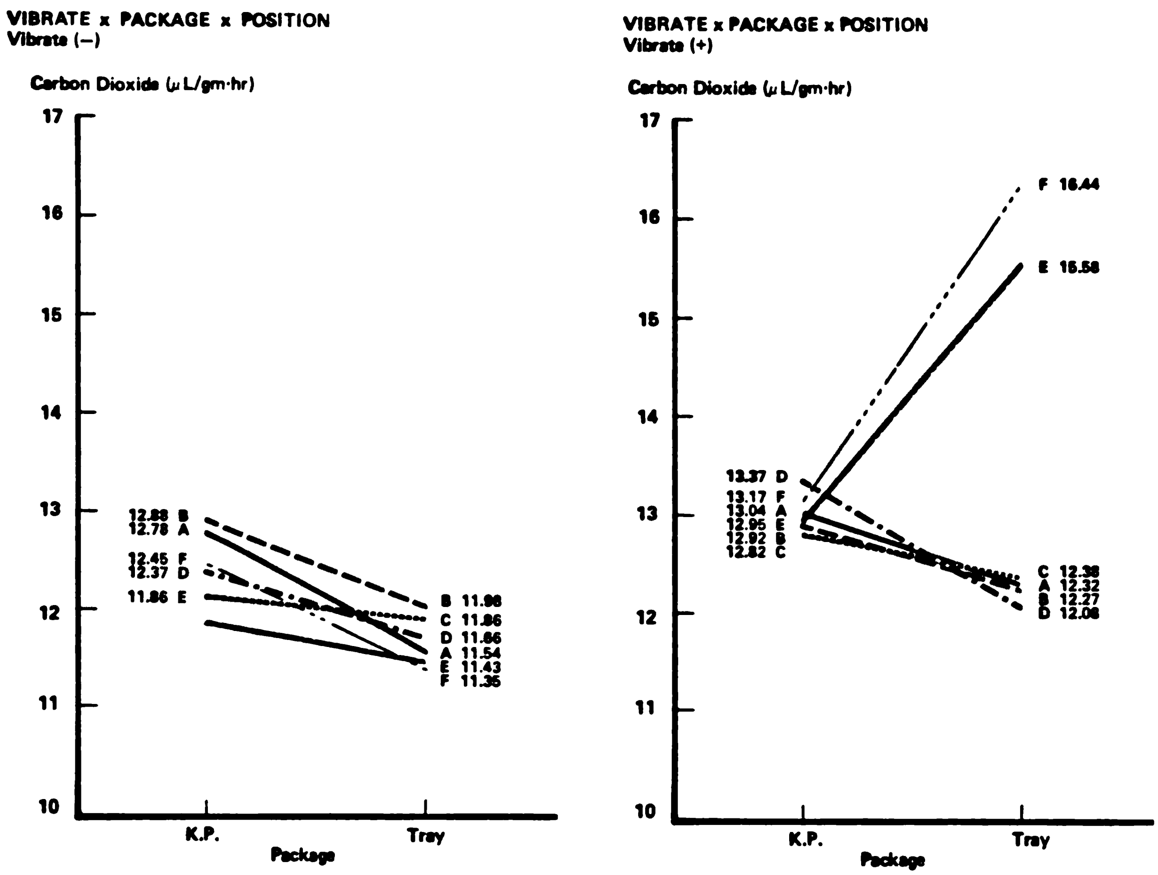
Figures 15 and 16. Interaction effect between dropping, compressing and package type on injury score of 'Empire' apples.



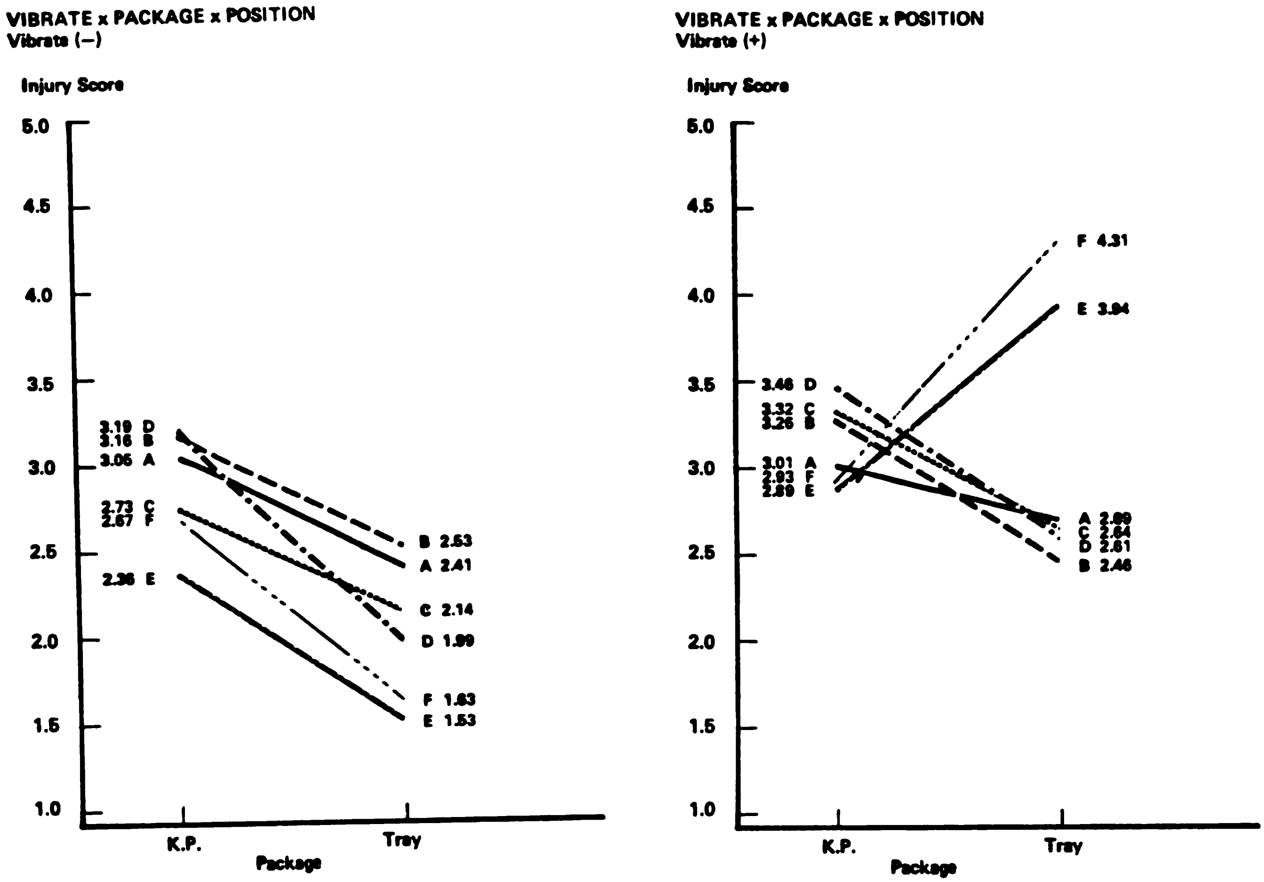
Figures 17 and 18. Interaction effect between dropping, package type and position on CO_2 µℓ/gm·hr evolved from 'Empire' apples measured 4 hours post treatment.

Vibrate x Package Type x Position (Figures 19-22)

Positions F and E (top layer) evolved the lowest levels of CO_2 $\mu\ell$/gm·hr and injury scores for non-vibrated tray-pack containers. Vibrating tray-pack containers caused Positions F and E to evolve the highest levels of CO_2 $\mu\ell$/gm·hr and injury scores. Vibrating K.P. containers did not change the ordering of positions for injury scores when compared to nonvibrating K.P. containers. Vibrating K.P. containers did change the ordering of positions for CO_2 $\mu\ell$/gm·hr, but the effect of vibrating and position was not as great as for vibrating tray-pack containers.



Figures 19 and 20. Interaction effect between vibrating, package type and position CO_2 µℓ/gm·hr evolved from 'Empire' apples measured 4 hours post treatment.



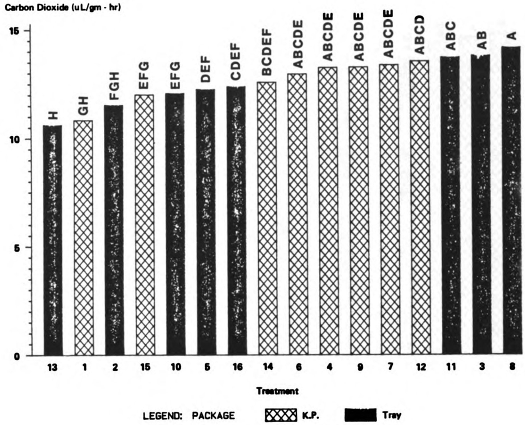
Figures 21 and 22. Interaction effect between vibrating, package type and position on injury score of 'Empire' apples.

Split Plot by Treatment Combination

The data obtained from this study was also analyzed as a split plot by treatment combination. For this analysis, the mean CO_2 output and injury scores of the six positions in each container were grouped together. Therefore, there was one CO_2 output and injury score reading for each container tested instead of six readings as in the split plot by factoral effects discussed previously. The split plot by treatment combination showed which treatment forces for a specific package type yielded the highest or lowest CO_2 output or injury scores without taking position into consideration.

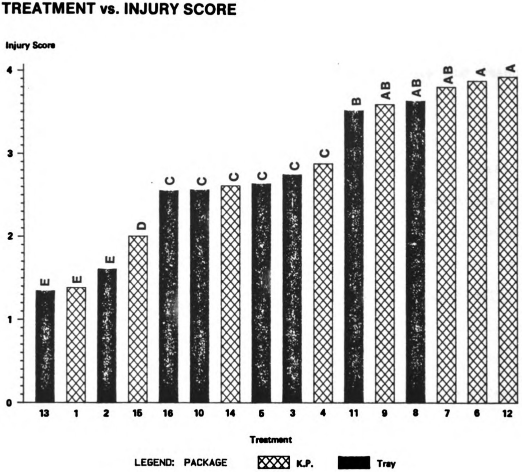
The split plot by treatment combination analysis of the data yielded significant differences among treatment combinations at 95% confidence limits by Duncan's multiple range test (see Figures 23 and 24). All forces applied (drop, vibrate and compress) produced the highest CO_2 output for the tray-pack container, and were significantly different than eight other treatment combinations; injury scores followed a similar trend. When forces were not applied, the lowest CO_2 output and injury score was obtained for the tray-pack container. The tray-pack container with no forces applied was significantly different than any container with a force applied, except for the compressed tray-pack container and the non-treated K.P. container. The dropped or compressed K.P. containers were not significantly different from one another. Mean CO_2 values differed from a high of 14.15 μℓ/gm·hr for the drop x vibrate x compress tray container to a low of 10.63 μℓ/gm·hr for the tray container with no forces applied, while injury score varied from a high of 3.91 for the drop x vibrate x compress K.P. container to 1.35 units for the tray with no forces applied.

TREATMENT vs. CARBON DIOXIDE (μL/gm-hr at Hour 4)



Treatment Number	Type of Force
1	None
2	Compress
3	Vibrate
4	Vibrate*Compress
5	Drop
6	Drop*Compress
7	Drop*Vibrate
8	Drop*Vibrate*Compress
9	Drop
10	Drop*Compress
11	Drop*Vibrate
12	Drop*Vibrate*Compress
13	None
14	Compress
15	Vibrate
16	Vibrate*Compress

Figure 23. Mean CO_2 production of 'Empire' apples 4 hours post treatment. Means with the same letter are not significantly different by Duncan's multiple range test, 5% level.



Treatment Number	Type of Force
1	None
2	Compress
3	Vibrate
4	Vibrate*Compress
5	Drop
6	Drop*Compress
7	Drop*Vibrate
8	Drop*Vibrate*Compress
9	Drop
10	Drop*Compress
11	Drop*Vibrate
12	Drop*Vibrate*Compress
13	None
14	Compress
15	Vibrate
16	Vibrate*Compress

Figure 24. Mean injury scores of 'Empire' apples examined 4 days after treatment. Means with the same letter are not significantly different by Duncan's multiple range, 5% level.

SUMMARY

1. The CO_2 response of apples subsequent to simulated transit testing provided an objective method for readily identifying and measuring the visual level of injury to apples.

2. The effects of dropping, compressing and vibrating were greater on CO_2 evolution and injury scores when each were applied individually than when any combination thereof was applied to a particular container. Vibrating resulted in the largest increase in CO_2 production following by dropping and compressing, respectively, when compared to non-damaged fruit.

3. The CO_2 evolution of apples post treatment detected the effects of different forces (dropping, vibrating and compressing) and on different shipping containers and how the effects of these forces interact. The CO_2 output of apples also provided an index which indicated the least injurious position for an apple within a particular container for a specific force or combination of forces.

4. Visual injury scores were significant for all the main effects (drop, vibrate, compress and package) and drop and vibrate were the only significant main effects for CO_2 evolution. Additionally, analysis of the data resulted in 9 and 4 significant two-way interactions for injury scores and CO_2 evolution, respectively.

DISCUSSION

The 4th-hour CO_2 reading yielded the highest r-square value for injury scores by the bucket method. There was a significant correlation between CO_2 evolution and injury scores; but, r-squares were not particularly high. The low correlation coefficients might have occurred because it was difficult to see all the damaged cells on the apple fruit or the increased CO_2 output may be detecting a different type of injury than simply mechanical damage. More study would be beneficial to determine the response of individual apple fruits to different destructive forces. The highest CO_2 outputs were obtained for the 1st-hour after-treatment and declined steadily through the 5th-hour reading (see Appendix). Klein (31) indicated that CO_2 output was highest between 3 and 6 hours post damage to apples. Pollack and Hills (27) showed a linear CO_2 response of bruised red tart cherry through the 6-hour post treatment, while Hyodo, Hasegawa, Iba and Manago (14) showed that CO_2 production was greatest immediately following damage of Satsuma Mandarin. Other studies (17, 20, 36) have shown the greatest CO_2 response after damage occurs within the first 24 hours following damage to horticultural crops.

Vibration had the largest effect on CO_2 evolution when compared to dropping or compressing. When the apples rolled within the containers during vibration, this may have damaged more cells than dropping or compressing, especially in the layers of fruit tissue closest to the epidermis. Additionally, a 2nd or 3rd injury (bruise) to tissue that had already sustained impact damage by vibration would likely show no great CO_2 response. However, vibration may have been a more severe treatment than either dropping or compressing. Since dropping was the first force treatment applied to the apples, followed by vibration and compression, the overall CO_2 response of dropping and vibration may not have been captured, thus suggesting a lower CO_2 output for dropping or vibration than what was actually observed.

The effect of compressing was decreased when containers were dropped, and the effect of dropping was decreased when containers were compressed. Compressing reduced the effect of dropping, but not to the extent that dropping reduced the effect of compressing. Possibly, dropping permitted settling of fruit within the containers; therefore, when containers were compressed, the opportunity for fruit to be damaged was likely reduced since the height of the fruit within the shipping container was reduced. The fact that compressing reduced the effect of dropping on CO_2 output and injury scores may indicate once again that a 2nd or 3rd bruise to tissue that had already been damaged may show no great CO_2 response or increased visible damage.

When containers were dropped, apples located near the bottom of the containers were injured the most, and apples located near the top sustained the least damage. Holt, Schrool and Lucas (12,13) showed that bruising was more severe on the bottom of shipping containers than on the top layers of fruit after dropping by impact. They claimed that fruit in the lower layers of shipping containers receive multiple impacts, whereas apples in the top layers receive only one during dropping. Additionally, apples in the lower portion of a container support the weight of the apples above.

The effect of vibrating on CO_2 production of apples was greater for tray-pack containers than for K.P. containers. Simulated vibration testing conducted prior to this study indicated that fruit within the K.P. containers resonated at approximately 8 Hz, while fruit in the K.P. containers resonated at approximately 12 Hz. During this pre-experimental study, it was noted that the trays in the tray-pack container acted as one large spring mass system, which permitted sustained bouncing of fruit. Movement of fruit in the K.P. container was less noticeable and occurred over a smaller range of frequencies than for the tray-pack container. Therefore, there was greater opportunity for apples in the tray-pack container to experience impacts due to bouncing from vibration, thus increasing CO_2 evolution and injury scores.

Holt and Schoorl (30) showed fruit located in the bottom portion of shipping containers experienced lower acceleration levels than fruit in upper levels. O'Brien (23) quantified the level of injury in various layers within produce containers and found upper layers of fruit had more injury after vibration testing. Similarly, in this study vibrating resulted in the highest CO_2 output and injury scores in the top layer of the shipping containers, positions E and F.

The effect of compressing on injury scores was greater for the K.P. container than for the tray-pack container because the K.P. container did not prevent the compressive load force from coming in contact with the fruit. Compression strength testing of the two types of containers yielded mean compression strength values of 1002 and 2645 for the K.P. and tray-pack corrugated shipping containers, respectively.

The effect of positions differed depending on the type of container tested. Positions E and F (top layer) in the tray-pack container had the highest CO_2 output, while positions A and B (bottom layer) had the highest CO_2 output for the K.P. container. This interaction effect occurred because positions E and F (top layer) were affected more by vibration in the tray-pack container and positions A and B being greatly affected by dropping in the K.P. container.

The effect of vibrating on CO_2 evolution and injury scores was less if containers were dropped and compressed; the effect of dropping on CO_2 evolution and injury scores was less if containers were vibrated and compressed; the effect of compressing on CO_2 evolution and injury scores was less if containers were dropped and vibrated. Vibrating and dropping permitted settling of fruit within the containers and may account for the reduced effect of compressing when containers were vibrated and dropped. Similarly, dropping containers settled fruit, which resulted in a denser pack, thus lessening the effects of vibration and compression.

The combined effect of dropping and compressing was greater for the K.P. than the tray-pack container on CO_2 output and injury scores, since: 1) the K.P. container had a lower mean compressive strength value (1002 lbs) compared to the tray-pack container (2645 lbs), and 2) dropping had a smaller effect in the tray-pack container because the trays probably provided shock-absorbing material during impact. These trends were seen in the significant Drop x Compress and Drop x Package interactions for injury scores and the significant Drop x Compress x Package Type interaction for CO_2 evolution and injury scores.

Dropping affected the ordering of the positions in the K.P. containers more than in tray-pack containers. The pulp trays within the tray-pack container provided protection against impact by dropping, thus, the position of an apple in a K.P. package was more critical than in a tray-pack container. This was evident when K.P. containers were dropped, causing CO_2 evolution to be highest for apples in the bottom of the container, while the CO_2 evolution from apples in the tray-pack containers was only negligibly affected by dropping.

Vibrating the K.P. container did change the ordering of positions for CO_2 evolution, but not to the extent that vibrating altered the ordering in the tray-pack container. Vibrating affected fruit located in the upper layer of the tray-pack containers more than in the K.P. containers since the trays amplified the simulated vibration inputs, resulting in sustained bouncing of the fruit. Additionally, apples located in the top layer of the tray-pack container were affected most, where the highest acceleration is.

CO_2 EVOLUTION AS METHOD TO DETERMINE THE PROTECTIVE CHARACTERISTICS OF SHIPPING CONTAINERS

Simulated transit handling of apples in shipping containers resulted in an increase in CO_2 evolution similar to those applied to individual fruits by previous investigators. Therefore, a damage detector system for assessing the protective characteristics of produce shipping containers which utilizes the objective increase in carbon dioxide of mechanically injured apples could be carried out as follows:

1. Select fruit of similar variety free from obvious physical damage and physiological disorders, uniform in size and maturity. An entire shipping container can be filled with optimum fruit or the fruit CO_2 response will be measured from can be carefully placed among less than optimum filler fruit of similar size and maturity.

2. Fruit should be pre-conditioned to the test temperature upon removal from cold storage.

3. Various forces (e.g., dropping, compression and/or vibration) are applied in a designated order to the different shipping containers the experimentor wishes to evaluate, or the CO_2 response could be measured from apples after a truck, rail or air ride.

4. Following damage treatment, the fruit is carefully removed and placed in an airtight container which provides a minimum amount of headspace.

5. Gas samples are analyzed from the airtight containers using a gas chromatograph or infrared CO_2 analyzer four to five hours after sealing the containers.

6. After sampling the accumulated CO_2 within the airtight containers the fruit is weighed.

7. The level of CO_2 detected by a gas chromatograph or infrared CO_2 analyzer is calculated based on fruit weight and headspace volume of the airtight containers.

8. The rates of CO_2 outputs from the apples that were located in different locations and/or shipping containers with various forces applied can then be compared to one another, and to nondamaged fruit of similar variety, size and maturity in the same test.

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APPENDIX

CO_2 Evolution 1, 2, 3, 4 and 5 Hours Post Treatment and Injury Score cv. 'Empire' Apples Damaged in Corrugated Shipping Containers for Each Treatment Combination

CO_2 Evolution 1, 2, 3, 4 and 5 Hours Post Treatment and Injury Scores for cv. 'Empire' Apples Damaged in Corrugated Shipping Containers for Each Treatment Combination

								% CO_2					CO_2 µl/gm·hr				
Repli-cation	Treat-ment	Drop	Vibrate	Compress	Package	Position	Injury Score	Hr. 1	Hr. 2	Hr. 3	Hr. 4	Hr. 5	Hr. 1	Hr. 2	Hr. 3	Hr. 4	Hr. 5
1	1	-	-	-	K.P.	A	1.2	0.45	0.72	0.96	1.21	1.49	15.46	12.37	10.99	10.39	10.24
1	1	-	-	-	K.P.	B	1.1	0.52	0.82	1.14	1.45	1.77	16.49	13.00	12.05	11.49	11.23
1	1	-	-	-	K.P.	C	1.4	0.51	0.80	1.07	1.34	1.64	15.34	12.03	10.73	10.08	09.87
1	1	-	-	-	K.P.	D	1.2	0.40	0.65	0.87	1.06	1.31	14.38	11.69	10.43	09.53	09.42
1	1	-	-	-	K.P.	E	1.1	0.50	0.80	1.07	1.34	1.64	15.74	12.59	11.23	10.55	10.33
1	1	-	-	-	K.P.	F	1.1	0.43	0.69	0.91	1.12	1.38	15.91	12.77	11.23	10.36	10.22
1	2	-	-	+	Tray	A	2.2	0.49	0.77	1.00	1.25	1.53	16.68	13.11	11.35	10.64	10.42
1	2	-	-	+	Tray	B	2.5	0.52	0.81	1.08	1.36	1.67	17.77	13.84	12.30	11.62	11.41
1	2	-	-	+	Tray	C	1.6	0.61	0.94	1.30	1.63	1.96	19.25	14.83	13.67	12.86	12.37
1	2	-	-	+	Tray	D	1.7	0.54	0.83	1.11	1.37	1.67	18.69	14.37	12.81	11.86	11.56
1	2	-	-	+	Tray	E	1.3	0.55	0.84	1.16	1.44	1.77	18.28	13.96	12.85	11.97	11.77
1	2	-	-	+	Tray	F	1.8	0.45	0.71	0.93	1.13	1.38	15.95	12.58	10.98	10.01	09.78
1	3	-	+	-	Tray	A	1.5	0.47	0.76	1.00	1.31	1.59	15.22	12.31	10.80	10.61	10.30
1	3	-	+	-	Tray	B	2.1	0.49	0.79	1.08	1.40	1.70	15.21	12.27	11.18	10.87	10.56
1	3	-	+	-	Tray	C	1.4	0.46	0.74	1.01	1.26	1.57	14.91	11.99	10.91	10.21	10.18
1	3	-	+	-	Tray	D	1.5	0.44	0.72	0.96	1.21	1.50	14.49	11.85	10.53	09.96	09.88
1	3	-	+	-	Tray	E	4.2	0.65	1.05	1.50	1.86	2.14	22.03	17.79	16.94	15.76	14.50
1	3	-	+	-	Tray	F	4.2	0.61	0.92	1.42	1.79	2.22	19.69	15.65	15.28	14.45	14.33
1	4	-	+	+	K.P.	A	1.6	0.40	0.70	0.96	1.22	1.56	13.51	11.82	10.81	10.30	10.54
1	4	-	+	+	K.P.	B	2.5	0.43	0.72	0.96	1.24	1.56	14.25	11.93	10.61	10.27	10.34
1	4	-	+	+	K.P.	C	2.9	0.45	0.77	1.05	1.39	1.70	16.04	13.72	12.47	12.39	12.12
1	4	-	+	+	K.P.	D	3.7	0.46	0.78	1.08	1.44	1.77	15.91	13.49	12.45	12.45	12.25
1	4	-	+	+	K.P.	E	2.7	0.43	0.75	1.01	1.32	1.64	15.36	13.40	12.03	11.79	11.72
1	4	-	+	+	K.P.	F	4.3	0.54	0.88	1.23	1.58	1.89	18.96	15.45	14.39	13.87	13.27
1	5	+	-	-	Tray	A	3.8	0.47	0.82	1.13	1.49	1.87	16.03	13.98	12.84	12.70	12.75
1	5	+	-	-	Tray	B	3.3	0.47	0.79	1.08	1.41	1.77	16.21	13.62	12.42	12.16	12.21
1	5	+	-	-	Tray	C	3.1	0.40	0.68	0.92	1.18	1.49	14.70	12.50	11.27	10.84	10.95
1	5	+	-	-	Tray	D	3.5	0.44	0.76	1.03	1.35	1.71	13.88	11.99	10.83	10.65	10.79
1	5	+	-	-	Tray	E	1.4	0.41	0.70	0.92	1.19	1.49	14.31	12.22	10.71	10.39	10.40
1	5	+	-	-	Tray	F	1.5	0.50	0.86	1.20	1.60	2.00	17.01	14.47	13.61	13.61	13.61

Appendix (Continued)

Repli-cation	Treat-ment	Drop	Vibrate	Compress	Package	Position	Injury Score	% CO_2 Hr. 1	% CO_2 Hr. 2	% CO_2 Hr. 3	% CO_2 Hr. 4	% CO_2 Hr. 5	CO_2 µl/gm·hr Hr. 1	CO_2 µl/gm·hr Hr. 2	CO_2 µl/gm·hr Hr. 3	CO_2 µl/gm·hr Hr. 4	CO_2 µl/gm·hr Hr. 5
1	6	+	-	+	K.P.	A	4.6	0.58	0.93	1.28	1.69	2.08	19.71	15.80	14.50	14.36	14.14
1	6	+	-	+	K.P.	B	4.3	0.57	0.91	1.23	1.63	2.04	20.05	16.01	14.42	14.33	14.35
1	6	+	-	+	K.P.	C	4.4	0.50	0.80	1.06	1.41	1.79	18.04	14.43	12.75	12.72	12.92
1	6	+	-	+	K.P.	D	4.1	0.47	0.76	0.99	1.32	1.67	18.34	14.83	12.88	12.88	13.04
1	6	+	-	+	K.P.	E	3.5	0.50	0.80	1.05	1.40	1.77	18.78	15.02	13.14	13.14	13.29
1	6	+	-	+	K.P.	F	3.2	0.49	0.79	1.05	1.38	1.74	18.07	14.57	12.91	12.72	12.83
1	7	+	+	-	K.P.	A	4.4	0.55	0.92	1.32	1.72	2.06	17.21	14.40	13.77	13.46	12.90
1	7	+	+	-	K.P.	B	4.2	0.46	0.78	1.08	1.43	1.75	16.17	13.71	12.66	12.57	12.31
1	7	+	+	-	K.P.	C	4.9	0.52	0.85	1.20	1.57	1.88	17.13	14.00	13.18	12.93	12.39
1	7	+	+	-	K.P.	D	4.8	0.46	0.77	1.06	1.38	1.68	16.55	13.85	12.71	12.41	12.09
1	7	+	+	-	K.P.	E	3.5	0.50	0.81	1.13	1.46	1.79	16.56	13.42	12.48	12.09	11.86
1	7	+	+	-	K.P.	F	2.6	0.42	0.70	0.94	1.21	1.50	15.18	12.65	11.33	10.94	10.85
1	8	+	+	+	Tray	A	4.2	0.48	0.84	1.18	1.56	1.88	16.06	14.06	13.16	13.05	12.58
1	8	+	+	+	Tray	B	3.5	0.48	0.83	1.16	1.54	1.87	16.48	14.25	13.28	13.22	12.84
1	8	+	+	+	Tray	C	4.1	0.54	0.92	1.32	1.72	2.10	18.35	15.63	14.95	14.61	14.28
1	8	+	+	+	Tray	D	4.2	0.63	1.08	1.59	2.07	2.40	17.33	14.85	14.58	14.23	13.20
1	8	+	+	+	Tray	E	3.8	0.57	0.97	1.42	1.87	2.21	19.61	16.68	16.28	16.08	15.20
1	8	+	+	+	Tray	F	5.0	0.67	1.18	1.79	2.30	2.75	23.00	20.25	20.48	19.74	18.88
1	9	+	-	-	K.P.	A	4.2	0.54	0.91	1.30	1.69	2.10	17.70	14.92	14.20	13.85	13.77
1	9	+	-	-	K.P.	B	4.2	0.48	0.80	1.09	1.44	1.82	19.13	15.94	14.48	14.35	14.51
1	9	+	-	-	K.P.	C	4.1	0.49	0.83	1.13	1.49	1.87	16.38	13.88	12.59	12.46	12.51
1	9	+	-	-	K.P.	D	4.5	0.48	0.84	1.16	1.54	1.93	16.28	14.24	13.11	13.06	13.09
1	9	+	-	-	K.P.	E	2.9	0.48	0.80	1.08	1.41	1.78	16.75	13.96	12.56	12.28	12.42
1	9	+	-	-	K.P.	F	3.0	0.45	0.77	1.03	1.35	1.72	15.53	13.28	11.85	11.65	11.87
1	10	+	-	+	Tray	A	3.2	0.53	0.84	1.12	1.47	1.84	17.45	13.83	12.29	12.10	12.12
1	10	+	-	+	Tray	B	3.5	0.49	0.82	1.12	1.47	1.86	16.56	13.85	12.62	12.42	12.57
1	10	+	-	+	Tray	C	2.8	0.48	0.80	1.08	1.43	1.80	17.91	14.92	13.43	13.34	13.43
1	10	+	-	+	Tray	D	2.5	0.44	0.74	0.98	1.28	1.64	15.46	13.00	11.48	11.24	11.52
1	10	+	-	+	Tray	E	1.9	0.51	0.84	1.14	1.51	1.92	16.74	13.79	12.47	12.39	12.61
1	10	+	-	+	Tray	F	1.6	0.44	0.73	0.97	1.27	1.62	15.40	12.77	11.31	11.11	11.34

Appendix (Continued)

Repli-cation	Treat-ment	Drop	Vibrate	Compress	Package	Position	Injury Score	% CO_2 Hr. 1	Hr. 2	Hr. 3	Hr. 4	Hr. 5	CO_2 µl/gm·hr Hr. 1	Hr. 2	Hr. 3	Hr. 4	Hr. 5
1	11	+	+	-	Tray	A	3.8	0.48	0.83	1.15	1.49	1.83	16.80	14.52	13.42	13.04	12.81
1	11	+	+	-	Tray	B	3.4	0.51	0.97	1.22	1.57	1.94	17.46	14.89	13.92	13.44	13.28
1	11	+	+	-	Tray	C	3.1	0.42	0.72	0.95	1.21	1.53	15.42	13.22	11.63	11.11	11.23
1	11	+	+	-	Tray	D	2.8	0.45	0.78	1.05	1.37	1.71	15.12	13.10	11.76	11.51	11.49
1	11	+	+	-	Tray	E	4.1	0.60	1.04	1.52	1.99	2.10	19.23	16.67	16.24	15.95	13.46
1	11	+	+	-	Tray	F	3.9	0.56	0.97	1.40	1.83	2.23	19.16	16.59	15.97	15.65	15.26
1	12	+	+	+	K.P.	A	4.3	0.63	1.05	1.47	1.93	2.36	19.74	16.45	15.36	15.12	14.79
1	12	+	+	+	K.P.	B	4.3	0.55	0.90	1.24	1.62	2.04	17.43	14.26	13.10	12.83	12.93
1	12	+	+	+	K.P.	C	4.8	0.55	0.90	1.25	1.66	2.07	19.61	16.04	14.86	14.80	14.76
1	12	+	+	+	K.P.	D	4.6	0.50	0.82	1.10	1.48	1.88	17.76	14.57	13.03	13.14	13.36
1	12	+	+	+	K.P.	E	2.7	0.48	0.78	1.04	1.39	1.78	18.00	14.63	13.00	13.03	13.35
1	12	+	+	+	K.P.	F	2.7	0.48	0.77	1.01	1.34	1.72	16.64	13.35	11.67	11.62	11.93
1	13	-	-	-	Tray	A	1.0	0.43	0.73	0.96	1.25	1.59	13.52	11.48	10.06	09.83	10.00
1	13	-	-	-	Tray	B	1.5	0.53	0.88	1.20	1.59	1.99	15.67	13.01	11.83	11.75	11.77
1	13	-	-	-	Tray	C	1.4	0.42	0.69	0.92	1.18	1.51	14.38	11.82	10.50	10.10	10.34
1	13	-	-	-	Tray	D	1.1	0.40	0.69	0.91	1.19	1.53	13.95	12.03	10.58	10.38	10.67
1	13	-	-	-	Tray	E	1.2	0.44	0.72	0.94	1.23	1.57	15.72	12.86	11.19	10.98	11.22
1	13	-	-	-	Tray	F	1.3	0.38	0.65	0.86	1.11	1.43	14.20	12.14	10.71	10.37	10.68
1	14	-	-	+	K.P.	A	3.2	0.57	0.90	1.25	1.60	2.05	18.70	14.76	13.67	13.12	13.45
1	14	-	-	+	K.P.	B	3.3	0.56	0.89	1.22	1.62	2.03	19.20	15.25	13.94	13.88	13.92
1	14	-	-	+	K.P.	C	2.5	0.60	0.95	1.33	1.76	2.20	19.29	15.27	14.25	14.14	14.14
1	14	-	-	+	K.P.	D	3.2	0.50	0.78	1.03	1.35	1.72	19.00	14.82	13.05	12.82	13.07
1	14	-	-	+	K.P.	E	2.3	0.55	0.85	1.12	1.44	1.85	19.92	15.39	13.52	13.04	13.40
1	14	-	-	+	K.P.	F	3.6	0.64	1.00	1.40	1.82	2.26	21.02	16.43	15.33	14.95	14.85
1	15	-	+	-	K.P.	A	1.5	0.39	0.71	0.93	1.19	1.50	13.27	12.08	10.55	10.12	10.21
1	15	-	+	-	K.P.	B	2.0	0.39	0.71	0.95	1.24	1.57	14.26	12.98	11.58	11.34	11.49
1	15	-	+	-	K.P.	C	2.5	0.39	0.71	0.95	1.24	1.55	13.53	12.32	10.99	10.76	10.76
1	15	-	+	-	K.P.	D	1.8	0.43	0.76	1.02	1.38	1.73	13.75	12.15	10.87	11.03	11.06
1	15	-	+	-	K.P.	E	1.8	0.46	0.78	1.05	1.38	1.74	16.53	14.01	12.57	12.39	12.50
1	15	-	+	-	K.P.	F	2.0	0.42	0.74	1.00	1.34	1.68	15.06	13.26	11.95	12.01	12.04

Appendix (Continued)

								% CO_2					CO_2 µl/gm·hr				
Replication	Treatment	Drop	Vibrate	Compress	Package	Position	Injury Score	Hr. 1	Hr. 2	Hr. 3	Hr. 4	Hr. 5	Hr. 1	Hr. 2	Hr. 3	Hr. 4	Hr. 5
1	16	-	+	+	Tray	A	1.4	0.46	0.76	0.99	1.31	1.65	15.96	13.18	11.45	11.36	11.45
1	16	-	+	+	Tray	B	1.2	0.43	0.71	0.91	1.19	1.51	16.47	13.60	13.42	11.40	11.57
1	16	-	+	+	Tray	C	1.5	0.45	0.75	0.97	1.29	1.64	15.44	12.87	11.10	11.07	11.26
1	16	-	+	+	Tray	D	2.0	0.49	0.81	1.05	1.40	1.78	16.74	13.83	11.96	11.96	12.16
1	16	-	+	+	Tray	E	3.6	0.56	0.93	1.26	1.70	2.10	20.22	16.79	15.17	15.35	15.17
1	16	-	+	+	Tray	F	4.1	0.57	0.94	1.29	1.75	2.21	21.34	17.60	16.10	16.38	16.55
2	1	-	-	-	K.P.	A	1.1	0.37	0.67	0.93	1.19	1.48	13.54	12.26	11.35	10.89	10.83
2	1	-	-	-	K.P.	B	1.4	0.46	0.79	1.11	1.45	1.79	15.64	13.65	12.58	12.33	12.17
2	1	-	-	-	K.P.	C	1.3	0.44	0.73	1.00	1.27	1.58	16.25	13.48	12.31	11.72	11.67
2	1	-	-	-	K.P.	D	1.6	0.47	0.85	1.22	1.58	1.96	15.18	13.73	13.14	12.76	12.66
2	1	-	-	-	K.P.	E	1.7	0.41	0.72	1.02	1.29	1.65	15.11	13.27	12.53	11.86	12.16
2	1	-	-	-	K.P.	F	1.6	0.38	0.65	0.89	1.12	1.39	14.19	12.13	11.08	10.45	10.38
2	2	-	-	+	Tray	A	1.6	0.47	0.83	1.20	1.58	1.91	15.90	14.04	13.53	13.37	12.93
2	2	-	-	+	Tray	B	2.1	0.48	0.80	1.11	1.43	1.73	15.97	13.31	12.31	11.89	11.51
2	2	-	-	+	Tray	C	1.5	0.45	0.80	1.15	1.49	1.82	16.26	14.46	13.85	13.46	13.15
2	2	-	-	+	Tray	D	1.4	0.41	0.74	1.05	1.37	1.70	14.98	13.52	12.79	12.51	12.42
2	2	-	-	+	Tray	E	1.4	0.48	0.78	1.07	1.37	1.67	16.48	13.39	12.25	11.76	11.47
2	2	-	-	+	Tray	F	1.2	0.31	0.55	0.75	0.92	1.09	12.79	11.34	10.31	09.49	08.99
2	3	-	+	-	Tray	A	1.3	0.43	0.77	1.10	1.42	1.77	16.00	14.32	13.64	13.21	13.17
2	3	-	+	-	Tray	B	1.6	0.59	0.95	1.37	1.75	2.11	18.85	15.18	14.59	13.98	13.49
2	3	-	+	-	Tray	C	2.2	0.54	0.91	1.33	1.69	2.07	17.80	15.00	14.61	13.93	13.65
2	3	-	+	-	Tray	D	1.9	0.53	0.92	1.37	1.73	2.13	17.47	15.16	15.05	14.26	14.04
2	3	-	+	-	Tray	E	4.1	0.60	1.07	1.63	2.08	2.49	21.01	18.74	19.03	18.21	17.44
2	3	-	+	-	Tray	F	4.8	0.71	1.22	1.84	2.30	2.73	23.88	20.52	20.63	19.34	18.37
2	4	-	+	+	K.P.	A	1.8	0.48	0.83	1.21	1.57	1.91	16.56	14.02	13.63	13.26	12.91
2	4	-	+	+	K.P.	B	2.0	0.45	0.77	1.10	1.43	1.76	15.86	13.57	12.92	12.60	12.41
2	4	-	+	+	K.P.	C	3.0	0.46	0.81	1.16	1.52	1.84	15.81	13.92	13.29	13.06	12.65
2	4	-	+	+	K.P.	D	2.5	0.42	0.75	1.07	1.40	1.73	15.87	14.17	13.48	13.23	13.08
2	4	-	+	+	K.P.	E	2.8	0.44	0.77	1.05	1.35	1.64	17.27	15.11	13.74	13.25	12.88
2	4	-	+	+	K.P.	F	3.8	0.50	0.90	1.32	1.72	2.06	18.91	17.02	16.64	16.26	15.58

Appendix (Continued)

Repli-cation	Treat-ment	Drop	Vibrate	Compress	Package	Position	Injury Score	% CO_2 Hr. 1	Hr. 2	Hr. 3	Hr. 4	Hr. 5	CO_2 µl/gm·hr Hr. 1	Hr. 2	Hr. 3	Hr. 4	Hr. 5
2	5	+	-	-	Tray	A	3.4	0.44	0.78	1.09	1.41	1.74	15.15	13.43	12.51	12.14	11.98
2	5	+	-	-	Tray	B	4.0	0.54	0.91	1.29	1.65	2.02	16.88	14.22	13.44	12.89	12.63
2	5	+	-	-	Tray	C	3.0	0.54	0.90	1.30	1.65	2.01	18.29	15.24	14.68	13.97	13.61
2	5	+	-	-	Tray	D	3.0	0.44	0.77	1.09	1.39	1.73	15.45	13.51	12.75	12.20	12.15
2	5	+	-	-	Tray	E	1.7	0.49	0.84	1.20	1.53	1.88	15.70	13.45	12.81	13.43	12.04
2	5	+	-	-	Tray	F	1.7	0.54	0.92	1.34	1.71	2.08	17.21	14.66	14.24	14.93	13.26
2	6	+	-	+	K.P.	A	4.1	0.45	0.82	1.17	1.54	1.88	16.19	14.75	14.04	13.86	13.53
2	6	+	-	+	K.P.	B	4.0	0.46	0.80	1.15	1.48	1.80	15.08	13.11	12.57	12.13	11.80
2	6	+	-	+	K.P.	C	4.0	0.48	0.80	1.11	1.42	1.72	18.38	15.32	14.17	13.60	13.17
2	6	+	-	+	K.P.	D	3.8	0.48	0.82	1.20	1.55	1.89	17.53	14.97	14.60	14.15	13.80
2	6	+	-	+	K.P.	E	2.9	0.43	0.75	1.06	1.37	1.68	15.75	13.74	12.95	12.55	12.31
2	6	+	-	+	K.P.	F	3.1	0.44	0.76	1.07	1.38	1.68	15.65	13.52	12.69	12.27	11.95
2	7	+	+	-	K.P.	A	4.5	0.55	0.97	1.45	1.84	2.25	16.77	14.79	14.74	13.95	13.72
2	7	+	+	-	K.P.	B	3.9	0.52	0.91	1.36	1.75	2.13	18.33	16.04	15.98	15.42	15.02
2	7	+	+	-	K.P.	C	3.7	0.47	0.77	1.03	1.31	1.61	17.29	14.16	12.63	12.05	11.84
2	7	+	+	-	K.P.	D	4.1	0.48	0.85	1.23	1.60	1.94	15.45	13.68	13.20	12.87	12.49
2	7	+	+	-	K.P.	E	3.5	0.48	0.84	1.22	1.61	1.97	17.06	14.92	14.45	14.30	14.41
2	7	+	+	-	K.P.	F	2.6	0.52	0.89	1.30	1.68	2.02	16.54	14.15	13.78	13.36	12.85
2	8	+	+	+	Tray	A	3.2	0.41	0.75	1.06	1.36	1.69	14.33	13.11	12.35	11.86	11.82
2	8	+	+	+	Tray	B	3.2	0.49	0.82	1.15	1.47	1.77	15.88	13.29	12.42	11.91	11.47
2	8	+	+	+	Tray	C	3.0	0.53	0.90	1.31	1.68	2.01	17.53	14.88	14.44	13.89	13.29
2	8	+	+	+	Tray	D	2.6	0.42	0.77	1.09	1.41	1.73	15.13	13.61	12.84	12.70	12.47
2	8	+	+	+	Tray	E	4.3	0.49	0.89	1.33	1.75	2.11	17.22	15.64	15.58	15.37	14.83
2	8	+	+	+	Tray	F	4.4	0.50	0.92	1.38	1.79	2.14	17.92	16.49	16.49	16.04	15.34
2	9	+	-	-	K.P.	A	4.7	0.55	0.97	1.43	1.85	2.25	17.53	15.45	15.19	14.74	14.34
2	9	+	-	-	K.P.	B	4.0	0.49	0.88	1.25	1.69	2.06	18.11	16.26	15.40	15.61	15.22
2	9	+	-	-	K.P.	C	3.8	0.53	0.85	1.16	1.51	1.85	19.15	15.36	13.97	13.64	13.37
2	9	+	-	-	K.P.	D	4.3	0.42	0.78	1.07	1.42	1.77	14.37	13.35	12.21	12.15	12.12
2	9	+	-	-	K.P.	E	2.8	0.35	0.66	0.89	1.15	1.46	12.58	11.86	10.66	10.33	10.49
2	9	+	-	-	K.P.	F	2.7	0.63	0.93	1.25	1.59	1.90	22.52	16.62	14.90	14.21	13.58

Appendix (Continued)

Replication	Treatment	Drop	Vibrate	Compress	Package	Position	Injury Score	% CO_2 Hr. 1	Hr. 2	Hr. 3	Hr. 4	Hr. 5	CO_2 µl/gm·hr Hr. 1	Hr. 2	Hr. 3	Hr. 4	Hr. 5
2	10	+	-	+	Tray	A	3.4	0.39	0.74	0.99	1.30	1.66	13.37	12.69	11.32	11.15	11.39
2	10	+	-	+	Tray	B	3.6	0.45	0.86	1.19	1.58	1.98	16.04	15.33	14.14	14.08	14.12
2	10	+	-	+	Tray	C	2.6	0.47	0.87	1.21	1.61	2.01	15.64	14.48	13.42	13.40	13.38
2	10	+	-	+	Tray	D	2.3	0.46	0.87	1.21	1.53	1.98	15.64	14.79	13.71	13.01	13.46
2	10	+	-	+	Tray	E	1.5	0.38	0.75	1.00	1.32	1.69	12.46	12.29	10.93	10.82	11.08
2	10	+	-	+	Tray	F	2.4	0.43	0.81	1.10	1.47	1.84	13.67	12.88	11.66	11.68	11.70
2	11	+	+	-	Tray	A	3.8	0.39	0.70	0.96	1.25	1.56	14.58	13.09	11.96	11.68	11.66
2	11	+	+	-	Tray	B	3.6	0.44	0.78	1.08	1.42	1.77	15.14	13.42	12.39	12.22	12.18
2	11	+	+	-	Tray	C	3.7	0.42	0.76	1.04	1.37	1.69	14.49	13.11	11.96	11.82	11.66
2	11	+	+	-	Tray	D	3.2	0.40	0.73	0.99	1.29	1.62	14.44	13.17	11.91	11.64	11.69
2	11	+	+	-	Tray	E	4.2	0.59	1.05	1.56	2.00	2.43	20.78	18.49	18.31	17.61	17.12
2	11	+	+	-	Tray	F	4.8	0.61	1.12	1.67	2.15	2.60	21.20	19.46	19.35	18.68	18.07
2	12	+	+	+	K.P.	A	4.1	0.42	0.80	1.11	1.46	1.85	14.87	14.17	13.10	12.93	13.10
2	12	+	+	+	K.P.	B	4.7	0.48	0.88	1.27	1.68	2.09	17.15	15.72	15.13	15.01	14.94
2	12	+	+	+	K.P.	C	4.2	0.47	0.85	1.20	1.58	1.97	16.76	15.16	14.27	14.09	14.05
2	12	+	+	+	K.P.	D	4.8	0.54	0.95	1.37	1.78	2.19	19.28	16.96	16.31	15.89	15.64
2	12	+	+	+	K.P.	E	4.1	0.46	0.85	1.18	1.58	1.99	13.77	12.72	11.77	11.82	11.91
2	12	+	+	+	K.P.	F	3.6	0.39	0.73	0.98	1.29	1.65	14.18	13.27	11.87	11.72	12.00
2	13	-	-	-	Tray	A	1.4	0.36	0.65	0.88	1.11	1.41	12.58	11.35	10.25	09.69	09.85
2	13	-	-	-	Tray	B	1.4	0.47	0.84	1.16	1.53	1.90	15.31	13.68	12.60	12.46	12.38
2	13	-	-	-	Tray	C	1.8	0.34	0.62	0.85	1.06	1.33	13.23	12.06	11.03	10.31	10.35
2	13	-	-	-	Tray	D	1.3	0.37	0.68	0.92	1.21	1.52	13.33	12.25	11.05	10.90	10.95
2	13	-	-	-	Tray	E	1.3	0.35	0.66	0.89	1.16	1.47	12.67	11.95	10.74	10.50	10.64
2	13	-	-	-	Tray	F	1.1	0.38	0.70	0.95	1.24	1.58	13.48	12.41	11.23	11.00	11.21
2	14	-	-	+	K.P.	A	1.6	0.46	0.85	1.19	1.58	1.99	14.72	13.60	12.70	12.64	12.74
2	14	-	-	+	K.P.	B	3.5	0.37	0.72	0.96	1.24	1.58	11.90	11.57	10.29	09.97	10.16
2	14	-	-	+	K.P.	C	1.6	0.34	0.66	0.89	1.15	1.48	12.41	11.71	10.52	10.20	10.81
2	14	-	-	+	K.P.	D	2.8	0.38	0.73	0.98	1.29	1.65	13.01	12.49	11.18	11.04	11.29
2	14	-	-	+	K.P.	E	2.3	0.38	0.71	0.95	1.24	1.58	13.39	13.00	11.16	10.92	11.13
2	14	-	-	+	K.P.	F	3.2	0.42	0.79	1.07	1.41	1.79	14.93	14.04	12.67	12.53	12.72

Appendix (Continued)

Repli-cation	Treat-ment	Drop	Vibrate	Compress	Package	Position	Injury Score	% CO_2 Hr. 1	% CO_2 Hr. 2	% CO_2 Hr. 3	% CO_2 Hr. 4	% CO_2 Hr. 5	CO_2 µl/gm·hr Hr. 1	CO_2 µl/gm·hr Hr. 2	CO_2 µl/gm·hr Hr. 3	CO_2 µl/gm·hr Hr. 4	CO_2 µl/gm·hr Hr. 5
2	15	-	+	-	K.P.	A	1.7	0.37	0.67	0.92	1.20	1.52	13.69	12.39	11.34	11.10	11.24
2	15	-	+	-	K.P.	B	1.8	0.32	0.61	0.83	1.05	1.32	11.80	11.24	10.20	09.68	09.73
2	15	-	+	-	K.P.	C	1.6	0.42	0.75	1.03	1.35	1.71	14.97	13.37	12.24	12.03	12.19
2	15	-	+	-	K.P.	D	2.3	0.50	0.89	1.27	1.67	2.06	16.40	14.60	13.88	13.69	13.51
2	15	-	+	-	K.P.	E	2.6	0.52	0.91	1.36	1.80	2.21	17.67	15.46	15.41	15.29	15.02
2	15	-	+	-	K.P.	F	3.0	0.62	1.01	1.43	1.85	2.25	21.41	17.44	16.46	15.97	15.54
2	16	-	+	+	Tray	A	2.1	0.37	0.71	0.95	1.25	1.60	13.49	12.95	11.55	11.40	11.67
2	16	-	+	+	Tray	B	1.8	0.32	0.64	0.86	1.09	1.38	11.67	11.67	10.45	09.94	10.06
2	16	-	+	+	Tray	C	2.2	0.32	0.64	0.85	1.08	1.38	12.03	12.03	10.65	10.15	10.38
2	16	-	+	+	Tray	D	2.3	0.35	0.68	0.91	1.18	1.52	12.72	12.36	11.03	10.72	11.05
2	16	-	+	+	Tray	E	3.4	0.45	0.87	1.23	1.64	2.07	15.48	14.96	14.10	14.10	14.24
2	16	-	+	+	Tray	F	4.1	0.48	0.85	1.18	1.55	1.93	17.93	15.82	14.69	14.47	14.42
3	1	-	-	-	K.P.	A	1.6	0.37	0.67	0.92	1.18	1.48	13.52	12.24	11.20	10.78	10.81
3	1	-	-	-	K.P.	B	1.5	0.34	0.63	0.86	1.08	1.34	12.33	11.43	10.40	09.80	09.72
3	1	-	-	-	K.P.	C	1.2	0.42	0.72	0.96	1.22	1.50	13.10	11.23	09.98	09.52	09.36
3	1	-	-	-	K.P.	D	1.5	0.38	0.69	0.93	1.21	1.50	13.21	11.99	10.78	10.51	10.43
3	1	-	-	-	K.P.	E	1.4	0.36	0.65	0.90	1.13	1.40	13.39	12.09	11.16	10.51	10.42
3	1	-	-	-	K.P.	F	1.4	0.37	0.65	0.90	1.15	1.41	13.74	12.07	11.14	10.68	10.47
3	2	-	-	+	Tray	A	1.5	0.35	0.64	0.89	1.13	1.39	12.82	11.72	10.86	10.34	10.18
3	2	-	-	+	Tray	B	1.5	0.39	0.73	1.01	1.30	1.61	13.11	12.72	11.31	10.92	10.82
3	2	-	-	+	Tray	C	1.5	0.37	0.68	0.93	1.19	1.46	13.12	12.06	10.99	10.55	10.35
3	2	-	-	+	Tray	D	1.2	0.34	0.62	0.86	1.08	1.34	12.84	11.71	10.83	10.20	10.12
3	2	-	-	+	Tray	E	1.4	0.34	0.63	0.88	1.12	1.38	12.66	11.73	10.92	10.43	10.28
3	2	-	-	+	Tray	F	1.7	0.34	0.63	0.87	1.10	1.36	11.71	10.85	09.99	09.47	09.37
3	3	-	+	-	Tray	A	1.8	0.42	0.75	1.04	1.35	1.66	14.81	13.23	12.23	11.90	11.71
3	3	-	+	-	Tray	B	2.0	0.33	0.62	0.86	1.07	1.32	13.16	12.36	11.43	10.66	10.52
3	3	-	+	-	Tray	C	2.7	0.44	0.79	1.13	1.48	1.83	16.95	15.22	14.51	14.25	14.10
3	3	-	+	-	Tray	D	2.7	0.47	0.83	1.19	1.53	1.88	16.17	14.28	13.65	13.16	12.94
3	3	-	+	-	Tray	E	4.0	0.44	0.81	1.19	1.58	1.93	16.55	15.23	14.92	14.86	14.52
3	3	-	+	-	Tray	F	4.4	0.55	1.00	1.53	1.96	2.35	16.97	15.43	14.74	15.12	14.50

Appendix (Continued)

Repli- cation	Treat- ment	Drop	Vibrate	Compress	Package	Position	Injury Score	% CO_2 Hr. 1	% CO_2 Hr. 2	% CO_2 Hr. 3	% CO_2 Hr. 4	% CO_2 Hr. 5	CO_2 µl/gm·hr Hr. 1	CO_2 µl/gm·hr Hr. 2	CO_2 µl/gm·hr Hr. 3	CO_2 µl/gm·hr Hr. 4	CO_2 µl/gm·hr Hr. 5
3	4	-	+	+	K.P.	A	2.0	0.43	0.77	1.08	1.41	1.72	14.37	12.87	12.03	11.78	11.50
3	4	-	+	+	K.P.	B	3.1	0.43	0.77	1.09	1.44	1.76	14.75	13.52	12.76	12.64	12.36
3	4	-	+	+	K.P.	C	3.4	0.51	0.88	1.25	1.64	1.95	17.16	14.81	14.02	13.80	13.12
3	4	-	+	+	K.P.	D	4.2	0.62	1.12	1.68	2.13	2.49	18.26	16.49	16.49	15.68	14.06
3	4	-	+	+	K.P.	E	3.5	0.59	1.07	1.63	2.10	2.50	17.03	15.44	15.68	15.15	14.43
3	4	-	+	+	K.P.	F	3.1	0.47	0.84	1.23	1.61	1.96	17.12	15.30	14.93	14.66	14.28
3	5	+	-	-	Tray	A	3.5	0.43	0.76	1.05	1.38	1.69	14.51	12.83	11.81	11.64	11.41
3	5	+	-	-	Tray	B	3.0	0.35	0.64	0.86	1.09	1.34	12.75	11.65	10.44	09.92	09.76
3	5	+	-	-	Tray	C	2.8	0.39	0.70	0.94	1.22	1.51	14.66	13.16	11.78	11.46	11.45
3	5	+	-	-	Tray	D	2.7	0.42	0.75	1.04	1.34	1.66	14.05	12.54	11.59	11.20	11.10
3	5	+	-	-	Tray	E	2.1	0.45	0.78	1.09	1.42	1.78	15.47	14.47	12.49	12.20	12.24
3	5	+	-	-	Tray	F	1.5	0.38	0.69	0.95	1.23	1.54	13.80	12.53	11.50	11.17	11.19
3	6	+	-	+	K.P.	A	4.7	0.45	0.81	1.16	1.50	1.84	14.88	13.39	12.79	12.40	12.17
3	6	+	-	+	K.P.	B	4.4	0.42	0.77	1.08	1.42	1.73	14.65	13.43	12.56	12.38	12.07
3	6	+	-	+	K.P.	C	3.9	0.40	0.72	0.99	1.29	1.57	14.77	13.30	12.19	11.91	11.60
3	6	+	-	+	K.P.	D	3.5	0.48	0.85	1.23	1.59	1.91	16.55	14.65	14.14	13.71	13.17
3	6	+	-	+	K.P.	E	2.7	0.36	0.65	0.89	1.12	1.37	12.41	11.21	10.23	09.66	09.45
3	6	+	-	+	K.P.	F	4.5	0.32	0.60	0.82	1.03	1.25	12.07	11.91	10.85	10.22	09.92
3	7	+	+	-	K.P.	A	4.1	0.48	0.86	1.27	1.61	1.96	16.80	15.05	14.82	14.09	13.72
3	7	+	+	-	K.P.	B	4.4	0.56	0.99	1.49	1.92	2.27	17.31	15.30	15.35	14.83	14.03
3	7	+	+	-	K.P.	C	3.9	0.45	0.83	1.19	1.55	1.89	14.88	13.73	13.12	12.82	12.50
3	7	+	+	-	K.P.	D	3.6	0.45	0.81	1.17	1.50	1.85	13.93	12.53	12.07	11.61	11.45
3	7	+	+	-	K.P.	E	3.2	0.40	0.73	1.02	1.33	1.64	13.36	12.19	11.36	11.11	10.96
3	7	+	+	-	K.P.	F	2.4	0.39	0.72	0.99	1.28	1.59	12.65	11.67	10.70	10.38	10.31
3	8	+	+	+	Tray	A	3.9	0.48	0.83	1.18	1.51	1.85	16.48	14.24	13.50	12.96	12.70
3	8	+	+	+	Tray	B	3.1	0.47	0.83	1.19	1.54	1.86	15.54	13.72	13.12	12.73	12.30
3	8	+	+	+	Tray	C	3.1	0.39	0.70	0.97	1.24	1.53	15.07	13.52	12.49	11.98	11.82
3	8	+	+	+	Tray	D	3.5	0.42	0.75	1.04	1.34	1.64	14.36	12.83	11.86	11.46	11.22
3	8	+	+	+	Tray	E	3.3	0.45	0.81	1.19	1.54	1.90	16.35	14.71	14.41	13.99	13.80
3	8	+	+	+	Tray	F	4.1	0.43	0.77	1.09	1.43	1.76	16.21	14.52	13.70	13.48	13.27

Appendix (Continued)

Repli-cation	Treat-ment	Drop	Vibrate	Compress	Package	Position	Injury Score	% CO_2 Hr. 1	% CO_2 Hr. 2	% CO_2 Hr. 3	% CO_2 Hr. 4	% CO_2 Hr. 5	CO_2 µl/gm·hr Hr. 1	CO_2 µl/gm·hr Hr. 2	CO_2 µl/gm·hr Hr. 3	CO_2 µl/gm·hr Hr. 4	CO_2 µl/gm·hr Hr. 5
3	9	+	-	-	K.P.	A	4.1	0.51	0.90	1.30	1.76	2.08	17.06	15.05	14.49	14.72	13.91
3	9	+	-	-	K.P.	B	4.1	0.51	0.88	1.27	1.68	2.03	17.51	15.11	14.54	14.42	13.94
3	9	+	-	-	K.P.	C	3.2	0.47	0.82	1.14	1.51	1.84	16.38	14.29	13.24	13.15	12.82
3	9	+	-	-	K.P.	D	4.1	0.47	0.82	1.18	1.56	1.89	15.95	13.92	13.35	13.24	12.83
3	9	+	-	-	K.P.	E	1.8	0.37	0.65	0.89	1.14	1.42	14.51	12.75	11.64	11.18	11.14
3	9	+	-	-	K.P.	F	2.3	0.46	0.80	1.09	1.47	1.80	16.14	14.03	12.75	12.89	12.63
3	10	+	-	+	Tray	A	3.2	0.46	0.80	1.12	1.46	1.78	15.16	13.18	12.30	12.03	11.73
3	10	+	-	+	Tray	B	3.4	0.44	0.79	1.11	1.45	1.77	14.69	13.19	12.35	12.10	11.82
3	10	+	-	+	Tray	C	2.7	0.39	0.70	0.97	1.25	1.55	14.57	13.08	12.08	11.67	11.58
3	10	+	-	+	Tray	D	1.7	0.43	0.76	1.05	1.39	1.70	14.29	12.63	11.63	11.55	11.30
3	10	+	-	+	Tray	E	1.9	0.42	0.76	1.06	1.38	1.72	12.90	11.67	10.85	10.60	10.57
3	10	+	-	+	Tray	F	1.7	0.39	0.69	0.94	1.24	1.53	13.61	12.04	10.93	10.82	10.68
3	11	+	+	-	Tray	A	3.1	0.45	0.79	1.12	1.46	1.80	16.21	14.23	13.45	13.15	12.97
3	11	+	+	-	Tray	B	2.7	0.42	0.75	1.05	1.38	1.70	15.28	13.64	12.73	12.55	12.37
3	11	+	+	-	Tray	C	3.1	0.48	0.82	1.16	1.54	1.88	16.92	14.46	13.63	13.57	13.26
3	11	+	+	-	Tray	D	3.2	0.44	0.78	1.09	1.45	1.79	15.90	14.10	13.13	13.10	12.94
3	11	+	+	-	Tray	E	3.5	0.49	0.87	1.27	1.68	2.03	17.98	15.97	15.54	15.42	14.90
3	11	+	+	-	Tray	F	4.0	0.51	0.89	1.33	1.76	2.15	17.75	15.49	15.43	15.32	14.97
3	12	+	+	+	K.P.	A	3.7	0.51	0.90	1.34	1.78	2.16	17.20	15.17	15.06	15.00	14.67
3	12	+	+	+	K.P.	B	4.0	0.46	0.83	1.19	1.59	1.96	16.00	14.44	13.80	13.83	13.64
3	12	+	+	+	K.P.	C	3.9	0.41	0.73	1.05	1.38	1.72	15.23	13.56	13.00	12.82	12.78
3	12	+	+	+	K.P.	D	4.3	0.56	0.98	1.46	1.90	2.29	18.88	16.52	16.40	16.01	15.44
3	12	+	+	+	K.P.	E	3.2	0.44	0.78	1.12	1.49	1.84	15.50	13.74	13.15	13.12	12.97
3	12	+	+	+	K.P.	F	3.3	0.46	0.82	1.16	1.53	1.88	16.32	14.55	13.72	13.57	13.34
3	13	-	-	-	Tray	A	1.1	0.28	0.50	0.72	0.89	1.08	11.01	09.83	09.44	08.75	08.49
3	13	-	-	-	Tray	B	1.6	0.39	0.67	0.92	1.18	1.45	13.80	11.85	10.85	10.44	10.26
3	13	-	-	-	Tray	C	1.3	0.37	0.60	0.80	0.98	1.20	14.30	11.59	10.31	09.47	09.28
3	13	-	-	-	Tray	D	1.4	0.41	0.71	0.99	1.30	1.58	14.24	12.31	11.46	11.29	10.97
3	13	-	-	-	Tray	E	1.1	0.34	0.61	0.84	1.08	1.32	12.34	11.07	10.16	09.80	09.58
3	13	-	-	-	Tray	F	1.6	0.43	0.73	1.01	1.32	1.62	14.87	12.63	11.65	11.41	11.21

Appendix (Continued)

Repli- cation	Treat- ment	Drop	Vibrate	Compress	Package	Position	Injury Score	% CO_2 Hr. 1	Hr. 2	Hr. 3	Hr. 4	Hr. 5	CO_2 µl/gm·hr Hr. 1	Hr. 2	Hr. 3	Hr. 4	Hr. 5
3	14	-	-	+	K.P.	A	1.8	0.41	0.74	1.04	1.38	1.70	14.63	13.21	12.37	12.31	12.13
3	14	-	-	+	K.P.	B	2.0	0.46	0.82	1.18	1.57	1.93	16.07	14.33	13.74	13.71	13.49
3	14	-	-	+	K.P.	C	1.6	0.44	0.77	1.07	1.41	1.74	15.21	13.31	12.33	12.18	12.03
3	14	-	-	+	K.P.	D	3.2	0.44	0.80	1.13	1.50	1.85	15.93	14.48	13.63	13.57	13.39
3	14	-	-	+	K.P.	E	2.3	0.48	0.84	1.20	1.58	1.88	15.44	14.39	13.70	13.53	12.88
3	14	-	-	+	K.P.	F	2.4	0.43	0.77	1.09	1.46	1.80	15.78	14.13	13.34	13.40	13.21
3	15	-	+	-	K.P.	A	1.8	0.42	0.72	1.02	1.35	1.67	15.07	12.92	12.20	12.11	11.99
3	15	-	+	-	K.P.	B	1.9	0.48	0.81	1.15	1.55	1.90	16.31	13.76	13.03	13.17	12.91
3	15	-	+	-	K.P.	C	2.2	0.44	0.76	1.05	1.41	1.74	16.50	14.25	13.12	13.22	13.05
3	15	-	+	-	K.P.	D	2.3	0.42	0.74	1.03	1.39	1.72	15.35	13.52	12.55	12.70	12.57
3	15	-	+	-	K.P.	E	2.0	0.45	0.79	1.11	1.49	1.85	16.25	14.27	13.37	13.36	13.37
3	15	-	+	-	K.P.	F	1.8	0.43	0.75	1.08	1.44	1.78	15.69	13.68	13.14	13.14	12.99
3	16	-	+	+	Tray	A	1.5	0.41	0.71	1.02	1.32	1.66	13.36	11.57	11.08	10.76	10.82
3	16	-	+	+	Tray	B	1.4	0.44	0.76	1.07	1.41	1.74	14.96	12.92	12.12	11.98	11.83
3	16	-	+	+	Tray	C	2.1	0.42	0.74	1.03	1.36	1.68	14.47	12.75	11.83	11.72	11.58
3	16	-	+	+	Tray	D	2.1	0.36	0.64	0.89	1.14	1.44	13.44	11.95	11.07	10.64	10.75
3	16	-	+	+	Tray	E	3.8	0.49	0.86	1.29	1.70	2.09	16.46	14.45	14.45	14.28	14.04
3	16	-	+	+	Tray	F	4.2	0.55	0.97	1.48	1.94	2.36	18.53	16.34	16.62	16.34	15.90
4	1	-	-	-	K.P.	A	1.4	0.45	0.80	1.11	1.48	1.80	13.73	12.20	11.29	11.29	10.98
4	1	-	-	-	K.P.	B	1.5	0.36	0.67	0.92	1.20	1.48	12.82	11.93	10.92	10.68	10.54
4	1	-	-	-	K.P.	C	1.4	0.35	0.67	0.92	1.20	1.48	11.85	11.34	10.38	10.16	10.02
4	1	-	-	-	K.P.	D	1.5	0.42	0.76	1.04	1.40	1.72	13.76	12.45	11.36	11.47	11.27
4	1	-	-	-	K.P.	E	1.5	0.40	0.74	1.01	1.34	1.65	13.63	12.60	11.47	11.41	11.24
4	1	-	-	-	K.P.	F	1.5	0.38	0.69	0.95	1.25	1.55	13.36	12.13	11.14	10.99	10.90
4	2	-	-	+	Tray	A	1.6	0.43	0.77	1.09	1.45	1.80	14.74	13.20	12.45	12.42	12.34
4	2	-	-	+	Tray	B	1.9	0.45	0.80	1.12	1.49	1.83	15.53	13.81	12.89	12.86	12.63
4	2	-	-	+	Tray	C	1.5	0.41	0.73	1.01	1.34	1.66	14.60	12.99	11.99	11.93	11.82
4	2	-	-	+	Tray	D	1.6	0.47	0.85	1.33	1.63	1.98	15.45	13.97	13.36	13.39	13.01
4	2	-	-	+	Tray	E	1.3	0.36	0.66	0.90	1.18	1.45	13.91	12.75	11.59	11.40	11.21
4	2	-	-	+	Tray	F	1.6	0.36	0.66	0.93	1.22	1.52	14.17	12.99	12.20	12.00	11.96

Appendix (Continued)

Repli-cation	Treat-ment	Drop	Vibrate	Compress	Package	Position	Injury Score	% CO_2 Hr. 1	Hr. 2	Hr. 3	Hr. 4	Hr. 5	CO_2 µl/gm·hr Hr. 1	Hr. 2	Hr. 3	Hr. 4	Hr. 5
4	3	-	+	-	Tray	A	2.2	0.48	0.86	1.27	1.68	2.07	14.67	13.15	12.94	12.84	12.66
4	3	-	+	-	Tray	B	1.9	0.48	0.85	1.22	1.62	1.97	15.71	13.91	13.31	13.26	12.90
4	3	-	+	-	Tray	C	2.7	0.50	0.87	1.27	1.70	2.06	16.17	14.07	13.69	13.75	13.33
4	3	-	+	-	Tray	D	2.1	0.44	0.81	1.13	1.54	1.88	14.51	13.35	12.42	12.69	12.40
4	3	-	+	-	Tray	E	3.8	0.46	0.86	1.27	1.72	2.11	16.39	15.32	15.08	15.32	15.04
4	3	-	+	-	Tray	F	4.7	0.58	1.07	1.65	2.16	2.59	19.82	18.29	18.80	18.46	17.70
4	4	-	+	+	K.P.	A	2.4	0.45	0.81	1.18	1.58	1.92	15.30	13.77	13.38	13.43	13.06
4	4	-	+	+	K.P.	B	2.9	0.48	0.86	1.25	1.66	2.02	16.09	14.42	13.97	13.91	13.55
4	4	-	+	+	K.P.	C	2.3	0.41	0.76	1.08	1.45	1.79	14.24	13.18	12.50	12.59	12.43
4	4	-	+	+	K.P.	D	3.0	0.43	0.79	1.13	1.53	1.89	16.59	15.24	14.53	14.76	14.58
4	4	-	+	+	K.P.	E	2.3	0.41	0.78	1.12	1.50	1.86	15.07	14.33	13.72	13.78	13.67
4	4	-	+	+	K.P.	F	3.1	0.43	0.80	1.16	1.52	1.87	15.04	13.99	13.52	13.29	13.08
4	5	+	-	-	Tray	A	2.8	0.44	0.79	1.11	1.48	1.80	16.06	14.42	13.51	13.51	13.14
4	5	+	-	-	Tray	B	3.4	0.44	0.79	1.11	1.48	1.80	15.55	13.96	13.08	13.08	12.73
4	5	+	-	-	Tray	C	2.2	0.48	0.82	1.15	1.53	1.84	16.88	14.42	13.48	13.45	12.94
4	5	+	-	-	Tray	D	2.3	0.43	0.78	1.08	1.44	1.77	14.63	13.27	12.25	12.25	12.04
4	5	+	-	-	Tray	E	1.5	0.44	0.79	1.10	1.45	1.79	15.13	13.59	12.61	12.47	12.31
4	5	+	-	-	Tray	F	2.0	0.41	0.74	1.01	1.33	1.64	14.93	13.47	12.26	12.11	11.94
4	6	+	-	+	K.P.	A	4.3	0.46	0.82	1.20	1.59	1.94	16.68	14.87	14.51	14.42	14.07
4	6	+	-	+	K.P.	B	4.6	0.56	1.00	1.49	1.95	2.32	18.32	16.36	16.25	15.95	15.18
4	6	+	-	+	K.P.	C	3.4	0.45	0.82	1.19	1.58	1.92	16.29	14.85	14.36	14.30	13.90
4	6	+	-	+	K.P.	D	4.4	0.40	0.73	1.02	1.35	1.65	13.94	12.72	11.85	11.76	11.50
4	6	+	-	+	K.P.	E	3.2	0.47	0.82	1.17	1.54	1.88	15.46	13.49	12.83	12.67	12.37
4	6	+	-	+	K.P.	F	3.1	0.47	0.84	1.20	1.59	1.94	15.12	13.51	12.87	12.79	12.48
4	7	+	+	-	K.P.	A	4.3	0.52	0.94	1.40	1.84	2.20	18.18	16.43	16.31	16.08	15.38
4	7	+	+	-	K.P.	B	4.3	0.51	0.91	1.34	1.78	2.15	17.13	15.28	15.00	14.95	14.44
4	7	+	+	-	K.P.	C	4.3	0.49	0.89	1.30	1.74	2.10	17.35	15.76	15.34	15.40	14.87
4	7	+	+	-	K.P.	D	4.0	0.51	0.93	1.39	1.85	2.23	17.21	15.70	15.64	15.61	15.05
4	7	+	+	-	K.P.	E	2.8	0.41	0.73	1.02	1.35	1.67	15.51	13.81	12.86	12.77	12.64
4	7	+	+	-	K.P.	F	3.0	0.46	0.85	1.21	1.62	1.98	16.75	15.47	14.68	14.74	14.42

Appendix (Continued)

Repli-cation	Treat-ment	Drop	Vibrate	Compress	Package	Position	Injury Score	% CO_2 Hr. 1	% CO_2 Hr. 2	% CO_2 Hr. 3	% CO_2 Hr. 4	% CO_2 Hr. 5	CO_2 µl/gm·hr Hr. 1	CO_2 µl/gm·hr Hr. 2	CO_2 µl/gm·hr Hr. 3	CO_2 µl/gm·hr Hr. 4	CO_2 µl/gm·hr Hr. 5
4	8	+	+	+	Tray	A	4.0	0.45	0.81	1.15	1.53	1.86	17.38	15.64	14.81	14.77	14.37
4	8	+	+	+	Tray	B	3.1	0.46	0.82	1.16	1.53	1.85	17.41	15.52	14.64	14.48	14.01
4	8	+	+	+	Tray	C	2.7	0.49	0.88	1.25	1.66	2.00	16.12	14.47	13.70	13.65	13.16
4	8	+	+	+	Tray	D	2.7	0.43	0.78	1.09	1.46	1.77	15.75	14.29	13.31	13.37	12.97
4	8	+	+	+	Tray	E	4.4	0.54	0.94	1.39	1.84	2.21	19.43	16.91	16.67	16.55	15.90
4	8	+	+	+	Tray	F	3.6	0.55	0.99	1.49	1.97	2.35	19.56	17.60	17.66	17.51	16.71
4	9	+	-	-	K.P.	A	3.8	0.51	0.90	1.29	1.64	2.05	17.10	15.09	14.42	13.75	13.75
4	9	+	-	-	K.P.	B	4.0	0.54	0.94	1.32	1.68	2.10	18.28	15.91	14.89	14.22	14.22
4	9	+	-	-	K.P.	C	3.8	0.46	0.83	1.17	1.51	1.88	16.28	14.69	13.80	13.36	13.31
4	9	+	-	-	K.P.	D	4.3	0.51	0.90	1.28	1.65	2.00	16.87	14.88	14.11	13.64	13.23
4	9	+	-	-	K.P.	E	2.5	0.42	0.75	1.01	1.36	1.70	14.96	13.36	12.00	12.11	12.11
4	9	+	-	-	K.P.	F	2.8	0.50	0.90	1.30	1.67	2.05	15.97	14.37	13.84	13.33	13.09
4	10	+	-	+	Tray	A	3.3	0.46	0.81	1.12	1.48	1.83	15.72	13.84	12.76	12.65	12.51
4	10	+	-	+	Tray	B	2.6	0.42	0.74	1.00	1.32	1.67	15.75	13.87	12.50	12.37	12.52
4	10	+	-	+	Tray	C	2.7	0.45	0.79	1.11	1.46	1.82	15.42	13.54	12.68	12.51	12.48
4	10	+	-	+	Tray	D	2.9	0.52	0.89	1.25	1.65	2.03	16.84	14.41	13.39	13.36	13.15
4	10	+	-	+	Tray	E	2.2	0.46	0.83	1.16	1.51	1.87	14.97	13.50	12.58	12.28	12.17
4	10	+	-	+	Tray	F	1.9	0.43	0.77	1.05	1.38	1.73	14.36	12.86	11.69	11.52	11.56
4	11	+	+	-	Tray	A	3.5	0.47	0.85	1.19	1.57	1.93	16.46	14.89	13.89	13.75	13.52
4	11	+	+	-	Tray	B	2.9	0.48	0.82	1.13	1.49	1.82	16.55	14.13	12.98	12.84	12.55
4	11	+	+	-	Tray	C	2.5	0.38	0.69	0.91	1.22	1.54	13.98	12.70	11.16	11.22	11.33
4	11	+	+	-	Tray	D	2.4	0.41	0.74	1.00	1.33	1.66	14.79	13.35	12.02	11.99	11.97
4	11	+	+	-	Tray	E	4.3	0.55	1.03	1.49	1.91	2.30	18.16	17.00	16.40	15.76	15.19
4	11	+	+	-	Tray	F	4.7	0.53	0.96	1.39	1.80	2.20	18.95	17.16	16.56	16.09	15.73
4	12	+	+	+	K.P.	A	4.1	0.48	0.87	1.22	1.60	1.94	17.02	15.43	14.42	14.19	13.76
4	12	+	+	+	K.P.	B	4.4	0.46	0.84	1.20	1.57	1.94	16.39	14.97	14.26	13.99	13.83
4	12	+	+	+	K.P.	C	3.6	0.40	0.70	0.91	1.20	1.54	15.43	13.50	11.70	11.57	11.88
4	12	+	+	+	K.P.	D	3.9	0.47	0.86	1.23	1.61	1.97	15.32	14.02	13.36	13.12	12.84
4	12	+	+	+	K.P.	E	3.1	0.41	0.70	0.95	1.28	1.61	15.14	12.92	11.69	11.82	11.89
4	12	+	+	+	K.P.	F	3.5	0.52	0.92	1.31	1.69	2.08	16.96	15.01	14.25	13.78	13.57

Appendix (Continued)

Repli- cation	Treat- ment	Drop	Vibrate	Compress	Package	Position	Injury Score	% CO_2 Hr. 1	Hr. 2	Hr. 3	Hr. 4	Hr. 5	CO_2 µl/gm·hr Hr. 1	Hr. 2	Hr. 3	Hr. 4	Hr. 5
4	13	-	-	-	Tray	A	1.5	0.42	0.73	0.97	1.27	1.62	15.50	13.47	11.93	11.72	11.96
4	13	-	-	-	Tray	B	1.2	0.39	0.69	0.90	1.19	1.53	14.03	12.41	10.79	10.70	11.01
4	13	-	-	-	Tray	C	1.8	0.41	0.70	0.96	1.25	1.60	13.70	11.69	10.69	10.44	10.69
4	13	-	-	-	Tray	D	1.2	0.41	0.71	0.96	1.27	1.60	13.74	11.90	10.73	10.64	10.73
4	13	-	-	-	Tray	E	1.3	0.42	0.75	1.02	1.35	1.71	14.22	12.69	11.51	11.42	11.58
4	13	-	-	-	Tray	F	1.4	0.41	0.72	0.98	1.29	1.63	13.77	12.09	10.97	10.83	10.95
4	14	-	-	+	K.P.	A	2.4	0.47	0.81	1.12	1.47	1.83	14.03	12.09	11.14	10.97	10.92
4	14	-	-	+	K.P.	B	2.7	0.41	0.69	0.93	1.22	1.58	14.55	12.24	11.00	10.82	11.21
4	14	-	-	+	K.P.	C	2.0	0.39	0.68	0.90	1.19	1.53	14.09	12.28	10.84	10.75	11.05
4	14	-	-	+	K.P.	D	3.1	0.43	0.74	0.99	1.33	1.68	15.04	12.94	11.54	11.63	10.41
4	14	-	-	+	K.P.	E	2.8	0.50	0.87	1.28	1.66	2.04	16.87	14.67	14.39	14.00	13.76
4	14	-	-	+	K.P.	F	3.2	0.61	1.09	1.54	1.93	2.33	19.83	17.71	16.68	15.68	15.15
4	15	-	+	-	K.P.	A	1.8	0.47	0.83	1.16	1.51	1.90	14.59	12.88	12.00	11.72	11.79
4	15	-	+	-	K.P.	B	1.8	0.38	0.67	0.89	1.17	1.49	12.52	11.04	09.78	09.64	09.82
4	15	-	+	-	K.P.	C	1.9	0.38	0.69	0.90	1.21	1.55	13.48	12.24	10.64	10.73	11.00
4	15	-	+	-	K.P.	D	1.5	0.35	0.65	0.83	1.11	1.44	12.26	11.38	09.69	09.72	10.19
4	15	-	+	-	K.P.	E	2.4	0.43	0.76	1.07	1.41	1.77	14.71	13.00	12.20	12.06	12.11
4	15	-	+	-	K.P.	F	2.1	0.41	0.72	0.99	1.32	1.66	14.26	12.52	11.47	11.48	11.54
4	16	-	+	+	Tray	A	1.7	0.39	0.70	0.93	1.23	1.57	13.57	12.18	10.79	10.70	10.92
4	16	-	+	+	Tray	B	1.8	0.39	0.71	0.95	1.24	1.58	13.64	12.41	11.07	10.84	11.05
4	16	-	+	+	Tray	C	2.2	0.42	0.73	0.99	1.33	1.67	14.13	12.28	11.11	11.19	11.24
4	16	-	+	+	Tray	D	2.5	0.35	0.63	0.81	1.09	1.39	12.78	11.50	09.86	09.95	10.15
4	16	-	+	+	Tray	E	4.3	0.51	0.92	1.32	1.70	2.08	17.62	15.89	15.20	14.68	14.37
4	16	-	+	+	Tray	F	4.0	0.50	0.92	1.34	1.74	2.10	18.33	16.87	16.38	15.95	15.40