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COMPARISON OF FIELD TESTING AND LABORATORY TESTING FOR TOMATOES IN DISTRIBUTION PACKAGES IN BRAZIL

By

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ABSTRACT

COMPARISON OF FIELD TESTING AND LABORATORY TESTING FOR TOMATOES IN DISTRIBUTION PACKAGES IN BRAZIL

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It is estimated that 10 to 30 % of fresh tomatoes are lost in the distribution system in Brazil as a result of inadequate packaging and transportation. The use of simulated transit tests would be valuable in designing or comparing shipping containers that would give maximum protection from postharvest damage.

Tomatoes (variety Santa Cruz, type AA) were packaged in corrugated and wooden shipping containers. Six boxes in a stack were submitted to actual transport and laboratory testing (vibration), for 100 and 500 km distance. Tomatoes in the boxes at top, middle, and bottom layers were evaluated for color, firmness, soluble solids, and mechanical injury.

There was no significant difference at 99 % confidence between transport and laboratory testing. Wooden boxes resulted in 100 and 50 % higher mechanical damage compared to corrugated boxes for 100 and 500 km, respectively. Boxes in top layers yielded higher injury scores followed by bottom (corrugated box) and middle layers.

This thesis is dedicated to

my husband	Aylton
my children	Gustavo and Thiago
my mother	Neurides

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LIST OF SYMBOLS AND ABBREVIATIONS

^{o}C	degree centigrade
CO_2	carbon dioxide
cm	centimeter
ft	feet
ft^2	square feet
g	gravity
ha	hectare
Hz	hertz
in	inch
km	kilometer
lb	pound
r.h.	relative humidity

CHAPTER 1

INTRODUCTION

Tomatoes for market represent a very important crop in Brazil, mainly in the State of Sao Paulo. In 1983, the total amount of fresh tomatoes sold in Brazil was 861.251 tons, 54.4 % produced in the State of Sao Paulo (Instituto de Economia Agricola, 1984).

Transport of tomatoes from farm to urban centers is accomplished by truck. Tomatoes are usually packed in wooden boxes called "caixa K", containing approximately 50.8 lb of product.

As a result of inadequate packaging and transportation practices it is estimated that 10 to 30 % of fresh tomatoes are lost in the physical distribution system (from harvest to consumption) due to mechanical damage. (Stokes, 1975; Madi, 1977).

To date, in Brazil, little has been published regarding transportation injury of fresh fruits and vegetables associated with the packaging containers (Madi, 1977). The specification of packaging for fresh produce has been done arbitrarily or based on questionable results from transport field tests. Such tests require a long time and involve high costs.

The use of simulated transit tests would be invaluable in designing or comparing shipping containers that would give maximum protection from postharvest damage. The hazards of distribution are many and varied, and it is usually difficult or impossible to predict exactly what a product-package system is going to encounter, but a package system can be designed to minimize the damage caused in distribution. (Brandenburg and Lee, 1984). Subjection of produce containers to small-scaled simulated transit tests would provide rapid, accurate, less expensive information regarding produce injury, useful for an appropriate package design.

Since little is known, in Brazil, about the nature and cause of mechanical damage of fresh fruit and vegetables and the effectiveness of simulated transit tests, the purpose of the research was: 1. to examine the effect of container type and location in the stack on the amount of injury of fresh tomatoes through transport field testing, 2. to compare the transport field test with laboratory tests (vibration) looking for an easy, rapid, and more adequate method for determining the protective characteristics of shipping containers.

CHAPTER 2

LITERATURE REVIEW

Existing System for Handling and Transport of Fresh Tomatoes in Brazil

Tomatoes are an important crop in Brazil, mainly in the State of Sao Paulo, which is the biggest producer for both intra- and interstate demand. Using alternative seasons of harvesting in different regions makes it possible for tomatoes to be found in the market during the entire year. (In 1983, the area planted in Brazil was 48,155 ha, with a production of 1.547 million tons. About 56 % of the total, or 861,251 tons, were marketed as fresh produce. 54.4 % of the fresh tomato was from the State of Sao Paulo). The harvest is done by hand and with the help of baskets and pushcarts.

After harvesting, the tomatoes are sent to covered sheds which have good air circulation for removal of surface moisture. They are spread in thin layers on the shelves or on the floor, where they will remain from two to twenty four hours. The fruit should be free of residual pesticides and dirt, and this cleaning is done by hand later.

After removal of dirt and damaged fruit, the sorting is done according to a grading system. Table 1 shows the grades

TABLE 1
Maximum Defects Permissible in a Box According to Tomato Types (Maximum Acceptable Number)

Tomato Defects	Grades			
	Extra AA	Extra A	Extra	Special
Deteriorated fruit	0	0	0	2
Fruit not well formed	0	2	5	9
Fruit with yellow color	3	5	7	12
Fruit with mixture in colors	3	5	10	15
Soft fruit	0	1	3	5
Fruit with color spots	0	2	3	5
Fruit with cracks	2	5	8	12
Fruit with mechanical damage	3	5	8	12

Reg no 76 "Ministerio da Agricultura" 1975.

and their maximum permissible defects in the boxes, according to regulation number 76 of February 25, 1975 of the "Ministerio da Agricultura do Brasil," Article number 8.

After sorting and grading the tomatoes are packed in wooden boxes called "caixa K." These boxes have internal dimensions of, length 19.5 in, width 13.8 in, depth 9.0 in, with tolerances of $\pm$ 0.2 in. The weight of the empty box varies from 6.6 to 8.8 lb without covers. The top slat cover weighs from 1.1 to 2.2 lb. 48.6 to 50.8 lb of tomatoes are put into each box.

The wooden boxes ("caixa K") are used not only in the State of Sao Paulo but throughout Brazil. The boxes are assembled manually and most handling is done by hand. There are some lift trucks used to transport the boxes from one place to another, but loading and unloading is all done by hand.

One of the disadvantages cited regarding the use of "caixa K," concerns mechanical damage caused to the fruit in this box during handling and transportation. Madi (1977) reported that for 100 and 400 km (62.5 and 250 miles) distances, the losses found for "caixa K" were 10.6 % and 14.7 %, respectively. The major cause for these losses was mechanical damage caused by overfilling and rough surfaces of the boxes. Stokes (1975) reported damage levels of 20 30 %.

Unfortunately, little has been published in this area in Brazil. Until now, the packaging specifications for fresh fruits and vegetables has been done arbitrarily, normally using traditional containers (wooden boxes). The introduction of new containers in the market requires laborious work. For approval, new containers are tested through transport field tests which involves a long time and high costs.

Evaluation of in-Transit Mechanical Injury of Fruits and Vegetables

There are at least three major approaches to evaluating the performance of shipping containers to protect produce from in-transit injury:

1. the use of commercial scale transport tests,
2. reproduction of damage observed in the transportation environment by simulated transport tests, and
3. use of established test methods at levels representative of the distribution environment.

The first one is laborious, and it may take weeks to obtain the necessary permits and to arrange for loading and transportation. Normally transport field tests involves several persons and the material and travel are costly. In addition, the nature of the impacts or vibrations that produces any particular type of damage is uncertain. The severity of the treatment is unknown and is not repeatable, depending on the suspension systems used in the trucks, roadbed conditions, etc.

Test methods at levels representative of the distribution environment have been designated to evaluate the performance of a packaging system when it is subjected to the vibration or impact conditions existing in the distribution. If a packaging system fails these tests it should be redesigned. However, if it passes the tests there is no guarantee that the packaged product will survive the shipment ((Brandenburg and Lee, 1984). The lack of knowledge of the distribution environment is also a disadvantage of approach 3.

It seems that a more promising approach is to subject the produce containers to simulated transit tests. Most of the work done in developed countries on in-transit mechanical injury of fruits and vegetables has used simulated transit testing. The emphasis in these tests is not on reproduction of the transportation environment, but the reproduction of their effects (Kawano et al., 1984); Iwamoto et al., 1979 a; Iwamoto et al., 1979 b; Iwamoto et al., 1984; O'Brien et al., 1963; O'Brien et al., 1965; Guillou et al.; 1962; Olorunda and Tung, 1985).

There are three main sources of mechanical damage of fruits and vegetables during distribution: impact by dropping, compression, and vibration (Brown, 1985; Olorunda and Tung, 1985; Goff and Twede, 1979; Guillou et al.; 1962). Impact damage usually results from dropping the container, vertical motion of the vehicle floor or sudden stops.

Fruits within containers are subjected to compression bruises when a shipping container collapses and the fruit is required to carry the weight from other containers. Compression damage can be caused also by other fruit where bin depth is excessive for the particular commodity, or where packages are stacked too high. There is no need for physical movement for compression damage to occur.

Vibration damage is mainly associated with transportation and results from repeated and prolonged vibration of the product. In-transit mechanical injuries such as abrasion, and cell rupture were the result of accumulation of damage caused by vibrating forces during transport (Kawano et al., 1984).

Brown (1985) subjecting fresh apples to various forces (dropping, compression, and/or vibration) found that dropping had the greatest effect on visible damage but vibration resulted in the largest increase in CO_2 production. Klein (1983) demonstrated that excess CO_2 production after submitting fresh apples to impact tests came exclusively from bruised tissue.

Goff and Twede (1979) reported that vibration may cause more bruising in fresh apples than dropping, mainly due to resonance. Sommer (1957), subjecting naked pears to simulated transit tests, observed that most of damage resulted from vibration and that the most extensive damage was in the top layer of the fruit. The same effect was observed for peaches and tomatoes (O'Brien et al., 1963), lettuce and strawberries (Kawano et al., 1984), and for apples (Goff and Twede, 1979; Brown, 1985).

Since, in actual transportation, the boxes are usually stacked only 6 to 7 tiers high on the loading bed, it is more important for designing a suitable box from the standpoint of protecting the products to know the vibrating characteristics of multi-stacked boxes than the compressive strength of an individual box (Kawano and Iwamoto, 1979). According to Kawano and Iwamoto, (1979), if the vibrating acceleration acting on an individual box in the stack is known the damage of the product can be predicted.

Vibration in Transit

Vibration frequencies encountered in transportation are primarily below 25 Hz, with 3-15 Hz being most prevalent (Goff and Twede, 1979). According to Godshall (1968) vibrations inputs are usually from 0.2 to 0.8 g at 3 to 10 Hz for rail transportation and from 0.1 to 0.8 g at 3 to 20 Hz for trucks. Iwamoto et al., (1979b) grouped the vibrating frequency, for trucks on paved roads into three classes 2-5 Hz, 10-14 Hz and 20-24 Hz. The lower two components were observed at all speeds of the truck.

O'Brien et al., (1963), in a study of the causes of fruit damage, reported that frequencies measured on fruit transport trucks can range from 3 to 20 Hz with accelerations less than 0.1 g to slightly higher than lg.

Vibration Simulated Testing

There are several different vibrators for transit simulation on the market. The emphasis is not on the reproduction the complete range of vibration amplitudes and frequencies of trucks, but to simulated conditions that cause a similar degree of damage in case of actual transport.

O'Brien et al. (1963) observed that by subjecting cling peaches to 10 minutes vibration under an acceleration of 0.25 g at a frequency of 10 Hz it was possible to duplicate in a laboratory the total amount of bruising observed after 100 miles of travel.

Guillou et al. (1962) reported that a test of 9.5 Hz at 1.1 g for 30 minutes satisfactorily reproduced damage in the laboratory in shipping containers. Goff and Twede (1979) allowed fresh apples in corrugated boxes to vibrate for 30 minutes, with an input acceleration of 0.25 g, at resonant frequency (4-6 Hz), to reproduce bruising resulting from actual shipment of 60 miles.

According to Iwamoto et al. (1979 b), in-transit mechanical injury of fruit and vegetables could be estimated by combinations of the vibrating acceleration level occurring at the bottom of the box and the S-N endurance curve which was useful for fatigue analysis of metallic materials. An S-N curve represents the relationship between the amplitude of stress (S) and number of repetitions (N) which is permitted before the product reaches a fatigue failure point. In case of transport, the stress to the product can be thought to correspond to the vibrating acceleration (G) during transport. Kawano et al. (1984) using this procedure calculated the equivalent vibrating acceleration which causes a similar degree of damage in the simulated transport test for various products, using a frequency of 7 Hz.

ASTM D-4169 (1984) recommends testing packages from 5-15 minutes (depending on assurance level chosen) at the resonant frequency of the package system at 0.5 g to simulate truck transport and at 0.25 g to simulate railroad transport at each possible shipping position of the container, up to four positions.

Pichler (1985) applying a sweep up and down between 5 and 100 Hz at a continuous logarithmic rate of 1 octave per minute and acceleration amplitude of 0.5 g, during 5 complete cycles, observed more bruising for fresh tomatoes in laboratory testing than the amount found in the actual transport. The same result was obtained with a frequency of 5 Hz at a constant g level of 1g, for 30 minutes. These conditions were recommended for ISO 2247 (1972) and for the BS 4826 (1974) test methods.

Olorunda (1985) reproduced the amount of damage found in transportation of fresh tomatoes in Nigeria for a distance of about 800 km (500 miles) using a single speed linear shaker, operating at 2.7 Hz, moving horizontally with an amplitude of 3.5 cm (1.38 in), during 1 minute.

CHAPTER 3

MATERIALS AND METHODS

Tomatoes (variety Santa Cruz, type extra AA) at the "pink" and "light red" stage of ripeness were obtained directly from farms in the State of Sao Paulo. Prior to each test tomatoes were randomly selected for size, color, firmness and soluble solids measurements. The initial characterization helped to eliminate bias due to possible differences in initial tomato quality.

Color was subjectively measured according to the United States Standards for Grades of Fresh Tomatoes (1975). Firmness was measured with a Fruit Pressure Penetrometer (Mod. FT 327) using a 5/16" plunger. Values were expressed in lb of pressure required to penetrate the tomato at a spot on the shoulder with the skin intact (Kearney and Coffey, 1983). Soluble solids were determined on three drops of juice from sliced segments, using a hand-held refractometer (Kearney and Coffey, 1983). The results were expressed in percentage, with correction to $20^{o}C$.

Two package types were tested: 1) wooden boxes having an internal dimension of length 19.5 in, width 13.8 in, and depth 9.0 in; and 2) full telescope design style corrugated board boxes having internal dimensions of length 19.5 in, width 14.0 in, and depth 8.7 in. The box and cover were corrugated combined board of 48/39/31/34/38 and 48/39/48 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 tomatoes were evaluated for compressive strength according to ASTM D-642 (1980), Compression Test For Shipping Containers. Corrugated board boxes were allowed to condition at approximately 65 % R.H. and 23 $\pm$ 1^{o}C for one week prior to being tested. The corrugated board material was evaluated for combined basis weight, bursting strength and edgewise compressive strength (short column). Basis weight was determined in accordance with ASTM D-646 (1980), Basis Weight of Paper and Paperboard, expressed in pounds per 1000 square feet. Bursting strength was evaluated in accordance with ASTM D-2529 (1980), Bursting Strength of Paperboard and Linerboard, the results expressed in pounds per square inch. Edgewise compression strength of corrugated board was measured on the ASTM D-2808 (1980) test method, Compressive Strength of Corrugated Fiberboard (Short Column Test), the results expressed in pounds.

Approximately 46.4 and 50.8 lb of tomatoes, without apparent bruises and defects and relatively uniform in size (diameter - 2.3 in), were packed in corrugated board and wooden boxes, respectively. All containers were filled manually.

Transport Field Testing

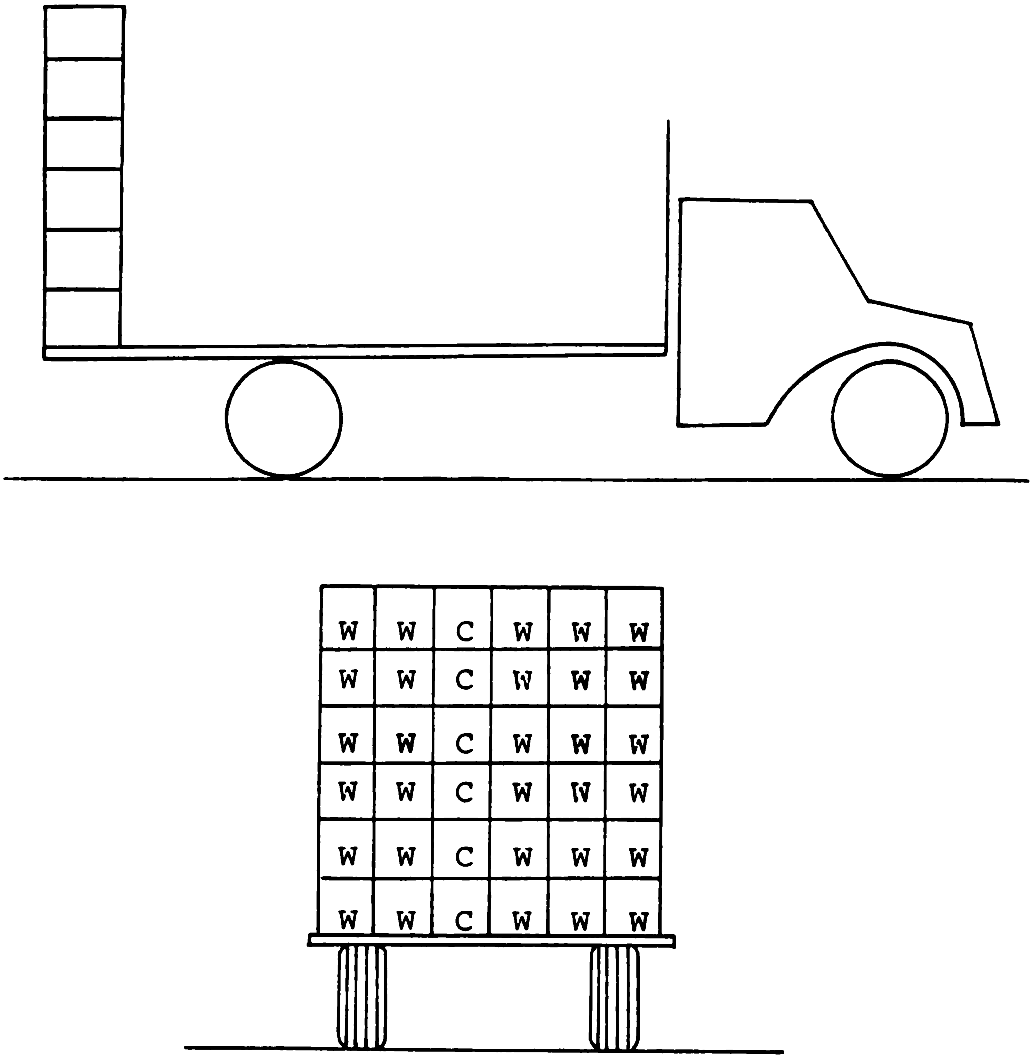
During the months of January through July, 1986, five shipping tests for tomatoes were conducted, three replications for a distance of 100 km, and two replication for 500 km.[1] Boxes for 100 km shipping test were packed at farms in Campinas and Itu and transported to Sao Paulo. For 500 km tests, boxes were packed at farms in Campinas and transported to markets in Rio de Janeiro and Curitiba. All tests were performed on asphalt roads.

Six corrugated board and six wooden boxes were used for each test. After lidding, the boxes were stacked at the rear of the truck bed, six layers high, as shown in Figure 1. It is generally accepted that this is the location were the most extensive damage will occur (Kawano et al., 1984).

Upon arrival, three corrugated boxes and two wooden boxes were selected for examination. Corrugated boxes were taken from bottom, middle, and top layers and wooden boxes from middle and top, as shown in Figure 2. Ten tomatoes were randomly selected from each box for color, firmness and soluble solids determination.

Each tomato in the three corrugated board boxes (about 540 tomatoes) and in the two wooden boxes (about 400 tomatoes) was examined for mechanical damage which was

[1] In the following pages distance will be referred only in the metric system. (100 km = 62.5 miles; 500 km = 312.5 miles)



C - Corrugated box

W - wooden box

Figure 1

Placement of Boxes on the Truck Bed for Transport Field Testing (100 and 500 km)

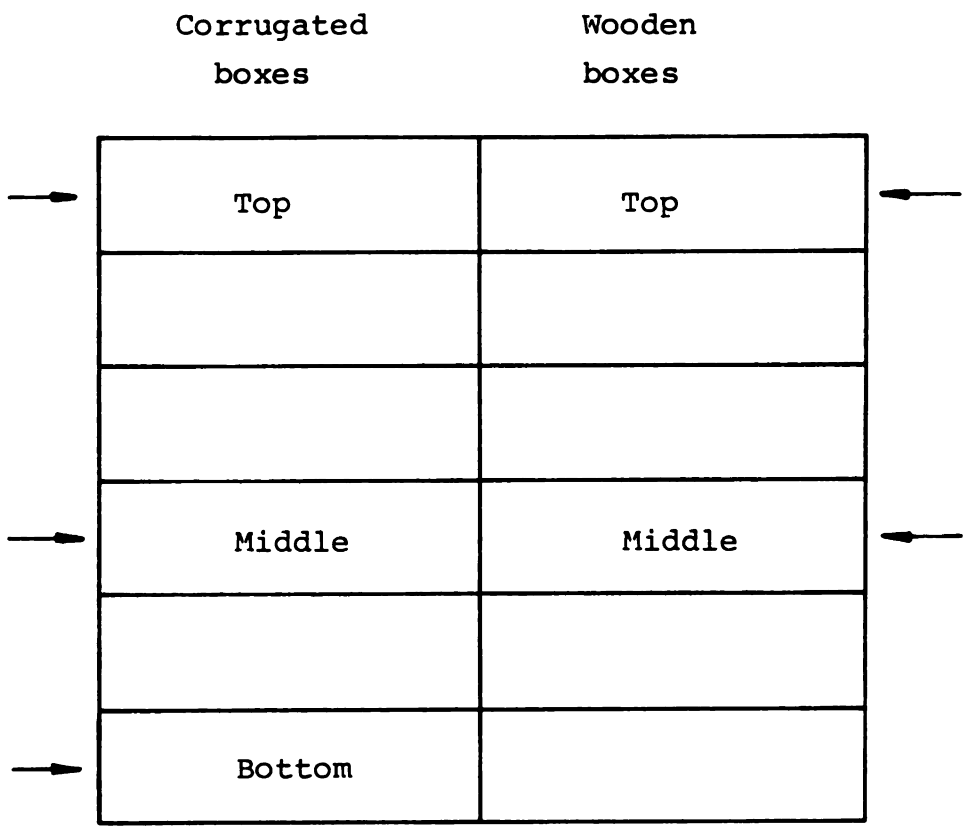


Figure 2

Diagram of Boxes Selected for Analysis

indexed for numerical value as shown in Table 2. An Equivalent Damage Index (EDI) was defined by:

E.D.I. = no damage (0) + slight (1) + moderate (2) + severe (3)

This definition permits pooling all four injury categories together for a more convenient statistical appraisal of the results.

Laboratory Testing

Tomatoes for laboratory testing were harvested from the same farms where tomatoes for transport field testing were obtained at the same stage of ripeness. Before testing, tomatoes were randomly selected for determination of size, color, firmness, and soluble solids according to the methodology previously described to minimize differences in tomato quality and assure the same quality used for transport testing.

After initial analysis, tomatoes without apparent bruises and defects and relatively uniform in size (diameter - 2.3 in), were packed in corrugated and wooden boxes as for transport field testing.

After packing, the wooden and corrugated boxes were carefully loaded in a single layer on an ITAL (Instituto de Tecnologia de Alimentos) small truck and transported to the IPT (Instituto de Pesquisa Tecnologica) in Sao Paulo, for simulated tests. IPT has the laboratory with the vibration equipment.

TABLE 2
Scale Used in Evaluating Tomato Damage

Degree of Damage	Index Value of Damage
No damage	0
Slight but noticeable. Small bruise, with diameter between 0.5"-0.75". No skin breaks	1
Moderate. Medium bruise, with diameter between 0.76"-1.00". Skin breaks. Loss of firmness. Affects market	2
Severe. Crushed and/or cracked. Loss of juice. Unmarketable	3

Simulated testing was performed on a MTS servo hydraulic vibration table (Mod. 840.03). The boxes were prevented from moving or bouncing off the table with two piece of wood which permitted free movement of the boxes vertically and approximately 0.4 in in any horizontal direction, as shown in Figure 3.

Six boxes (height equivalent to transport field testing) were stacked in a column on the vibration table and vibrated at 0.25 g through a frequency sweep at a continuous logarithmic rate of 1 octave per minute from 3 to 100 Hz and then swept back. The resonant frequencies were recorded. The treatment was applied for both corrugated and wooden boxes.

All resonant frequencies for corrugated and wooden boxes were in the range of the most prevalent vibration encountered in the transportation (3-15 Hz). For corrugated boxes resonant frequencies were found between 5-6 Hz and 14-15 Hz. For wooden boxes resonant frequencies were around 10 Hz.

The simulation test consisted of bringing the table up sinusoidally from 3 to 25 Hz at a continuous logarithmic rate of 1 octave per minute, and then sweep back to 3 Hz at a constant g level of 0.25 g, 0 to peak, for 25 minutes to simulate damage for 100 km and for 75 minutes to simulate damage for 500 km.

A total of twelve tests were performed, six for corrugated boxes and six for wooden boxes. Three repetitions

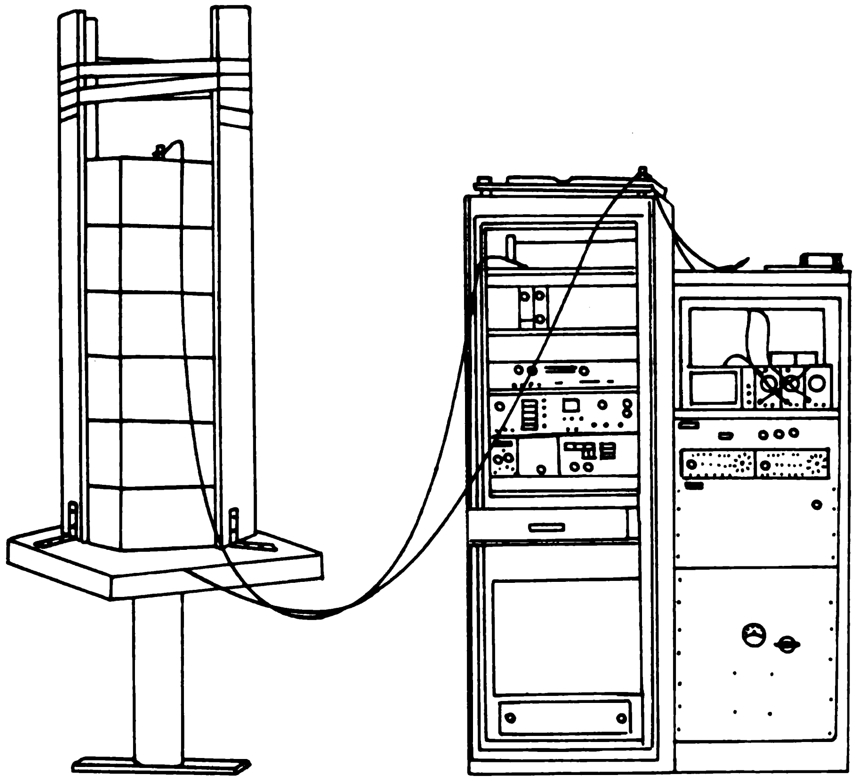


Figure 3

Boxes on the Vibration Table

were performed for 100 km and three repetitions for 500 km distances for each box type.

Tomatoes for 500 km distance simulated testing were stored in the laboratory at ambient condition (about 70 % R.U. and 23^{o}C) for 12 hours prior to testing in order to minimize differences due to maturation degree, since actual transportation took 12 hours.

Before each test tomatoes were evaluated for firmness, soluble solids, and visible damage that occurred during transportation from farms to IPT. Any mechanical damage was circled. After simulated testing the tomatoes were classified for mechanical damage according to Table 2. Boxes for damage analysis were taken from same position showed in Figure 2. After injury examination, ten tomatoes from each box were evaluated for firmness and soluble solids.

CHAPTER 4

RESULTS

The type of construction, capacities, dimensions, and compression resistance of the boxes used for tomatoes are shown in Table 3. The characteristics of corrugated board materials used for corrugated boxes are presented (Table 4).

The data for field testing and laboratory testing for corrugated boxes are in Table 5 and 6 and for wooden boxes in Table 7 and 8. Color, firmness, and soluble solids content were determined for 100 km only before testing. Due to the short distance traveled there is no difference in these parameters after testing. For 500 km, tomatoes became slightly riper after field testing with color changing from pink to light red and from light red to red (Table 6 and 8). Tomatoes for laboratory testing were conditioned 12 hours prior to testing to reach the same stage of ripeness as tomatoes after field testing.

Tomatoes showed higher decreases of firmness in the boxes at upper layer of the stacks than in the boxes at middle and bottom layers for both types of containers. For corrugated boxes (Table 6) the decrease was 2.3 lbs after transport testing and 1.3 lbs after laboratory testing. The decrease of firmness for tomatoes in the wooden boxes

TABLE 3
Specification of Boxes Used for Tomatoes in
Transport and Laboratory Testing

Type	Style	Volume (gallon)	Internal Dimensions (in)	Net weight of the box (lb)	Capacity (lb of tomato)	Compression Resistance (lb)
Corrugated box	Full Telescope	8.5	length - 19.5	2.6 ± 0.2[(1)]	46.4 ± 2.6[(1)]	1450
			width - 14.0			
			depth - 8.7			
Wooden box	Caixa "k"	8.8	length - 19.5	8.6 ± 1.1[(1)]	50.8 ± 1.1[(1)]	3304
			width - 13.8			
			depth - 9.0			

(1) Mean and standard deviation.

TABLE 4
Characteristics of Corrugated Board Used
for Corrugated Boxes

Box		Tests			
		Corrugated board Specification ($lb/1000\ ft^2$)	Combined board basis weight ($lb/1000\ ft^2$)	Bursting Strength (lb/in^2)	Compression Resistance (Short Column) (lb/in)
Corrugated					
	Body	48/39/31/34/48	207	343 ± 23[1]	51.0 ± 2.8[1]
	Cover	48/39/48	136	253 ± 23[1]	34.2 ± 3.4[1]

(1) Mean ans standard deviation.

TABLE 5
Tomato Characteristics in Transport and Laboratory
Testing in Corrugated Shipping Containers
at 100 km Distance[1].

Treatment	Position	Color	Firmness (lb)	Soluble solids (%)	Damage (%) No damage	Slight	Moderate	Severe	Equivalent Damage Index (Number)
TRANSPORT TESTING	TOP	pink to light red	12.0	4.1	85.8±1.6	12.9±1.6	1.2±1.1	0	0.15±0.03
	MIDDLE	pink to light red	12.0	4.1	87.8±3.1	9.2±2.3	1.1±0.8	0	0.11±0.04
	BOTTOM	pink to light red	12.0	4.1	87.4±2.7	12.4±2.3	0.9±0.7	0	0.14±0.03
LABORATORY TESTING	TOP	pink to light red	10.7	4.1	82.9±2.2	17.1±2.2	0	0	0.17±0.02
	MIDDLE	pink to light red	10.7	4.1	86.3±1.6	13.7±1.6	0	0	0.14±0.02
	BOTTOM	pink to light red	10.7	4.1	84.7±3.0	15.1±0.3	0.2±0.3	0	0.16±0.03

(1) Color, firmness, and soluble solids did not change after testing.

TABLE 6
Tomato Characteristics in Transport and Laboratory
Testing in Corrugated Shipping Containers
for 500 km Distance.

Treatment	Position	Color	Firmness (lb)	Soluble solids (%)	Damage (%) No damage	Slight	Moderate	Severe	Equivalent Damage Index (Number)
TRANSPORT TESTING	TOP	(1) pink to light red	12.5	4.5	59.7±1.5	36.6±0.3	3.5±2.1	0.3±0.2	0.44±0.03
		(2) light red to red	10.2	4.3					
	MIDDLE	(1) pink to light red	12.5	4.5	65.1±1.3	33.7±2.3	1.3±1.1	0	0.36±0.0
		(2) light red to red	11.4	4.2					
	BOTTOM	(1) pink to light red	12.5	4.5	58.9±7.1	39.7±4.7	1.5±1.5	0.3±0.2	0.43±0.10
		(2) light red to red	11.3	3.9					
LABORATORY TESTING	TOP	(1) light red to red	10.1	3.9	59.7±6.6	38.8±6.6	1.7±1.1	1.0±1.0	0.42±0.07
		(2) light red to red	8.8	3.4					
	MIDDLE	(1) light red to red	10.1	3.9	62.0±7.1	37.7±6.5	0.7±0.6	0	0.38±0.07
		(2) light red to red	9.8	3.6					
	BOTTOM	(1) light red to red	10.1	3.9	61.4±6.8	38.1±7.3	0.2±0.3	0	0.39±0.06
		(2) light red to red	9.6	3.8					

(1) Before testing.
(2) After testing.

TABLE 7
Tomato Characteristics in Transport and Laboratory Testing in Wooden Boxes, for 100 km Distance[1]

Treatment	Position	Color	Firmness (lb)	Soluble solids (%)	Damage (%) No damage	Slight	Moderate	Severe	Equivalent Damage Index (Number)
TRANSPORT TESTING	TOP	pink to light red	12.5	4.3	74.5±2.0	22.8±2.7	2.8±0.2	1.2±0.3	0.29±0.03
	MIDDLE	pink to light red	12.5	4.3	80.0±5.0	17.5±5.1	2.3±0.3	0	0.23±0.05
LABORATORY TESTING	TOP	pink to light red	13.7	4.3	72.0±4.0	27.0±4.7	0.8±0.3	0.4±0.3	0.29±0.03
	MIDDLE	pink to light red	13.7	4.3	75.5±2.4	24.0±2.4	0.8±0.8	0	0.25±0.03

(1) Color, firmness, and soluble solids did not change after testing.

TABLE 8
Tomato Characteristics in Transport and Laboratory Testing in Wooden Boxes, for 500 km Distance

Treatment	Position	Color	Firmness (lb)	Soluble solids (%)	Damage (%) No damage	Slight	Moderate	Severe	Equivalent Damage Index (Number)
TRANSPORT TESTING	TOP	(1) pink to light red	12.3	4.2	42.4±5.4	46.2±3.8	10.4±4.2	0.8±0.3	0.67±0.09
		(2) light red to red	10.5	4.3					
	MIDDLE	(1) pink to light red	12.3	4.2	45.1±3.7	51.9±3.8	2.5±0.8	0.6±0.1	0.57±0.04
		(2) light red to red	11.8	4.4					
LABORATORY TESTING	TOP	(1) light red to red	13.7	4.3	50.5±3.4	44.1±2.3	4.5±1.0	0.9±0.2	0.56±0.05
		(2) light red to red	12.7	4.1					
	MIDDLE	(1) light red to red	13.7	4.3	55.5±2.8	42.5±2.7	1.6±1.6	0.3±0.3	0.47±0.04
		(2) light red to red	13.0	4.3					

(1) Before testing.
(2) After testing.

(Table 8) for the upper layer was 1.8 lbs after transport testing and 1.3 lbs after laboratory testing.

The amount of injury incurred is presented in Tables 5 through 8 as the percentage of tomatoes exhibiting damage and as an equivalent damage index (Table 2). The equivalent damage index was a weighted average calculated by multiplying the number of tomatoes in each category by the index for that category, summing these totals, and dividing by the total number of tomatoes examined. The following expression was used:

$$\frac{n_1 + 2\ n_2 + 3\ n_3}{N}$$

where,

n_1 = number of tomatoes with slight damage

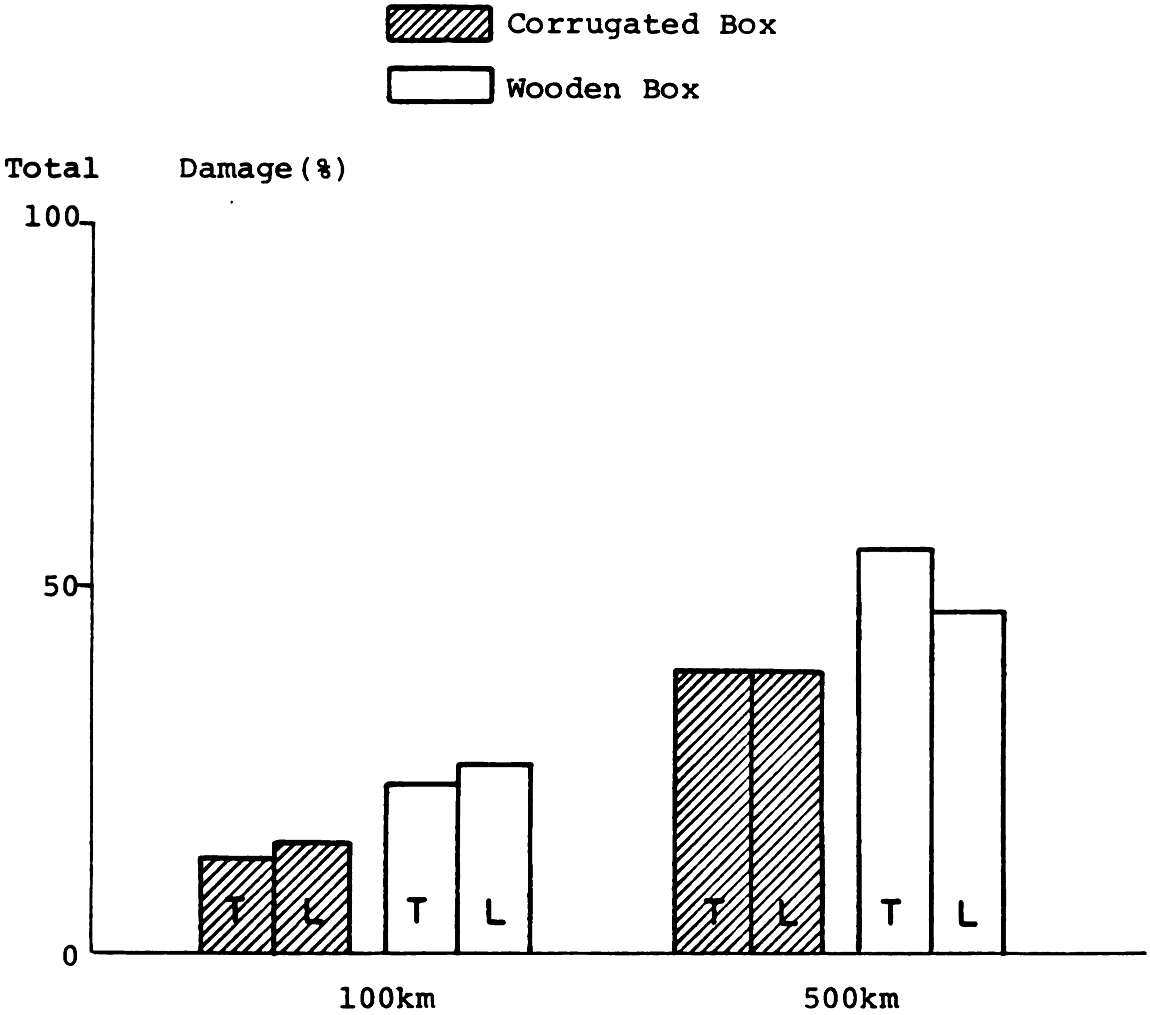
n_2 = number of tomatoes with moderate damage

n_3 = number of tomatoes with severe damage

N = total of tomatoes in the box

Results are presented as one mean of three repetitions and the associated standard deviation. The total percent of damaged tomatoes for each box type, transport and laboratory testing and distance are presented in Figure 4.

Injury score as determined by the damage index was analyzed as a four-way analysis of variance by factorial effect where all 4 variables were included (treatment, package, distance and position) (Table 9). In the following



T - Transport testing

L - Laboratory testing

Figure 4

Percentage of Total Damaged Tomatoes, Considering Box Type, Distance and Type of Test.

TABLE 9

Four-way Analysis of Variance by Factorial Effects for Injury Scores of Tomatoes Damaged in Transport and Laboratory Testing in Corrugated and Wooden Boxes

Source	DF	Anova SS	F
Treatment { Transport / Laboratory	1	0.0033	1.89^{ns}
Distance	1	0.9296	534.42**
Package	1	0.2465	141.72**
Position	1	0.0444	25.52**
Treatment x Distance	1	0.0147	8.46**
Treatment x Package	1	0.0097	5.56*
Treatment x Position	1	0.0010	0.59^{ns}
Distance x Package	1	0.0056	3.24^{ns}
Distance x Position	1	0.0030	1.74^{ns}
Package x Position	1	0.0019	1.09^{ns}
Treatment x Distance x Package	1	0.0075	4.28*
Treatment x Distance x Position	1	0.0001	0.03^{ns}
Treatment x Package x Position	1	0.0001	0.02^{ns}
Distance x Package x Position	1	0.0004	0.22^{ns}
Treatment x Distance x Package x Position	1	0.0007	0.42^{ns}
Error	32	0.0557	
Total	47		

* Significant at 5% level

** Significant at 1% level

ns not significant

discussion, a significant difference means the effects were different at the 99 % confidence level.

Four-way Analysis of Variance by Factorial Effects-Main Effects

The variables distance, package, and position had a statistically significant effect on injury scores. Distance had the greatest effect on injury scores, followed by package and position, respectively. There was no significant difference between the injury scores of the simulation and actual transport tests.

Treatment (Transport and Laboratory Testing)

There was no statistically significant difference in injury scores for transport and laboratory testing. Therefore, simulation tests in a statistical sense reproduced the same amount of damage encountered in actual transport testing, for fresh tomatoes.

Distance

Distance had the highest significant effect on injury scores. Injury scores were significantly higher by 2 or 3 times for 500 km than for 100 km, depending on package type.

Package

Injury scores were significantly higher for tomatoes packed in wooden boxes than those packed in corrugated boxes. Wooden boxes exhibited between 1.5 to 2 times more product damage than corrugated boxes.

Position

The position of boxes in a stack had a significant effect on their injury scores. Boxes in top layers yielded higher injury scores than boxes in middle layers. Analysis of variance in Table 9, considered top and middle positions, since bottom was not included for wooden boxes. A separated three-way analysis of variance was carried out for corrugated boxes, considering the three positions top, middle and bottom (Table 10).

Bottom layers, for corrugated boxes, produced almost the same amount of damage as the top layers. Even though significant differences were found by ANOVA for corrugated box position (Table 10), Duncan's multiple range test applied to the three positions (top, middle and bottom) showed no significant difference between them (Table 11).

Factorial Effect - Two-way Interaction

The comparisons of Treatment x Distance, Treatment x Package, Treatment x Position, Distance x Package, Distance x Position and Package x Position for corrugated and wooden boxes are presented in Figure 5 through 10. For these comparisons there were statistically significant interactions only between Treatment x Distance and Treatment x Package.

TABLE 10
Three-way Analysis of Variance by Factorial Effects for Injury Scores of Tomatoes Damaged in Transport and Laboratory Testing in Corrugated Boxes.

Source	DF	Anova SS	F
Treatment { Transport / Laboratory	1	0.0001	0.05^{ns}
Distance	1	0.5980	293.73^{**}
Position	2	0.0144	3.55^{*}
Treatment x Distance	1	0.0022	1.07^{ns}
Treatment x Position	2	0.0021	0.51^{ns}
Distance x Position	2	0.0006	0.15^{ns}
Treatment x Distance x Position	2	0.0012	0.28^{ns}
Error	24	0.0489	
Total	35		

* Significant at 5% level

** Significant at 1% level

ns not significant

TABLE 11
Comparison of Position Main Effects on Injury Score for Tomatoes Damaged in Corrugated Boxes

Variables			Means	Duncan Grouping
		Top	0.15	A
Transport	100km	Middle	0.11	A
		Bottom	0.14	A
		Top	0.44	B
	500km	Middle	0.36	B
		Bottom	0.43	B
		Top	0.17	A
Laboratory	100km	Middle	0.14	A
		Bottom	0.16	A
		Top	0.42	B
	500km	Middle	0.38	B
		Bottom	0.39	B

Means with the same letter are not significantly different at $\alpha = 0.05$.

TREATMENT x DISTANCE

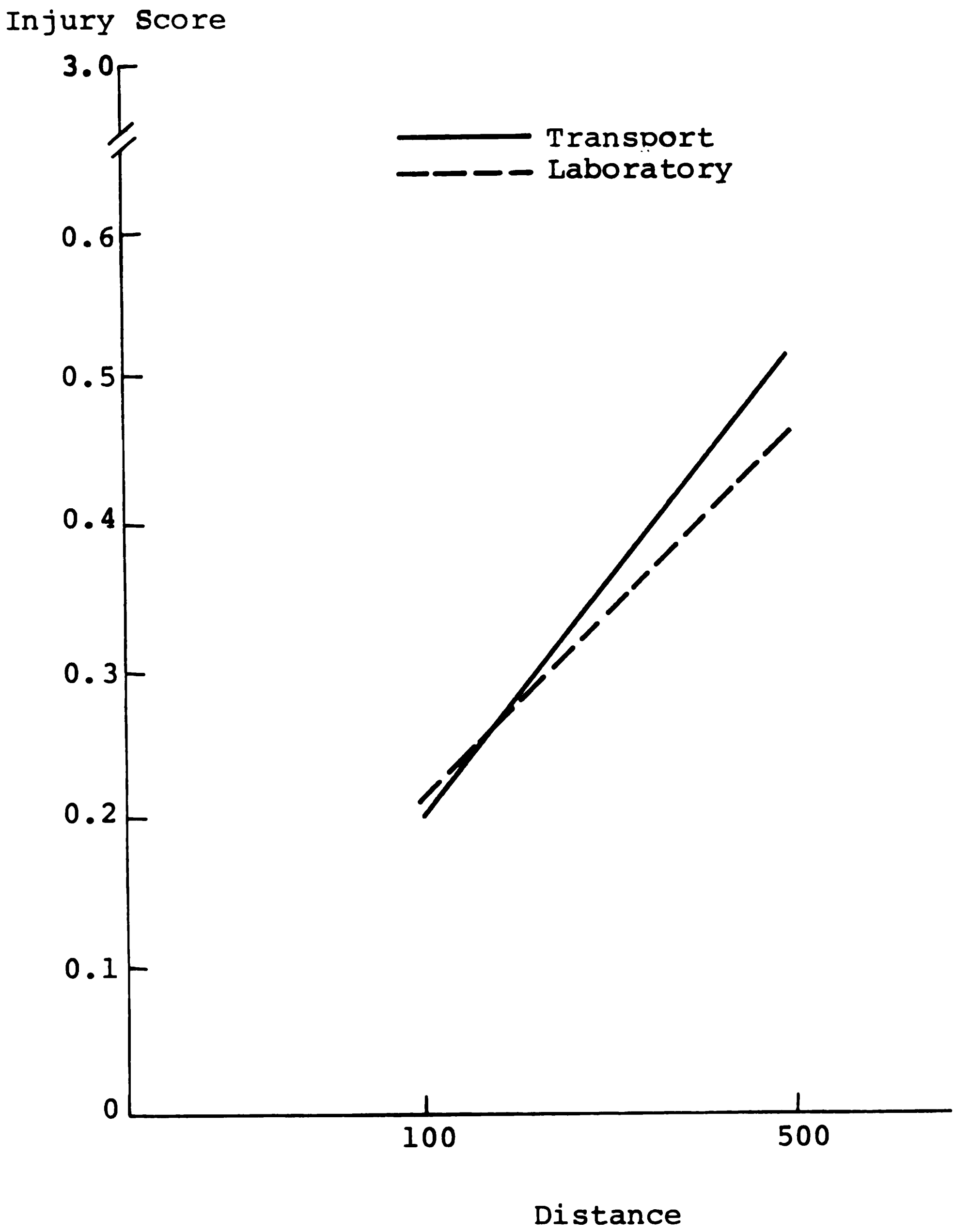


Figure 5

Interaction Effect Between Treatment and Distance on Injury Score of Tomatoes

TREATMENT x PACKAGE

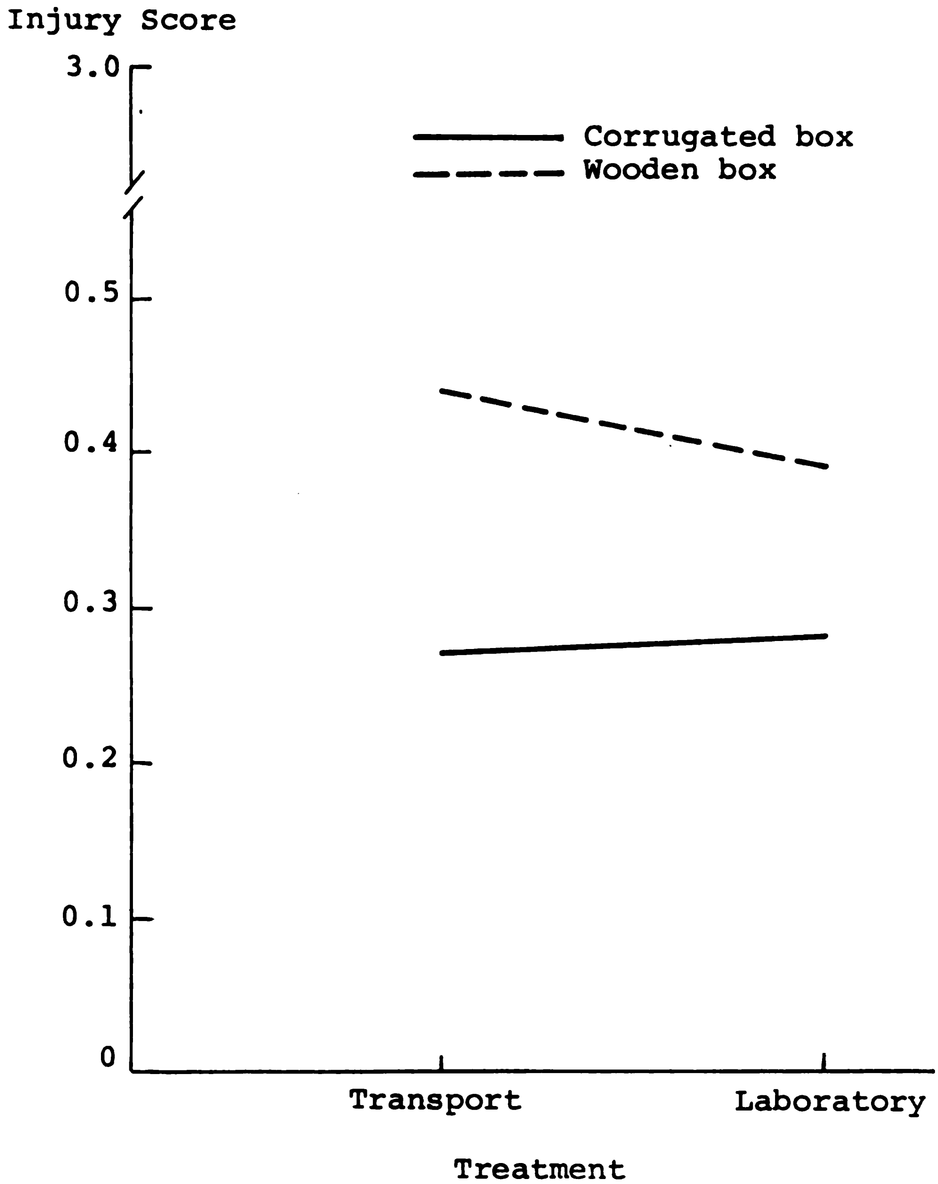


Figure 6

Interaction Effect Between Treatment and Package Type on Injury Score of Tomatoes

TREATMENT x POSITION

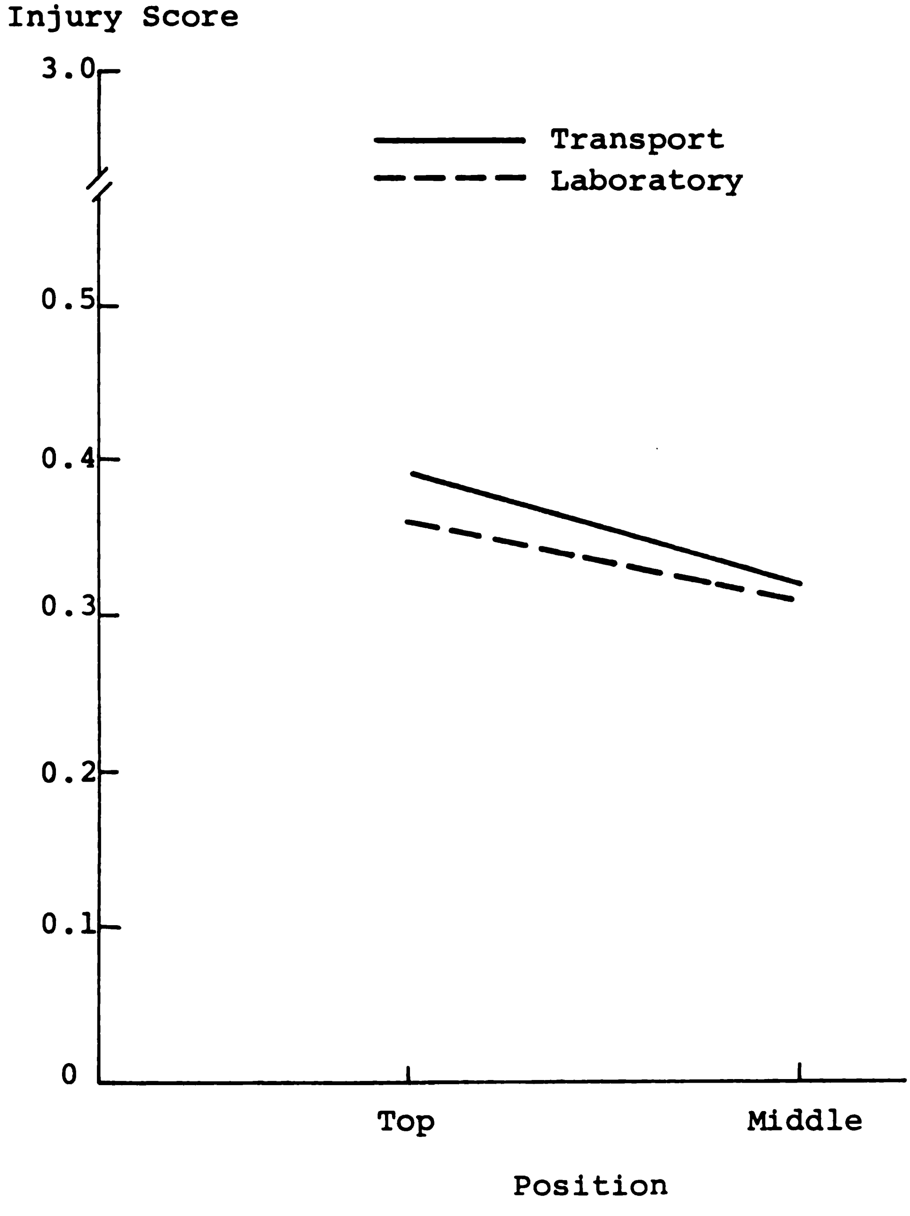


Figure 7

Interaction Effect Between Treatment and Position on Injury Score of Tomatoes

PACKAGE x DISTANCE

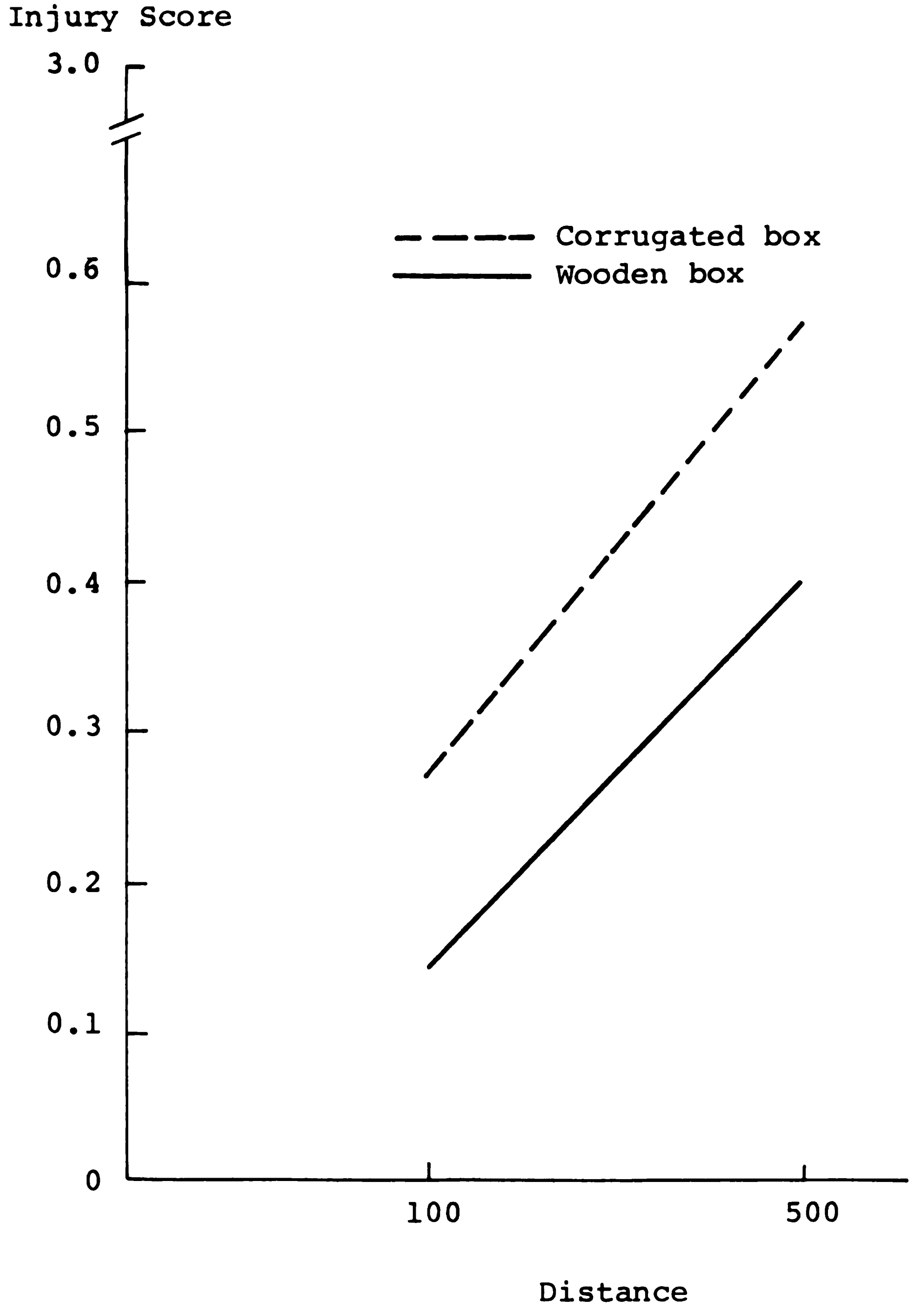


Figure 8

Interaction Effect Between Package Type and Distance on Injury Score of Tomatoes

POSITION x DISTANCE

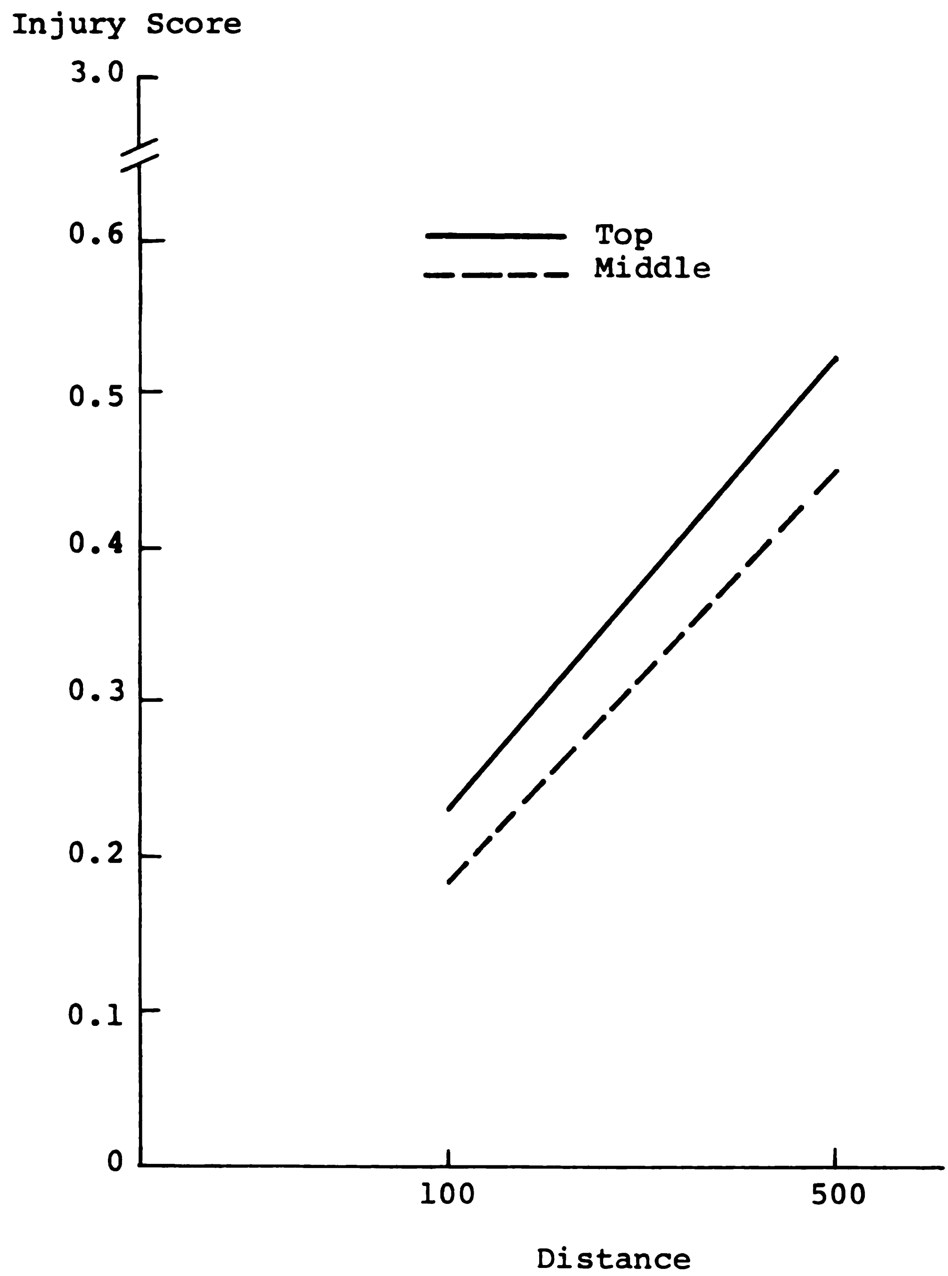


Figure 9

Interaction Effect Between Position and Distance on Injury Score of Tomatoes

PACKAGE x POSITION

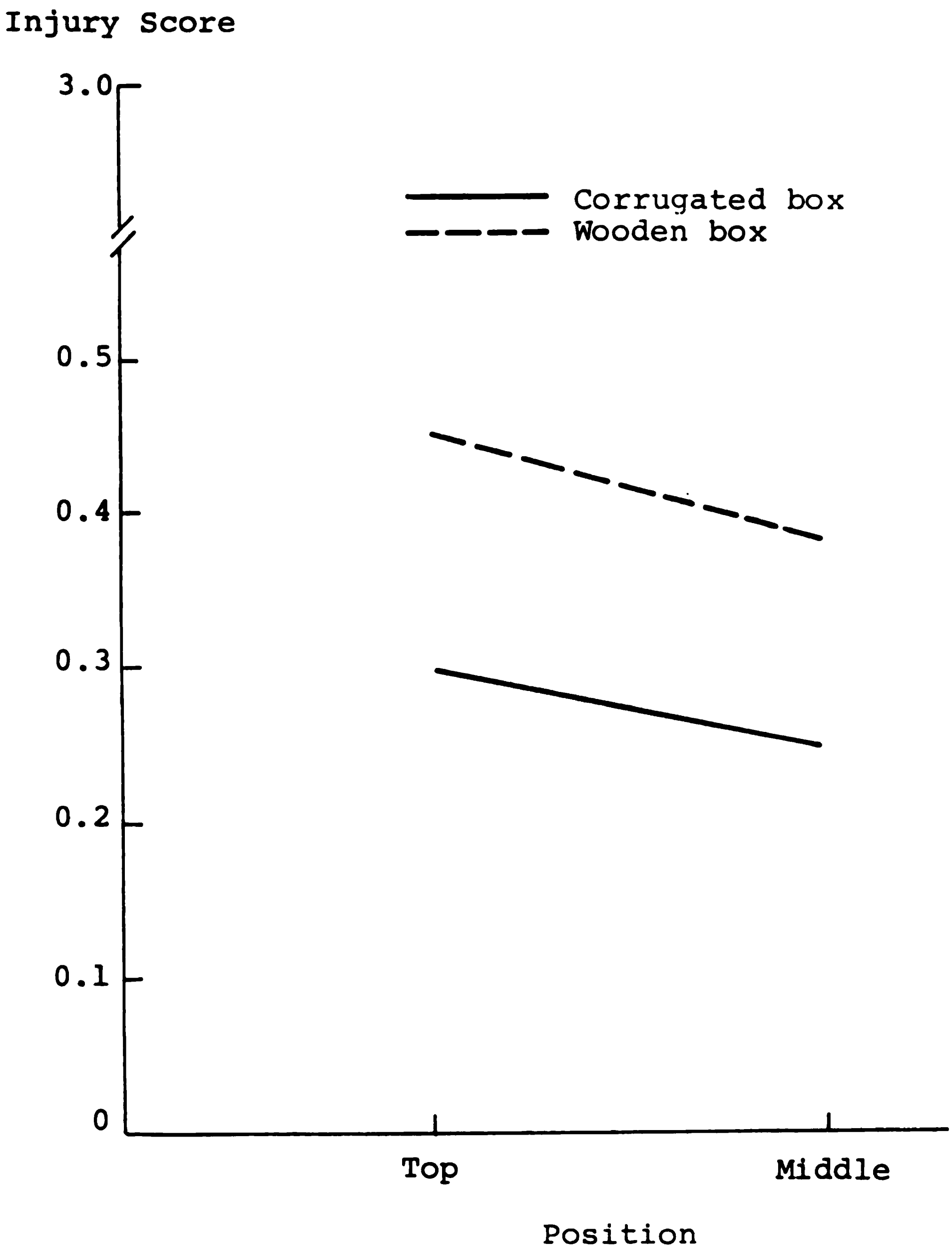


Figure 10

Interaction Effect Between Package Type and Position on Injury Score of Tomatoes

The comparisons of Treatment x Distance, Treatment x Position, Distance x Position only for corrugated boxes are presented in Figures 11 through 13. There was no statistically difference between any of these comparisons.

The purpose of Figures 5 through 13 is only to represent the trend of each variable.

Treatment x Distance

Injury scores were higher for 500 km than for 100 km, for both transport and laboratory testing. For transport testing an increase of 5 times in distance resulted in an average increase of 2.8 times more damage. Simulated conditions for an increase of 5 times in distance resulted an average increase of 2.3 times in tomato injure scores.

However, injury scores in actual transport and in simulated testing did not show the same trend for both distances, 100 and 500 km. For 100 km, injury scores for transport testing were slightly lower than for laboratory testing, but for 500 km, transport testing yielded higher injury scores than laboratory testing (Figure 5). Analysis for corrugated boxes showed a similar trend (Figure 11). Therefore the condition used in laboratory to simulate 100 km distance had higher effect on tomatoes damage than the condition used to simulate 500 km distance.

TREATMENT x DISTANCE

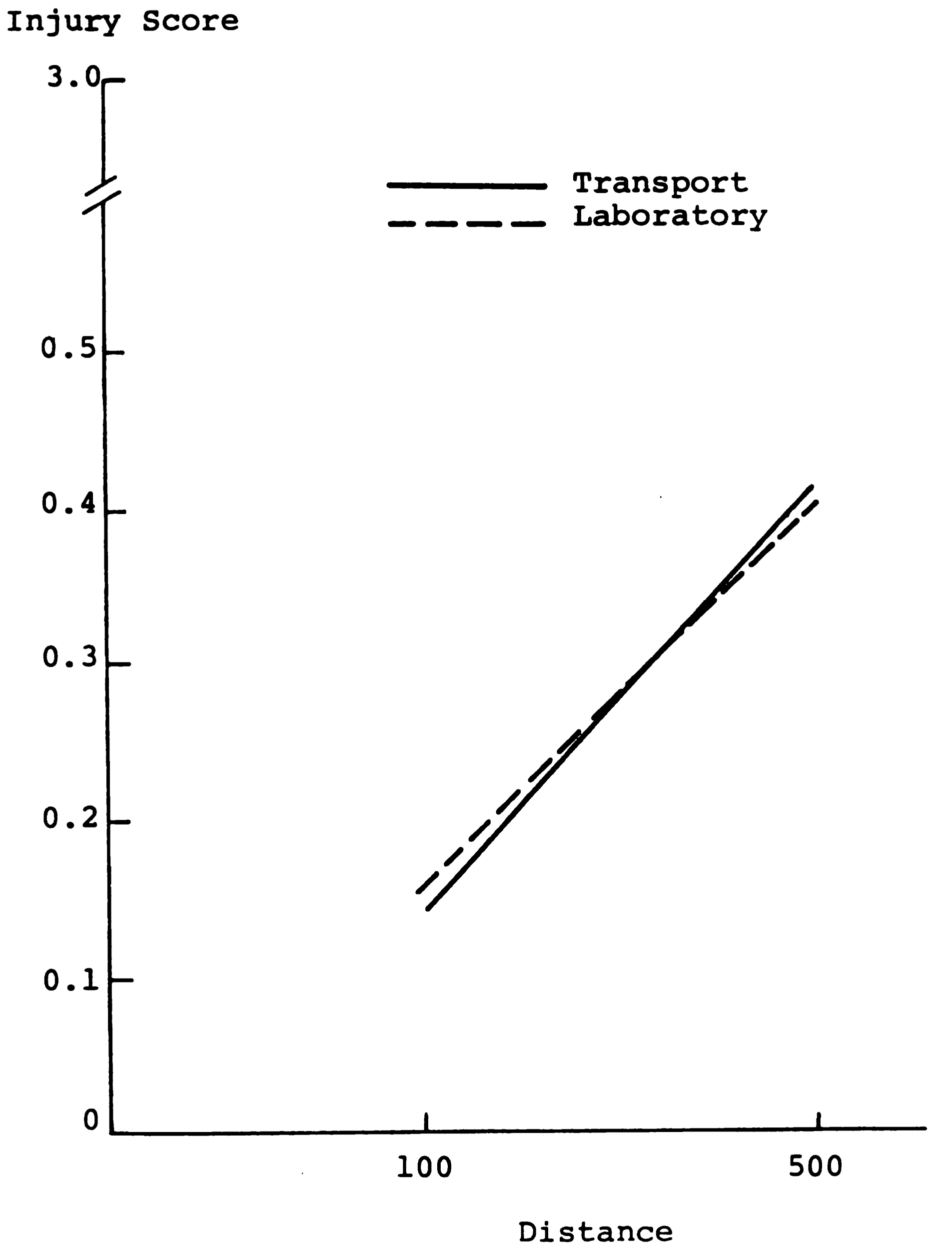


Figure 11

Interaction Effect Between Treatment and Distance on Injury Score of Tomatoes, in Corrugated Boxes

TREATMENT x POSITION

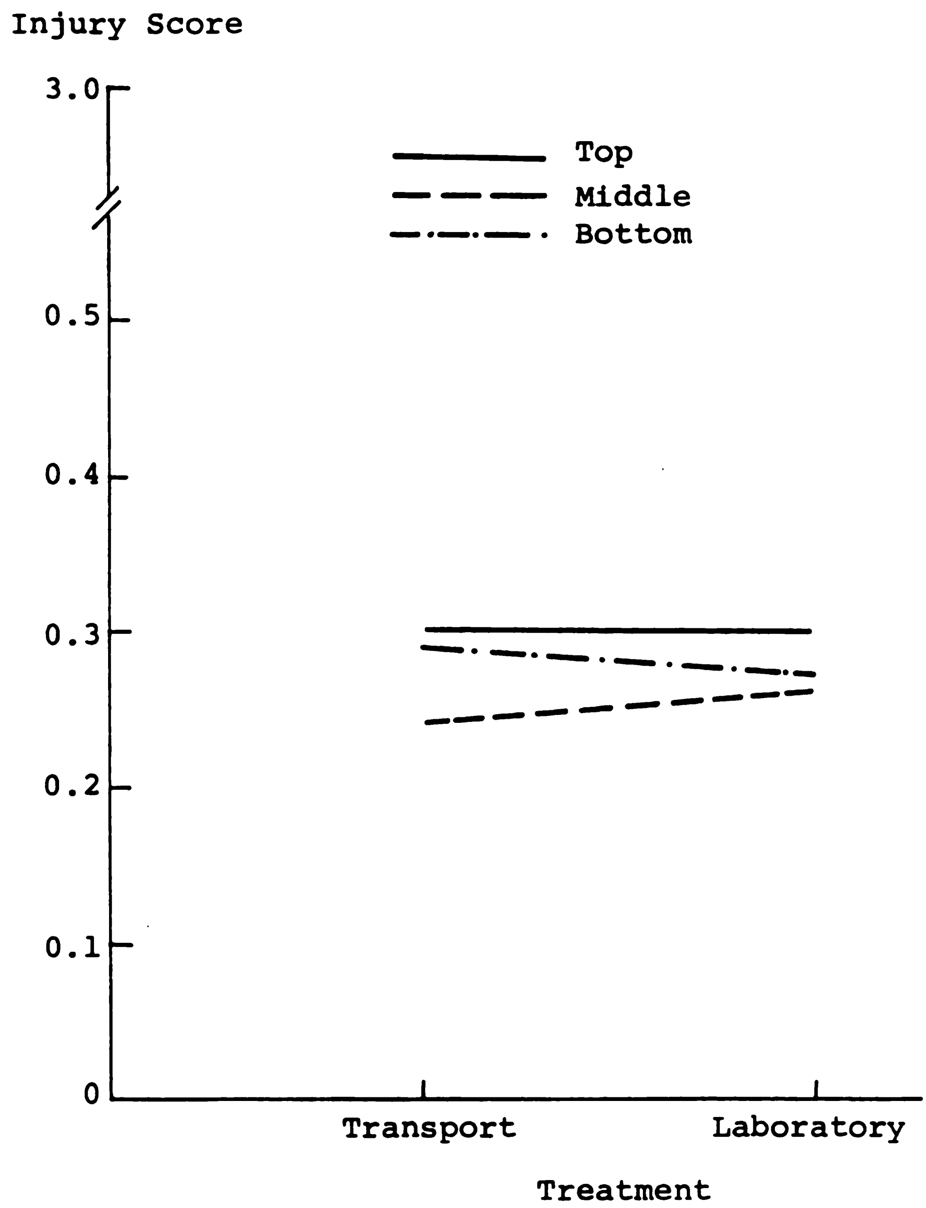


Figure 12

Interaction Effect Between Treatment and Position on Injury Score of Tomatoes, in Corrugated Boxes

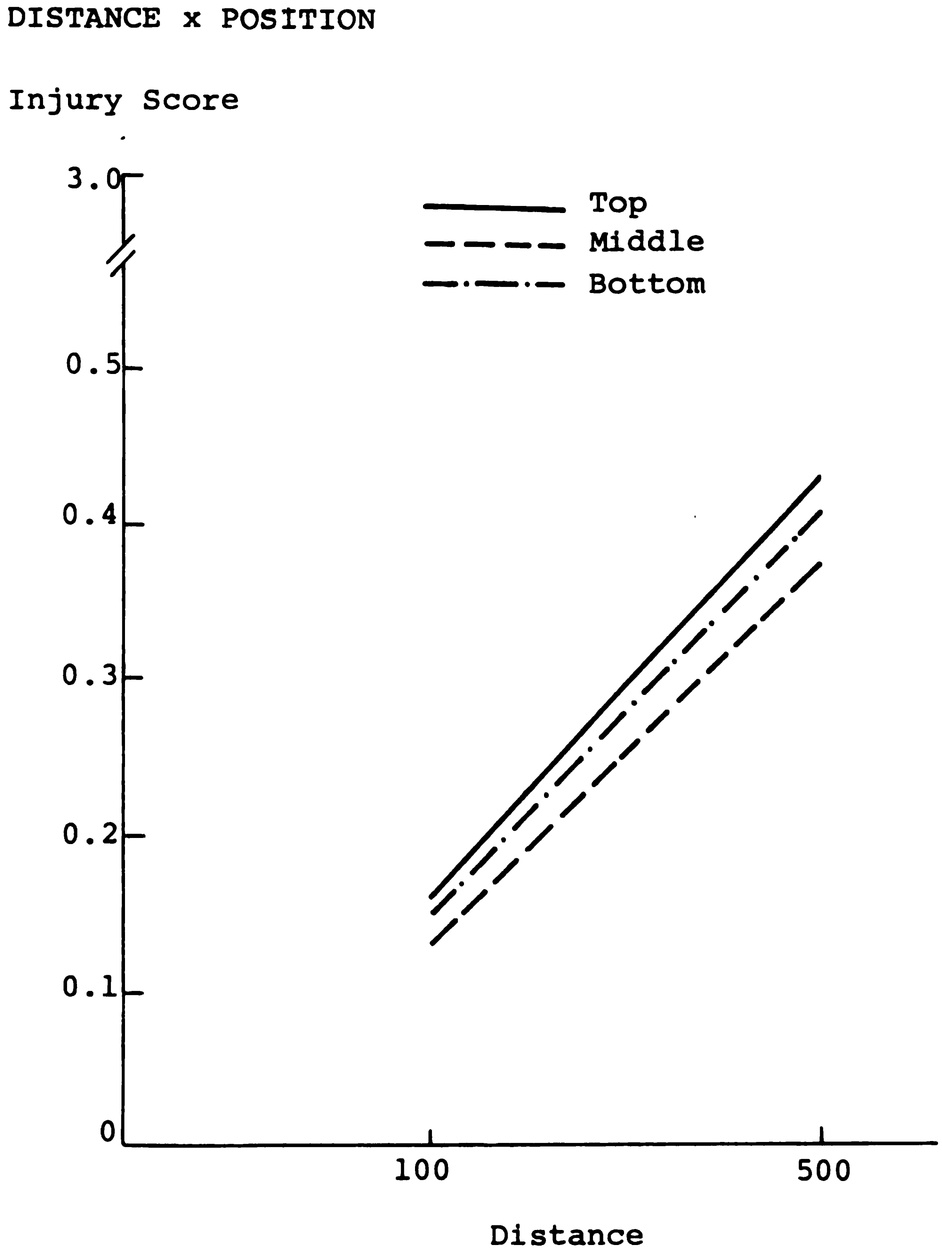


Figure 13

Interaction Effect Between Distance and Position on Injury Score of Tomatoes, in Corrugated Boxes

Treatment x Package

Corrugated boxes yielded a similar amount of damage for both transport and laboratory testing. Wooden boxes showed lower results for laboratory testing than for transport testing, mainly for 500 km (Figure 6). Therefore the reproducibility of damage in laboratory testing was statistically lower at the 95 % confidence level for wooden boxes than for corrugated boxes.

Treatment x Position

The middle position resulted in lower injury scores than top position for both transport and laboratory testing (Figure 7). Injury scores were approximately 16 and 22 % higher in top position than middle for laboratory and transport testing, respectively.

Injury scores for top, middle, and bottom position for corrugated boxes showed a similar trend for transport and laboratory testing (Figure 12).

Therefore, whatever the test applied, top layers yielded the highest injury scores, followed by bottom (corrugated boxes) and middle position.

Distance x Package

500 km yielded higher injury scores than 100 km for both corrugated and wooden boxes (Figure 8). For corrugated boxes an increase of 5 times in distance increased the injury score 2.9 times. For wooden boxes, the same increase

in distance resulted an increase of 2.1 times in the injury score. Even though corrugated boxes were more affected by distance than wooden boxes, this effect was not statistically significant.

Distance x Position

Boxes in the top layer of the stack yielded higher injury scores than boxes in middle layers, for both 100 and 500 km (Figure 9). For 100 km, injury scores for top position were 0.05 units higher than for middle position. For 500 km, injury scores were 0.07 units higher for top position.

For corrugated boxes, bottom layers showed almost the same amount of damage as top layers. Boxes in middle layers showed the lowest injury scores (Figure 13). Therefore, for both distances tested top layers yielded the highest injury score, followed by bottom (corrugated boxes) and middle positions.

Package x Position

Injury scores were higher for top layers than middle layers, for corrugated and wooden boxes. Injury scores for corrugated boxes in top layers were 0.05 points higher than for middle layers. For wooden boxes top layers yielded 0.08 points more of injury (Figure 10). Therefore both types of package tested showed higher injury score for top layers.

Factorial Effect - Three-Way Interaction

Treatment x Distance x Package

Corrugated boxes had lower injury scores in transport testing than in laboratory testing for 100 km. For 500 km corrugated boxes yielded higher injury scores for transport testing than for laboratory testing. Wooden boxes yielded lower injury scores in transport testing for 100 km, but higher for 500 km compared to laboratory testing. In general, 100 km yielded less damage in transport testing and 500 km yielded less damage in laboratory testing for both types of packages tested. This trend is statistically different at the 95 % confidence level.

Treatment x Distance x Position

Top layers of stacks yielded higher injury scores for 100 and 500 km in both transport and laboratory testing.

Bottom layers for corrugated boxes yielded almost the same amount as top layers for 100 and 500 km, for transport and laboratory.

Therefore tomatoes were more damaged in top layers for the two distances tested, whatever the test used (transport or laboratory).

Treatment x Package x Position

Top layers of stacks yielded higher injury scores than middle layers for corrugated and wooden boxes, for transport and laboratory testing.

Therefore, top layers yielded more damage for the two kinds of packages used, for both treatments (transport and laboratory).

Distance x Package x Position

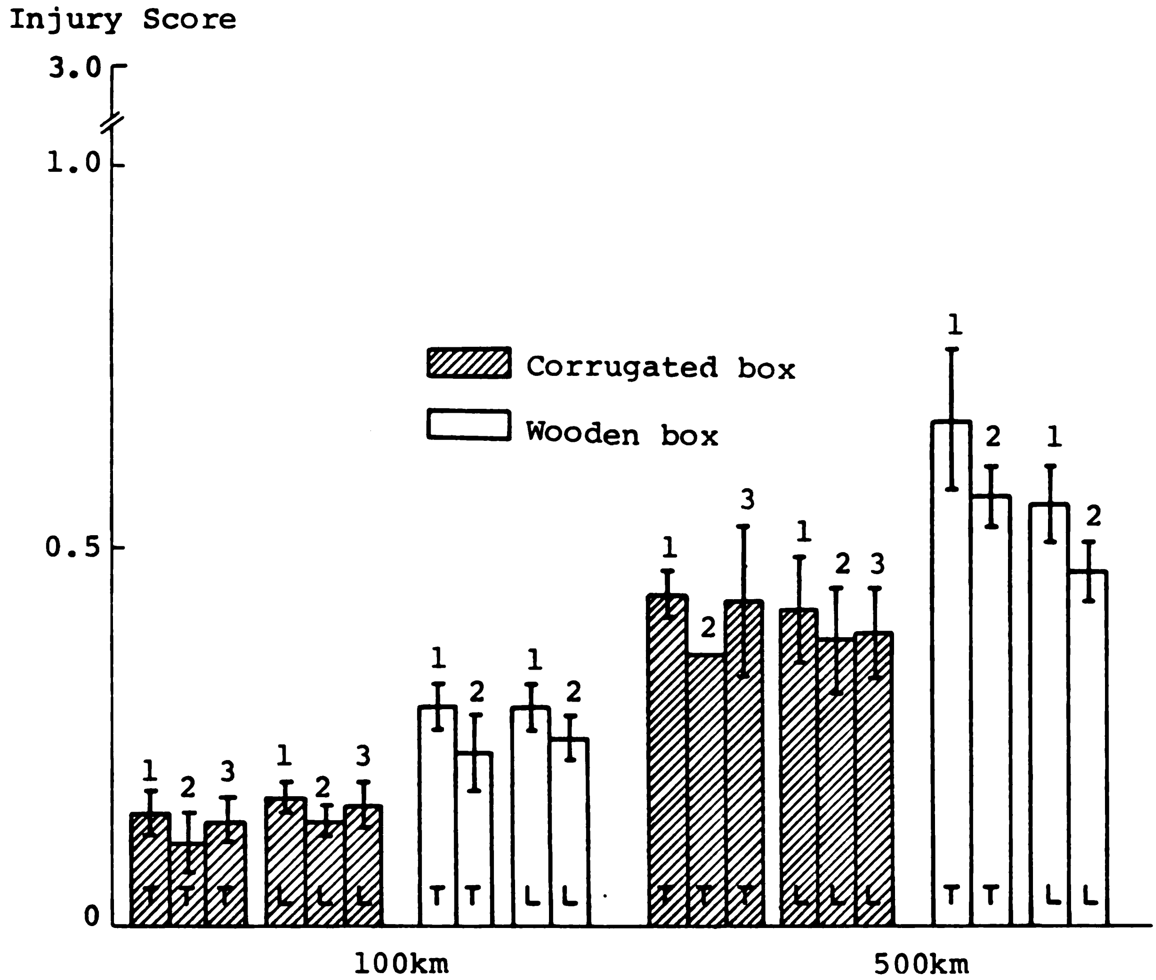
Top layers of stacks had higher injury scores for corrugated and wooden boxes, for 100 and 500 km. For corrugated boxes bottom layers yielded almost the same amount of damage as top layers, for both distances 100 and 500 km.

Therefore, top position yielded the highest injury scores for the two types of packages tested in both distances 100 and 500 km, followed by bottom (corrugated boxes) and middle position.

Factorial Effect - Four-Way Interaction

Treatment x Package x Distance x Position

In general, the condition used for simulated tests reproduced a similar amount of damage for fresh tomatoes as the actual transport testing. Tomatoes in wooden boxes yielded more damage than tomatoes in corrugated boxes. The increase in distance resulted in an increase in tomato damage and boxes at top layers yielded higher injury scores than boxes at middle and bottom layers. Therefore, for both tests used (transport and laboratory), more damage was observed in wooden boxes at top layers of a stack, after they had been tested for 500 km distance. All comparisons are grouped in Figure 14.



1 - Top

2 - Middle

3 - Bottom

T - Transport testing

L - Laboratory testing

Figure 14

Mean Injury Score of Tomatoes in Corrugated and Wooden Boxes for 100 and 500 km Distance, at Top, Middle and Bottom Position, When They Were Submitted to Transport and Laboratory Testing

CHAPTER 5

DISCUSSION

Simulated testing applied for fresh tomato packages resulted in good reproducibility of damage observed in actual transport testing. In general, somewhat greater damage was observed for transport testing (Tables 5 to 8). The equipment used in this study has limitations which prevent reproduction of impacts like sudden stops, rough handling, and bad road conditions. Such impacts can increase damage in actual transport as compared to laboratory testing. However a statistical difference between tomato damage for simulated and actual transport testing was not observed.

The frequency range (3 to 25 Hz) was selected for this study because it includes the frequencies most prevalent for trucks during transportation (O'Brien et al., 1963; Godshall, 1968; Goff and Twede, 1979; Iwamoto et al., 1979b). Acceleration level (0.25 g's) and time were selected by trial and error in preliminary tests. More study would be beneficial to determine the response of tomatoes to different acceleration levels.

The decrease of firmness observed for tomatoes mainly in the boxes at top layer (Tables 6 and 8), was likely to occur mainly due to the amplification of vibration inputs. Nakamura et al. (1977), observed a decrease of firmness for tomatoes submitted to vibration acceleration level higher than 1 g.

Tomato color for this study was between pink and light red because this is the stage of ripeness that is normally chosen for shipment to markets of 100 and 500 km distances. For market shipments greater than 1000 km tomatoes are normally shipped at the green stage of maturity. Less damage is expected at the green stage due to higher firmness of the fruit. Olorunda and Tung (1985) in a study of effects of maturity on mechanical damage of fresh tomatoes, found a higher percentage of distortion and rupture for tomatoes at the red stage of ripeness than at the green and turning stages.

Red tomatoes are sometimes shipped for close markets (100 km distance). In this case, more crushed and cracked tomatoes are expected in wooden boxes caused by the closing system and hard surfaces of the boxes. Generally, wooden boxes are overfilled to prevent movement of the fruit and some tomatoes are compressed or dented during the nailing operation.

Corrugated boxes have been shown to be a good alternative to wooden boxes for shipping fresh tomatoes with respect to mechanical damage. For 100 km injury scores were about 2 times higher for wooden boxes than for corrugated boxes and for 500 km damage was about 1.5 times higher in wooden boxes. Economical aspects are beyond the scope of this study. Re-use of wooden boxes (commonly 4 trips can be achieved) reduces the cost of wooden boxes below that of corrugated boxes. However, the cost of transporting empty wooden boxes and the contamination of fresh tomatoes with residual pieces of fruit remaining in the boxes should be considered. Madi (1977) observed 7.9 % loss of fresh tomatoes in wooden boxes against 3.6 % in corrugated boxes, for 100 km. For 400 km he found 14.7 % and 10.6 % losses in wooden and corrugated boxes, respectively. Unfortunately it was not possible to directly compare the results of the present study to Madi's work in terms of damage percentage because the injury evaluation system was different. However, it can be seen for the cited work (Madi, 1977) that damage in wooden boxes was 2.2 and 1.4 times higher than in corrugated boxes for 100 and 400 km, respectively, which compares well with the values reported here.

Tomatoes in wooden boxes were shown to be less sensitive to distance increases than in corrugated boxes because of the rigidity of the wooden containers. In this work an increase in 5 times in distance resulted in an increase of 2.9 times in damage for corrugated boxes and 2.1 times for wooden boxes. Madi (1977), observed that when increasing distance from 100 to 400 km the differences between damage in wooden and corrugated boxes fell from 2.9 to 1.9 times. A significant percentage of damage in wooden boxes occurs during the packing and closing process due to overfilling and the rough surface of the boxes. According to Madi (1977), compression and dents on the top layers of boxes caused about 15 % of all fruit damage. Tomatoes in corrugated boxes are expected to be more damaged due to rolling within the container and due to compressive forces (impacts) caused by resonant frequencies during the transportation system. Repetitive impacts during transportation increases the head space of the corrugated boxes allowing more free movement of tomatoes in the top layer. Wooden boxes are normally overfilled which prevents this effect. Overfilling corrugated boxes during the packing process will result in a deformation of box structure due to internal pressure. Therefore, distance may have greater effect for corrugated boxes than for wooden boxes.

Even though wooden boxes appeared to be less affected by the increase to 500 km from 100 km distance, this effect can not be extrapolated to longer distances. The rough surface of wooden boxes and the closing system causes more cracking and crushing of tomatoes than in corrugated boxes. For longer distances (over 1000 km) cracked tomatoes become moldy and can contaminate other tomatoes. In addition, the damage of tomatoes in wooden boxes was mainly due to contact of fruit with the package. Due to the roughness of the surface, as the repetition of inputs increases, the probability of rupture of tomato skin increases. Moldy tomatoes and a high percentage of skin breakage due to repetitive friction of fruits against wooden surfaces were observed in a preliminary study of a 1200 km shipment.

The position of boxes in a stack had a significant effect on the product injury scores. Top layers yielded higher injury for both corrugated and wooden boxes, followed by bottom (corrugated boxes) and middle. Boxes in a stack can act as a mass-spring system, which amplifies the vibration inputs (Kawano et al., 1979). The transmissibility of acceleration input of boxes was affected by the package type and its location in the stack. In this study maximum transmissibility was found for top corrugated boxes at the frequency of 5-6 Hz (1.7 g's). For wooden boxes, maximum transmissibility was found for top boxes at 10 Hz (1.3 g's). When vibration acceleration for the box exceeds 1.0 g's, it is probable that the product inside the box will be subjected to serious injury. Therefore, tomatoes in boxes in the top layers had a tendency to be more injured.

In wooden boxes amplification inputs resulted in more tomato skin breaks due to friction of the fruit against the rough surface of the boxes. For corrugated boxes, amplification inputs resulted more in loss of firmness caused by the movement of the tomato within the container, and in more bruises caused by impacts with fruit to fruit.

Tomatoes in corrugated boxes at the bottom layers of the stacks yielded almost the same amount of damage as tomatoes at the top layers of the stacks. Compression strength testing of the two types of containers yielded mean compression strength values of 1450 lb and > 3304 lb for the corrugated and wooden boxes, respectively. Due to the lower compression resistance of corrugated boxes, tomatoes in these boxes at the bottom layers of the stacks were subjected to higher effects of compressive forces than tomatoes in wooden boxes at the same position of the stacks.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

- Simulated testing applied for fresh tomato packages resulted in good reprodutibility of damage observed in actual transport testing.

- A sweep from 3 to 25 Hz at a continuous logarithmic rate of 1 octave per minute, and then sweep back to 3 Hz, at a constant g level of 0.25 g's, 0 to peak, for 25 minutes and 75 minutes satisfactorily reproduced damage for 100 and 500 km, respectively. The results can not be extrapolated to longer distances with confidence.

- Tomatoes were more damaged in wooden boxes than in corrugated boxes. For 100 km the injury score in wooden boxes was 100 % higher than in corrugated boxes and for 500 km it was 50 % higher. Probable explanations for these observed differences include overfilling and rough surface of wooden boxes. It would appear that the smooth surface of the corrugated box reduces the incidence of mechanical damage.

- Amplification of vibration inputs increases tomato mechanical damage. For wooden boxes it is probably due to the increase of friction between tomatoes and the rough surface of the boxes. For corrugated boxes it is likely that damage results from tomato rolling in the container and also due to compressive forces (impacts) at resonant frequencies.

- Top layers yielded higher injury scores for both corrugated and wooden boxes. In corrugated the middle layer exhibited the least amount of damage.

- Tomatoes in corrugated boxes, at bottom layers, were subjected to higher effects of compressive forces than tomatoes in wooden boxes. This is likely due to the lower compression resistance of corrugated boxes.

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