Vibration and Impact Performance Tests on Cherry Tomato Transport Packages

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Abstract: The reasons for damage to packaged cherry tomatoes in storage and transportation were investigated. By choosing a typical cherry tomato package, four tests were performed. These tests included: stacking strength test, sinusoidal vibration transmissibility of multi-packages stacking test, vertical impact tests and drop tests. The tests were carried out according to national test standards. It is determined by the stacking strength test that the maximum number of allowable stacking layers is 9. The natural frequencies of layered packages were determined by using a 9 stacking layer vibration transmissibility experiment with a variable frequency. The natural frequencies were 36.61 HZ, 10.76 HZ and 6.44 HZ for the bottom, middle and top layers, respectively. Curves of acceleration and vibration transmissibility of every layered package versus time were obtained. The relationships of its natural frequency and peak value of vibration transmissibility versus stack height were studied. On the basis of the above findings, the fragility of cherry tomatoes for each package is 89.58 by carrying out the vertical impact test. Also, the allowable maximal dropping height is 580mm according to the drop test. Finally, the protection capability of the packages on cherry tomatoes was evaluated.

Keywords: Cherry tomato, transport package, corrugated box, resonance frequency, stacking, vibration transmissibility, fragility, drop

1. Introduction

The production of the fruits and vegetables has relatively strong seasonality and regionalist, so that the fruits and vegetables storage and transportation problems should be considered. With the development of the logistics industry and the improvement of people's living standard, the fruits and vegetables storage and transportation problems are increasingly prominent. Compared with foreign countries, the fruits and vegetables have enormous losses in the storage and transportation process in China. In developed countries, the fruits and vegetables loss rate is lower than 5.0%; it is only 1.0%~2.0% in the US. However, it is higher than 20% in China. The total loss value is nearly 80 billion RMB per annum[1, 2].

The cherry tomato is also called a small tomato, pearl tomato, grape tomato, saint fruit and so on. It belongs to both the fruit and vegetable categories. It is seedless, sweet, good tasting, and with high nutritive value. The cherry tomato contains special materials such as glutathione and lycopene. These materials can promote growth and development, increase the body resistance and delay senility. Besides, lycopene can protect the body from the carcinogens of automobile exhaust gas. It can prevent and cure a variety of cancers especially prostrate cancer. The vitamin PP content of cherry tomato ranks at the top for fruits and vegetables. It can protect the skin, maintain normal secretion of gastric juices, promote the formation of red blood cells, and provide therapy for liver trouble. As a consequence, the cherry tomato is listed by the United Nation FAO as one of the four fruits and vegetables to widely promote.

The impact and vibration during transportation are the main reasons to cause packages to be damaged[3]. The fruits and vegetables packages come under impact, vibration, dropping, swinging, static pressure and many other factors in storage and transportation with the result of damaged fruits and vegetables.

In order to prevent the cherry tomato from damage in the storage and transportation process, we need to actualize each kind of package cushioning, to guarantee transportation security of the farm product and to reduce the package cost.

Corrugated boxes have such advantages as light weight, low cost, are easy to be processed and printed and can be reasonably designed. Corrugated boxes are easy to recycle, non-polluting and reusable. In addition, because the empty box can be folded up, the empty box is compact and is easy to be transported and stored[4-6].

In recent years, domestic and foreign scholars carried out various researches for cherry tomatoes vibration damage mechanism[7-10]. This article studies stacking strength test, vibration transmissibility of multiwall stacking test, vertical impact and drop tests on cherry tomatoes in storage and transportation in a macro perspective. The protection capability of the packages on cherry tomatoes is then evaluated. Finally, some suggestions for the packages design are given.

2. Specimen and Experimental Description

The subject fruit investigated in this article was the red cherry tomatoes which are also named ‘saint fruits’ as produced in Hainan[11]. The package known as 0301-type corrugated box with B-type edge are popular in current market and is as shown in Figure 1.

Fig.1 Cherry tomato transport packages produced in Hainan

The dimensions are 405×275×195(mm^3). The net and gross weights are 10 kg and 12 kg respectively.

In order to ensure the accuracy of the test results, the procedures used in this article are strictly in accordance with the national testing standards[12-14]. Eighteen randomly selected packages of cherry tomatoes moderate sizes were selected. They were under constant humidity and temperature which were same as the transportation environment[15].

By performing stacking strength test, the maximal allowable stacking layers are determined. By a multiwall stacking vibration test at variable frequency, the natural frequencies of every layer package were determined; curves of acceleration and vibration transmissibility of every layer package versus time were obtained; the relationship of its natural frequency and peak value of vibration transmissibility versus stack height is discussed. On above basis, the fragility and the maximal dropping height were obtained based on vertical impact test and drop test. Finally, some conclusions are drawn.

3. Stacking Strength Test

The stacking strength test was conducted by using the XYD-15K corrugated box compression testing machine produced by Jinan Languang Electro-Mechanical Technology Co. Ltd. The compression strength and the protection ability to the internal cherry tomatoes can be determined after the stacking test[16].

Three selected packages tests were carried out. One of the selected packages was placed on the lower platen of the compression test machine. Before starting, a preload 22daN (i.e. 22kg) setting was made on the upward acting plate and test specimen so as to fit tightly. The upward acting plate was descended slowly to put pressure on the package. When the load pressure reached the pre-set value, the package’s deformation in the vertical direction was measured. The damaged condition of the cherry tomatoes in the box was then checked. If there was no damage, the load pressure was increased. The test was repeated until some cherry tomatoes were damaged. The gradual increased pressure value was to be equal to the package’s gross weight of 12 kg. The averaged laboratory experimental data and the final load pressure of the three packages tests are summarized in Table 1.

Table 1. Stacking test results

Preload /Kg	Load pressure/ Kg	Vertical deformation /mm	Damaged condition
	22	0.00	well
	34	0.72	well
	46	1.48	well
	58	2.27	well
22	70	3.14	well
	82	3.86	well
	94	4.62	well
	106	5.51	Well
	118	6.31	damaged

As can be seen from Table 1, the specimen in the test can withstand the pressure of 106 kg. Therefore, the maximum number of allowable stacking layers is [106/12]+1=9. For the storage and transportation process, the cherry tomato packages maximal allowable stacking height is 195×9=1755mm.

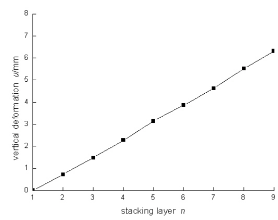

Fig. 2 Stacking layers and vertical deformation curve

The curve of stacking layer versus vertical deformation is plotted in Figure 2. It can be seen that the relationship between load pressure and deformation is basically linear.

4. Vibration Transmissibility of Multiwall Stacking Test

4.1. Time Domain Responses of Stacking Packages

By using the DY-600-5 low frequency vibration table produced by Suzhou test instrument factory, the sinusoidal vibration transmissibility of 9 packages stacking test at variable frequency were carried out[17].

Three sensors were put into the 1st, 5th, and 9th layer stacking specimen packages filled with cherry tomatoes. In order to reduce the testing interference and improve the accuracy of the test data, the sensors may be fixed in some small rectangular thin planks. The packages were put on the vibration table, after supporting erect, stacking, using a hemp rope tied up to ensure its fastness. The 4th sensor was fixed on the surface of the vibration table. The acceleration was set 5 m/s^2 and allowed to scan back and forth between 3HZ~100HZ. The rate of scan-

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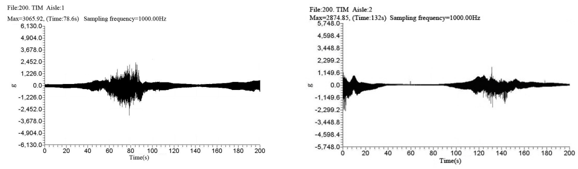
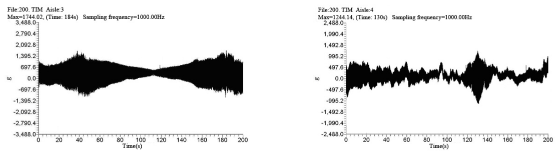
ning frequency was pre-set to 1/2 Octave for each minute. The time domain responses are as shown in Figure 3 (a, b, c, d).



(a) Top layer (b) Middle layer



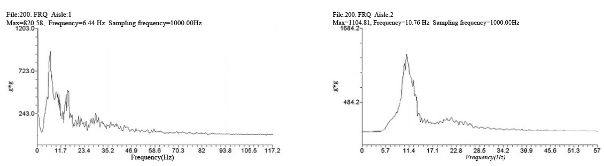
(c) Bottom layer (d) Vibration Table

Fig. 3 Time domain responses of stacking layers and the vibration table

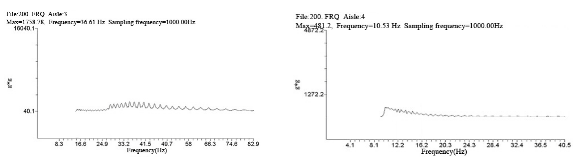
In the figure 3, the time domain response acceleration is amplified a hundred times.

4.2. The Natural Frequency Determination of Stacking Packages

The corresponding self power spectra can be transformed from the above time domain responses by using the VIB' SYS microcomputer data gathering system and are as shown in Figure 4 (a, b, c, d).



(a) Top layer (b) Middle layer



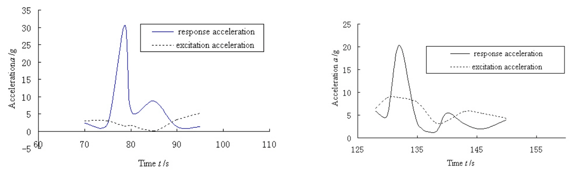
(c) Bottom layer (d) Vibration Table

Fig. 4 Spectra analysis curves of stacking layers and the vibration table

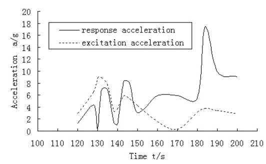
When the natural frequency of a package is equal to the excitation frequency, resonance happens; this occurs in the peak point of the spectrum analysis curves. From Figure 4, the natural frequency of the bottom, middle and top layers are 36.61, 10.76 and 6.44HZ, respectively. It can be seen from Figure 4, the resonance frequencies reduce gradually from the bottom to the top. Since the 9 layers are tied together, the gravity center is in the 5^{th} layer. Therefore, 10.76HZ is also the overall stacking natural frequency.

4.3. Vibration Responses Acceleration and the Excitation Acceleration Analysis of Stacking Packages

The resonance times and the corresponding peak accelerations of the top, middle and bottom packages can be obtained from Figure 3; they are (78.6s, 30.65g), (132s, 20.32g), (184s, 17.44g), respectively. One then reads the response accelerations of each layer package in some near field at the resonance time point and then determines and records the corresponding excitation acceleration of the vibration table. The contrasting curves are plotted in Figure 5(a, b, c).



(a) Top layer and table (b) Middle layer and table



(c) Bottom layer versus vibration table

Fig. 5 Vibration responses of stacking layers versus the vibration table excitation acceleration

From Figure 5, the resonance peak acceleration increases gradually from the bottom to top. Besides, the resonance response accelerations of each layer package are greater than corresponding excitation accelerations respectively.

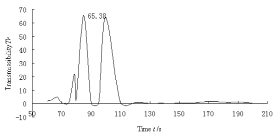
4.4. Vibration Transmissibility Analysis for Stacking Layers

The vibration response of every stacking layer packages caused by the vibration of transport tools can be used to describe as the vibration transmissibility. Vibration transmissibility is defined as a ratio between the vibration response acceleration of the product in cushioning package and outside excitation acceleration, which denoted by T_r, and can be formulated as follows [18]:

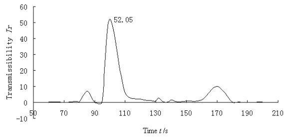
$$T_r = \frac{g_n}{g_0} \qquad (1)$$

where, g_0 is the outside excitation acceleration, g_n is the vibration response acceleration of the product in cushioning package described in Figure 5(a),(b),(c). Curves of vibration transmissibility of the top, middle and bottom layer packages versus time are shown in

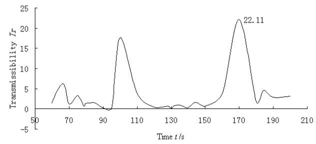
Figure 6(a, b, c).



(a) Top layer



(b) Middle layer



(c) Bottom layer

Fig. 6 Vibration transmissibility curves of stacking layers

As can be seen from Figure 6, the maximal vibration transmissibility of the bottom, middle and top are 22.11, 52.05 and 65.38, respectively, and rendering the increasing trend from the bottom to the top.

5. Vertical Impact Test

The fragility of the cherry tomatoes can be obtained by vertical impact test by using the CL-200 impact testing machine produced by the Suzhou test instrument factory.

The 3rd, 5th, 7th stacking layers were selected as vertical impact experimental samples (in which the damaged cherry tomatoes are replaced by good ones). The following procedure was used:

Step 1. Let the package be fixed onto the impact test bed according to the national standard.
Step 2. Set the minimal initial impact height as 50mm.
Step 3. Carry out the impact test at every pre-setting height with the increasing interval of 40mm.
Step 4. Use the intended impact half-sine wave to carry out the impact test to the test specimen.
Step 5. Record the peak acceleration parameters
Step 6. Check the damage condition of cherry tomatoes. If the cherry tomatoes are damaged, then stop the test; otherwise, continue to carry out with increasing the height 40 mm until the test specimen is damaged.

Because the cherry tomatoes are small in size and large in numbers, the damage can be represented by a damage rate. If there are N cherry tomatoes in the package and M damaged, then we can define the damage rate as M/N. Combined with the life experiences, this article assumes that, when the damage rate reaches to 3‰, we define the specimen as damaged. One package contains about 500 ± 5 cherry tomatoes weighing 10 kg. The final test data of the three specimens are summarized in Table 2 (all of three specimens are damaged at the same height of 290 mm).

Table 2. The three specimens impact test data

Impact height/mm	Peak acceleration /ms^{-2}			
	Specimen1	Specimen2	Specimen3	Average
50	259.32	271.32	273.15	267.93
90	326.94	333.67	349.45	318.85
130	429.67	426.53	415.81	424.00
170	509.31	526.56	510.87	515.58
210	687.35	676.08	695.82	686.42
250	831.29	783.61	809.54	808.15
290	948.93	926.31	973.04	949.42

Taking the average on the above three test data sets, then the curve of the height versus average peak acceleration is plotted in Figure 7 by piecewise linear fitting.

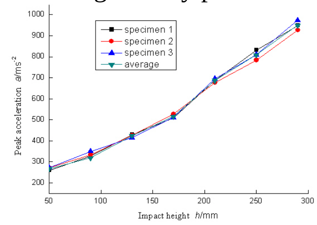


Fig. 7 The height—peak acceleration impact test curve

The fragility of cherry tomatoes can be calculated as the average value between the corresponding peak acceleration of the damaged dropping height and the last test value of no damage. From Column 2 about Specimen 1 in Table 2, cherry tomatoes breakage occurs at the dropping height of 290 mm, and corresponding peak acceleration test value is 948.93 m/s^2. The last test value without damage is 831.29m/s^2; therefore, the fragility of test Specimen 1 is G_c^1=(831.29+948.93)/2/g =890.11/g =90.73. In the same way, we can get the fragilities of Specimen 2 and Specimen 3 respectively as $G_c^2 = 87.15$, $G_c^3 = 90.86$. Finally, by taking the average of above three experiments, the fragility was determined to be $G_c = 89.58$.

6. Drop Test

By using the DY-315A drop test machine produced by Suzhou Dongling vibration test instrument factory, the allowable maximal dropping height of the package can be gained by successively doing drop tests of surface, edge and vertex[19]

The purpose of the proposed three kinds of drop tests to cherry tomatoes packages was to evaluate the impact resistance and protection capability of the packages carrying the cherry tomatoes.

The 2nd, 4th, 6th stacking layers after stacking vibration transmissibility test were selected as surface dropping experimental samples (in which, the damaged cherry tomatoes are replaced by new ones). The procedure was:

Step 1. Set the minimal initial surface dropping height

978-1-935068-36-5

as 300 mm.

Step 2. Start the experiment according national standard[19].

Step 3. Checking and recording the breakage numbers of the cherry tomatoes.

Step 4. If the damage rate reaches to 3‰, then stop the test; otherwise continue to carry out with increasing the height 80mm until the test specimen is damaged.

Step 5. Before next test, the damaged cherry tomatoes should be replaced by good ones.

The test results are summarized in Table 3.

Table 3. The three specimens surface dropping test data

Dropping height/mm	Specimen1	Specimen2	Specimen3	Average damage rate
300	No damage	No damage	No damage	0‰
380	No damage	No damage	No damage	0‰
460	No damage	No damage	No damage	0‰
540	No damage	No damage	1 damaged	0.67‰
620	2 damaged	3 damaged	2 damaged	4.67‰
700	5 damaged	8 damaged	6 damaged	12.67‰

The 1st, 8th, 9th stacking layers were selected after the stacking vibration transmissibility test as edge drop experimental samples. Because the edge drop is theoretically safer than the surface drop, the edge drop test can be started from a height of 380 mm, which is higher than the initial surface dropping height 300 mm. The test results are summarized in Table 4.

Table 4. The three specimens edge dropping test data

Dropping height/mm	Specimen1	Specimen2	Specimen3	Average damage rate
380	No damage	No damage	No damage	0‰
460	No damage	No damage	No damage	0‰
540	No damage	No damage	No damage	0‰
620	2 damaged	1 damaged	No damage	2‰
700	6 damaged	3 damaged	4 damaged	8.67‰

Three new packages were selected as vertex drop experimental samples. Because the vertex drop is safer theoretically than the edge drop, the vertex drop test can be started from a height of 460mm, which is higher than the initial edge dropping height of 380 mm. Consequently, the test results are summarized in Table 5.

Table 5 The three specimens vertex dropping test data

Dropping height/mm	Specimen1	Specimen2	Specimen3	Average damage rate
460	No damage	No damage	No damage	0‰
540	No damage	No damage	No damage	0‰
620	No damage	No damage	No damage	0‰
700	No damage	1 damaged	1 damaged	1.33‰
780	5 damaged	4 damaged	6 damaged	10‰

The results show that allowable maximal surface dropping height is (540+620)/2=580 mm; the allowable maximal edge dropping height is (620+700)/2=660 mm, the allowable maximal vertex dropping height is (700+780)/2=740 mm. Thus, in order to ensure the cherry tomatoes in transportation will not be damaged, the allowable maximal dropping height is 580mm.

7. Conclusions

7.1. Stacking Strength Test

Through the stacking strength test, the maximal allowable number of stacking layers was determined to be 9 and the maximal stacking height was 1755 mm.

7.2. Vibration Transmissibility of Multiwall Stacking Test

Because packages need to be stacked during transportation, the vibration transmissibility test was carried out at the allowable maximal number of stacking layers. The following results were obtained:

- The natural frequencies of the bottom, middle and top layers were 36.61 HZ, 10.76 HZ, and 6.44 HZ, respectively.
- The resonance peak response accelerations of the bottom, middle and top layers were 17.44g, 20.32g and 30.65g respectively.
- The maximal vibration transmissibility of the bottom, middle and top layers were 22.11, 52.05 and 65.38 respectively

7.3. Vertical Impact Test

To simulate the real handling process, the vertical impact test was carried out. Since both the vertical impact test and the drop test are more destructive than others, the vibration test at variable frequency and stacking layer test was done first. The other two tests were done next since this is more realistic. The fragility of cherry tomatoes is 89.58.

7.4. Drop Test

The allowable maximal dropping heights are 580 mm, 660 mm, 740 mm for the surface, edge and vertex dropping, respectively.

7.5 Evaluation of the Package Protective Ability

- The top peak acceleration in the stacking layers vibration test at variable frequency (30.65 g) was the largest for all 9 layers. Obviously, 30.65 g is much less than 89.58 g which demonstrates that the package can prevent cherry tomato damage during normal transportation.
- The allowable maximal dropping height in the test is 580 mm. For normal adults, the height in handling is above 600 mm. In addition, according to the national standards[5], the highway, railway and aviation transportation package of

the quality of 10 kg to 20 kg needs 600 mm dropping height, so the allowable maximal dropping height 580 mm is slightly less.

7.6. Analysis of the Test Procedure

The test method used in this investigation is applicable to the mechanical properties of other similar farm produce. Similar test results can evaluate the advantages and disadvantages of other types of packages and provide a reference for the package's optimum design.

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