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Vibration Simulation Testing of Banana Bulk Transport Packaging Systems

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ABSTRACT: *Previous studies have reported that 20-30% of the banana harvest (9,000-13,500 t) is going into waste annually in Sri Lanka mainly due to mechanical damage. The distance of bulk transportation in main distribution channels is about 200 km. Therefore, this study was conducted to investigate an appropriate bulk packaging system for banana bulk transportation to minimize postharvest losses occurring due to mechanical damage in Sri Lankan distribution channels. A vibration bed operating at 6 mm amplitude at a 3.5 Hz frequency was used for transportation simulation tests. Three bulk packaging methods; laying of styrofoam sheets of the thicknesses: 10, 8 and 5 mm between bunch layers, wrapping individual banana bunches with styrofoam sheets of 3 and 5 mm thickness and packing banana hands in corrugated fibreboard boxes (CFB) were tested for mechanical damages and final fruit quality. Intact banana bunches were stacked without any packaging as the control. Fruits of the cultivar 'Embul' were subjected to 120 minutes vibration to simulate 100 km distance of travel. Although packing of banana hands in CFB resulted the least mechanical damage (5.9%) fruits lead to rapid ripening. Highest mechanical damage was found in the control (20.8%). Wrapping of individual bunches with Styrofoam sheets reduced the damage but packaging and handling costs were considerably high. Lying of styrofoam sheets of 8 or 10 mm thickness as a cushioning material between the layers of bunches was found to be an appropriate method in terms of reducing mechanical damage. Although, there were no significant differences of damage between 10 and 8 mm thickness sheets, 8 mm sheet reduced the cost of packaging. Therefore, considering the technical and economical feasibility, laying of 8 mm styrofoam sheets in between banana bunch layers for long distance bulk transportation could be recommended under local conditions.*

Key wards*: Bulk packing, embul banana, mechanical damage, postharvest losses, styrofoam sheets, vibration*

INTRODUCTION

Banana postharvest losses are relatively high due to mechanical damages occur during postharvest handling and transportation. Although bananas are harvested at the mature green stage, the external appearance of the ripened bananas at the retail shops is poor because of excessive mechanical damages caused by improper handling throughout the supply chain

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(Sarananada, 2000). Ekanayake and Bandara, (2002) reported that, the postharvest losses of banana in Sri Lanka accounts for about 30% and these are mainly due to lack of appropriate packaging methods to transport from farm gate to the consumer. Mechanical damages not only leads to postharvest losses, but also creates various stresses to fruits leading to physiological and morphological changes of the fruit subsequently (Shewfelt *et al.*, 1987).
Under local conditions in the conventional marketing system, banana is mainly transported in open trucks without using any packaging. Due to the nature of banana bunches, other rigid packaging used for perishables are not suitable for packaging. According to Dharmasena and Sarananda (2012), 97% of the fruits and vegetables in Sri Lanka are handled through the conventional distribution chains in which agricultural produce is channelled through economic centres with the involvement of middlemen using improper handling practices. Cuts, vibrations, abrasion, compression, and impacts are the main causes of mechanical damages to produce during handling and transportation. Compression damage occurs when fruits are over loaded and usually the weight of the load is supported by the product than the container in most of the fruit handling systems. Vibration damage is prominent in vehicles fitted with steel leaf-spring-suspension systems (Vigneault *et al.*, 2009).

Increasing investments in postharvest handling of banana can have a major impact on reducing waste and increasing food supply, leading to improved income while greening the whole industry. Therefore, design and development of an appropriate packaging system for banana bulk handling and transportation in conventional distribution chains is an essential task for the Sri Lankan postharvest system. According to Wasala *et al.*, (2014), all stakeholders in the supply chain prefer to transport and handle banana as whole bunches.

Vibration simulation testing is used in most produce package testing as it saves time and money (Peleg, 1985). This method is based on the assessment of effect of vibration during transportation on the fruit and enables to assess the performance of different packaging or cushioning methods on banana transportation. Therefore, this study was conducted to investigate the suitability of different packaging systems for bulk handling and transportation of banana under local transport conditions.

METHODOLOGY

Seven packaging methods were developed to transport banana as whole bunches and hands (Fig. 1). Styrofoam sheets were identified as the cushioning material to be used for banana bunches in bulk transportation after evaluating its protective qualities on banana (Wasala *et al.*, 2012). Styrofoam, a commonly used cushioning material for fruits, has a high mechanical strength in compression, tension, bending and shear, and has smooth surface, high water and vapour resistance properties. It is also resistant to most acids and salts, and can be used repeatedly for an extended period of time.

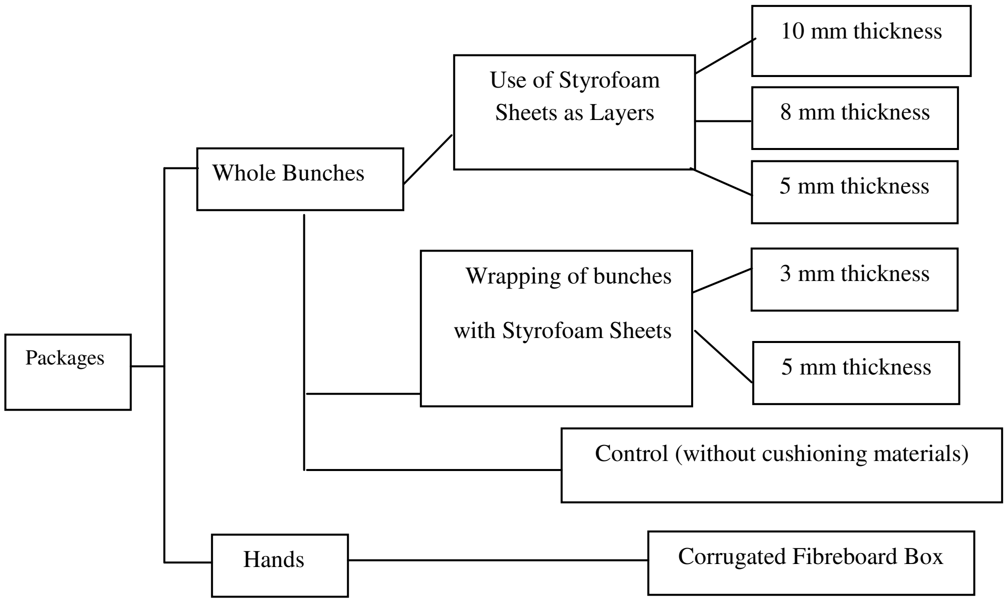

Fig. 1. Treatments used in the experiment

Design and fabrication of a transport simulation vibrator

A transport simulation vibration bed was designed and fabricated (Fig. 2) to test new packaging prototypes at laboratory level by giving road vehicle vibration conditions. This structure consists of a main frame, 0.7 kw single phase geared motor, chain drive, four connecting rods, two rotating shafts with an eccentricity and vibration table. The vibration simulator was powered by a geared electric motor. The original motor speed was reduced by the gear drive and the motor speed was controlled using a variable speed drive (VSD) connected to the motor. There is an eccentricity on four rotational shafts and this make sudden shock on the vibration bed when it is operated. Then a vertical vibration is created on the bed.

Laboratory testing of new packaging methods for whole bunches

Testing of developed packages was conducted at the engineering workshop of the Institute of Postharvest Technology, Anuradhapura in year 2012. Vertical vibration frequency of 3.5 Hz and 6 mm of amplitude for 120 min were used for this experiment to simulate the road transport condition similar to 100 km travel as reported by Hinsch *et al.*, (1993); Slaughter *et al.*, (1998) and Zhou *et al.*, (2007). Banana cultivar *Embul* was used for package testing as it is the most widely grown and highest demanding banana variety in Sri Lanka. Six packaging methods; lying of styrofoam sheets of the thickness; 10, 8 and 5 mm in between banana bunch layers, wrapping individual banana bunches with styrofoam sheets of 3 and 5 mm thickness and packaging of banana hands in telescopic type corrugated fibreboard boxes with the standard 12.5 kg capacity were subjected to testing. Banana bunches were stacked without any packaging material as the control.

After conducting the test, samples of banana bunches from each method were tested for mechanical damage and fruit quality. The experiment was repeated three times. All the banana samples obtained after the vibration test were stored under ambient conditions (Temperature: 29 ± 5^o C and Relative Humidity: 69 ± 8%) for five days.

Data collection

Data related to the environmental conditions and fruit properties at different time intervals i.e. before conducting the simulated test, immediately after the test, two and five days after the test were recorded under ambient storage conditions.

Assessment of mechanical damage and quality deterioration

Mechanically damaged fruits during harvesting were identified visually, and then weighed, converted to percentage of loss as reported by Dadzie and Orchard (1997) using Equation 01,

$$MD = \frac{W_2}{W_1} \times 100\% \qquad [01]$$

MD - Percentage of mechanical damage, W_2 - Damaged fruit weight, W_1 - Initial sample weight

Visual quality rating (VQR) and Ripeness Index (RI) were determined by visual observations of fruits and using guidelines given by Kader and Cantwell (2007).

The physiological loss in weight (PLW) of banana fruits was determined from the difference in weight of fruits at regular time intervals after conducting the experiment. Same banana samples were used to determine the weight difference from harvesting to the end of the experiment (Ram *et al.*, 2008).The firmness of banana fruits were measured using a digital fruit firmness tester with a 4 mm cylindrical shape (flat end) probe (TR Model 53205). Three readings were taken from each fruit at short, middle and long points. Respiration rate was measured based on the changes in CO_2 emission by the fruit using a gas chromatograph (Model VARIAN, CP 3800). Gas samples were collected before simulation test, after simulation test and one time per day during the storage period. The control experiment was conducted using the vibration transport simulator without any packaging or cushioning materials.

The experimental design was a Complete Randomized Design. Data gathered were analyzed using Analysis of Variance (ANOVA) by Statistical Analysis System. Percentage data was transformed to arc sin values prior to analysis (SAS Institute, Inc, 1994). Differences between treatment means were obtained by Duncan's Multiple Range Test (DMRT) at 5% significance level ($p<0.05$).

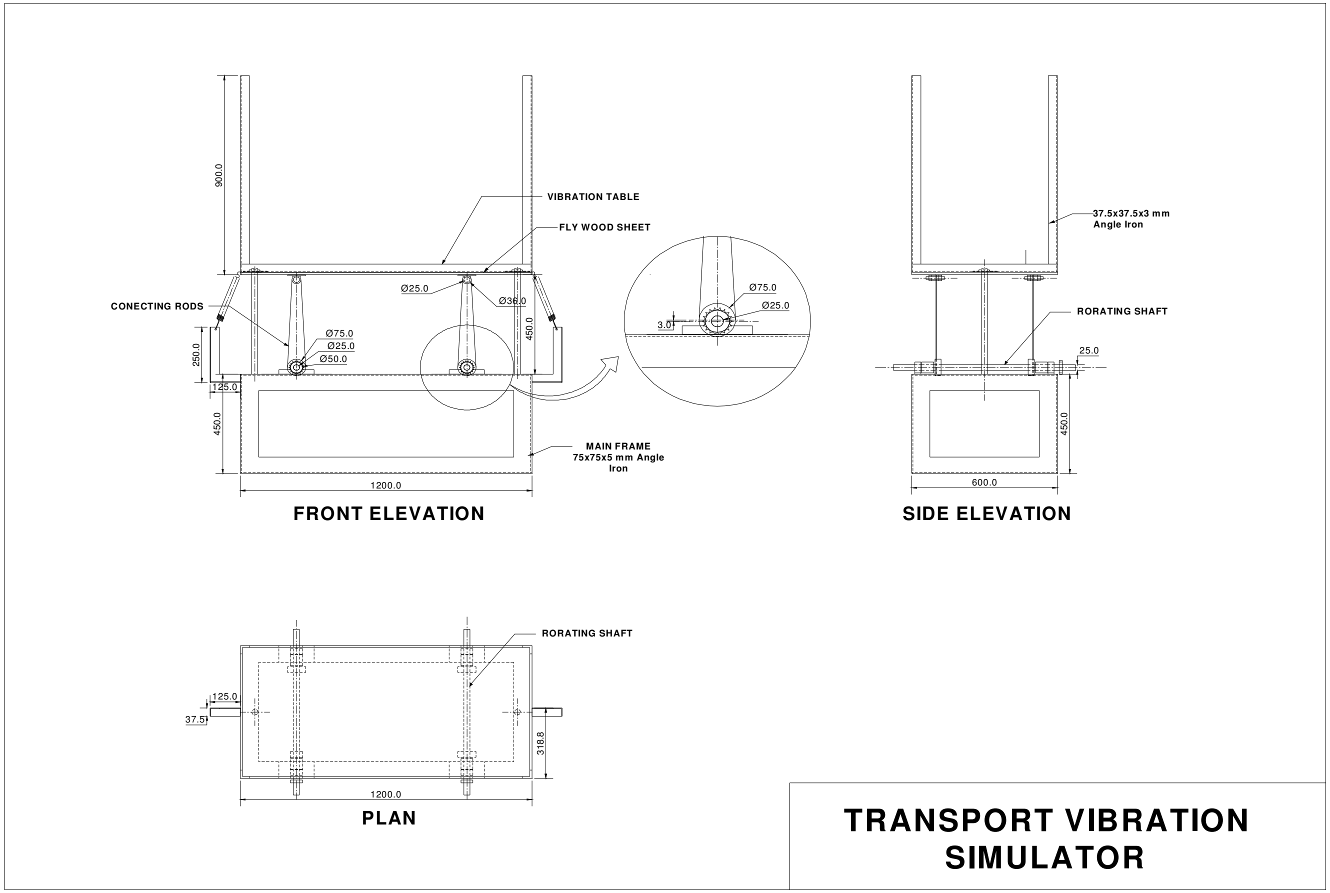

Fig. 2. Transport vibration simulator

RESULTS AND DISCUSSION

Mechanical damage to fruits

Mechanical damage to fruits under different packaging methods is presented in Table 01. The cumulative mechanical damage percentage of the control (C) after five days was significantly higher than all other packaging methods ($p>0.05$) while the lowest value was produced of fruits in the corrugated fibreboard box (P_6). The highest proportion of mechanical damages was observed at two days after the test for all methods. Mechanical damages of 10 mm and 8 mm layers (P_1 & P_2) were not significantly different. Experiments conducted with styrofoam sheets under simulated transport condition significantly reduced the mechanical damages. Vursavus and Ozguven (2004) have also reported that the use of cushioning materials can help to reduce damage to fruits during transportation.

Table 1. Mechanical damages to fruits under different packaging methods with time

	Mechanical damages						
	P_1	P_2	P_3	P_4	P_5	P_6	C
Initial	0.66^{ab}	0.75^{a}	0.60^{b}	0.71^{a}	0.68^{ab}	0.69^{ab}	0.69^{ab}
24 h after vibration	1.73^{bc}	1.79^{bc}	2.14^{b}	1.65^{c}	1.59^{c}	1.12^{d}	4.55^{a}
24 h to two days	2.63^{cd}	2.79^{c}	4.52^{b}	2.46^{cd}	2.24^{cd}	2.13^{d}	8.45^{a}
Between two to five days	2.36^{c}	2.56^{c}	3.54^{b}	2.14^{c}	2.08^{c}	1.94^{c}	7.15^{a}
Total	7.38^{cd}	7.89^{c}	10.80^{b}	6.96^{de}	6.59^{ef}	5.88^{f}	20.84^{a}

Values with the same letter at the same row are not significantly different at $p>0.05$

Packaging methods: P_1=10 mm thick styrofoam layers, P_2 = 8 mm thick styrofoam layers, P_3 = 5 mm thick styrofoam layers, P_4 = wrapping with 3 mm styrofoam, P_5 = wrapping with 5 mm styrofoam, P_6 = CFB, C = control

Fruit firmness

Loss of fruit firmness can be used as an index to estimate and measure the damages occurred during harvesting, handling and transporting process (Ranathuge *et al.*, 2008). Fruit firmness values at different time intervals for different packaging methods are shown in Table 02. Initial fruit firmness values of all methods were within the range of 77 – 82 N and fruit firmness decreased with time under all packaging methods compared to the initial values. Thakur *et al.*, (2005) also reported that along the postharvest handling and distribution channels, fruit firmness decreased due to metabolic activities. However, maximum changes were observed in fruits packed in corrugated cartoon box (P_6), while minimum changes were observed in fruits packed using 10 mm styrofoam layers (P_1). Zhou *et al.*, (2007) also reported that fruits exposed to vibration stress exhibited a faster softening and this continues during storage under ambient temperature.

Table 2. Fruit firmness under different packaging methods at different time intervals

	Firmness (N) for different packaging types						
	P1	**P2**	**P3**	**P4**	**P5**	**P6**	**C**
Initial	80.08^{a}	77.73^{a}	76.67^{a}	80.08^{a}	82.21^{a}	80.14^{a}	80.68^{a}
After vibration test	71.08^{a}	71.31^{a}	59.36^{c}	63.70^{bc}	64.63^{bc}	68.07^{ab}	53.70^{d}
2 days after	55.39^{b}	61.90^{a}	57.20^{b}	57.32^{c}	56.89^{b}	38.81^{d}	48.31^{c}
5 days after	51.19^{a}	43.02^{ab}	37.86^{bc}	41.11^{ab}	45.11^{ab}	25.38^{d}	33.77^{cd}

Values with same letter at same row are not significantly different at $p>0.05$

Packaging methods: P_1=10 mm thick styrofoam layers, P_2 = 8 mm thick styrofoam layers, P_3 = 5 mm thick styrofoam layers, P_4 =wrapping with 3 mm styrofoam, P_5 = wrapping with 5 mm styrofoam, P_6 = CFB, C = control

Physiological loss in weight (PLW)

PLW of banana fruits for tested packaging methods at different stages are shown in Table 03. The minimum total PLW was observed in whole bunches placed with 10 mm thick styrofoam layers (P1) and maximum was observed in the control. PLW of banana in storage increased from second day to fifth day in all treatments. This is due to continuous transpiration of moisture from fruits and accelerated respiration process as reported by Jindal *et al.,* (2005). These results indicated that the use of styrofoam sheets as layers or wrapping of whole banana bunches significantly reduced the PLW than the control.

Table 3. Effect of different packaging methods on physiological loss in weight

	PLW (%) for different packaging types						
	P1	**P2**	**P3**	**P4**	**P5**	**P6**	**C**
During vibration testing	2.32^{c}	2.56^{bc}	3.95^{ab}	2.51^{bc}	2.86^{bc}	2.01^{c}	4.54^{a}
During two days after test	1.56^{ab}	1.62^{ab}	1.90^{a}	1.45^{ab}	1.35^{ab}	2.22^{ab}	2.09^{a}
During two to five days	2.24^{bc}	2.29^{bc}	3.20^{a}	3.15^{a}	3.02^{ab}	3.71^{a}	2.90^{ab}
Cumulative loss	6.12^{c}	6.48^{c}	9.05^{a}	7.11^{bc}	7.23^{bc}	7.94^{b}	9.53^{a}

Values with the same letter within the same row are not significantly different at $p>0.05$

Packaging methods: P_1=10 mm thick styrofoam layers, P_2 = 8 mm thick styrofoam layers, P_3 = 5 mm thick styrofoam layers, P_4 = wrapping with 3 mm styrofoam, P_5 = wrapping with 5 mm styrofoam, P_6 = CFB, C = control

Visual quality rating (VQR)

Changes of visual qualities of banana tested are shown in the Fig. 3. VQR of the banana bunches did not have any symptoms of deterioration at the initial stage. After subjecting to the simulated vibration test, VQR of control (C) was in good condition (rate - 7) and changed continuously to fair condition at two days later and to poor condition (rate – 3) at fifth day.

VQR of banana packed using 10 and 8 mm styrofoam sheets as layers, wrapped with 5 mm sheets and in corrugated boxes were observed at good quality (rate – 7) five days after the test. These results indicated that the use of packaging for banana transportation maintains visual quality. Use of cushioning material for the fruit packaging during bulk transportation can help in reducing bruising (Vursavus and Ozguven, 2004). During storage period, peel colour changes were observed due to abrasion and impact damage which directly influenced the visual quality. Browning of the damaged regions occurs due to oxidation of poly phenols (enzyme activity) giving an unpleasant appearance to the consumer. Similar findings were reported by Maia *et al.*, (2011) for Banana.

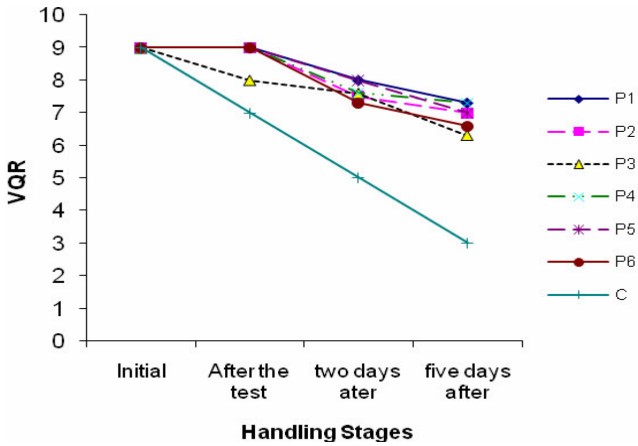

Fig. 3. Effect of different packaging methods on visual quality of fruits

Packaging methods: P_1=10 mm thick styrofoam layers, P_2 = 8 mm thick styrofoam layers, P_3 = 5 mm thick styrofoam layers, P_4 = wrapping with 3 mm styrofoam, P_5 = wrapping with 5 mm styrofoam, P_6 = CFB , C =control

Visual quality ratings: 9 = Excellent **(**Essentially no symptoms of deterioration), 7= Good (minor symptoms of deterioration, not objectionable), 5 = Fair (deterioration evident, but not serious, limit of saleability), 3 = Poor **(**serious deterioration, limit of usability), 1= Extremely poor **(**Not usable)

Ripeness index (RI)

Changes of ripeness index of banana fruits are presented in Fig. 4. At the initial stage, all banana bunches were in mature green colour. After the test, bananas in CFB changed to light green colour (RI-2) while other bananas remained unchanged. Bananas packed in CFB and the control ripened early. Ferris *et al.*, (1998) have also reported that cutting of banana cause reduction of ripening period. Fruit sellers have also recognized that fast ripening is the main problem they face when hands are separated.

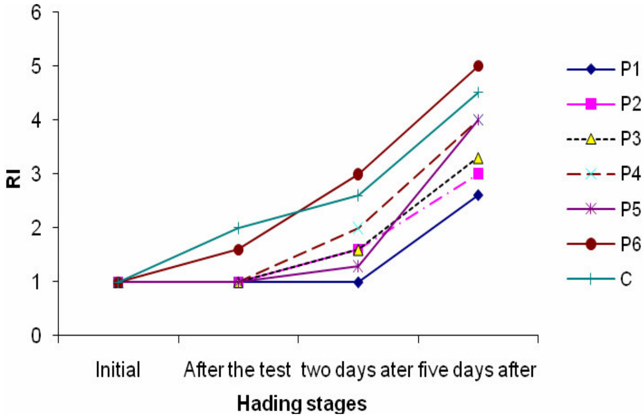

Fig. 4. Effect on banana ripeness index under different packaging methods

Packaging methods: P_1=10 mm thick styrofoam layers, P_2 = 8 mm thick styrofoam layers, P_3 = 5 mm thick styrofoam layers, P_4 = wrapping with 3 mm styrofoam, P_5 = wrapping with 5 mm styrofoam, P_6 = CFB, C = control

Banana ripeness indexes: 1 = all green, 2 = light green, 3-50% green, 50% yellow, 4 = more yellow than green, 5 = yellow with green tips, 6 = full yellow, and 7 = yellow flecked with brown

Respiration rate of fruits

Respiration rate of banana fruits is shown in Fig. 5. Higher respiration rates were indicated in the control and P6 where significantly higher mechanical damages and ripening rates were recorded. Liadó and Domínguez (1998) showed that the level of mechanical damage significantly affected the physiological development of the fruits (respiration) and Zhou *et al.*, (2007) stated that vibration treatment could result in changes in respiration. The respiration rate during the experimental period remained between 27 – 81 mg CO_2kg^{-1} h^{-1}. Almost similar results were shown by Wall (2007) for banana. Mechanically damaged fruits have a higher rate of starch-sugar conversion and this simulates respiration process (Maia *et al.*, 2011).

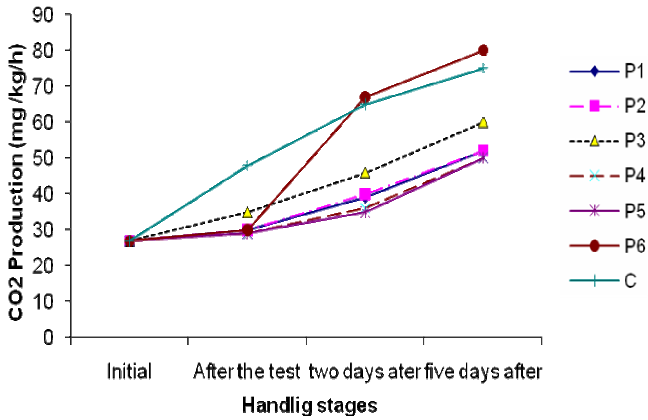

Fig. 5. Effect of different packaging methods on respiration rate of banana

Packaging methods: P_1-10 mm thick styrofoam layers, P_2 - 8 mm thick styrofoam layers, P_3 - 5 mm thick styrofoam layers, P_4 - wrapping with 3 mm styrofoam, P_5 - wrapping with 5 mm styrofoam, P_6 – CFB , C –control

Postharvest diseases

Crown rot disease condition was observed on cut surfaces of banana hands tested in CFBs during the storage period under ambient conditions from second day after the test. Sarananda and Wijerathnam (1994) also reported that this disease in *Embul* cultivar is common under ambient conditions.

Packaging cost

The unit cost of packaging per kilogram of *Embul* banana for different packaging methods are shown in Table 04.

Table 4. The unit cost of packaging for different packaging methods

	Packaging Types						
	P1	P2	P3	P4	P5	P6	C
Packaging cost (Rs./kg)	1.48	0.79	0.67	2.05	1.35	2.60	-

Packaging methods: P_1=10 mm thick styrofoam layers, P_2 = 8 mm thick styrofoam layers, P_3 = 5 mm thick styrofoam layers, P_4 = wrapping with 3 mm styrofoam, P_5 = wrapping with 5 mm styrofoam, P_6 = CFB, C = control

Low packaging costs per one kilogram were for 3 mm and 8 mm styrofoam layers while packaging in corrugated fibreboard box is the most expensive (Fig. 8)

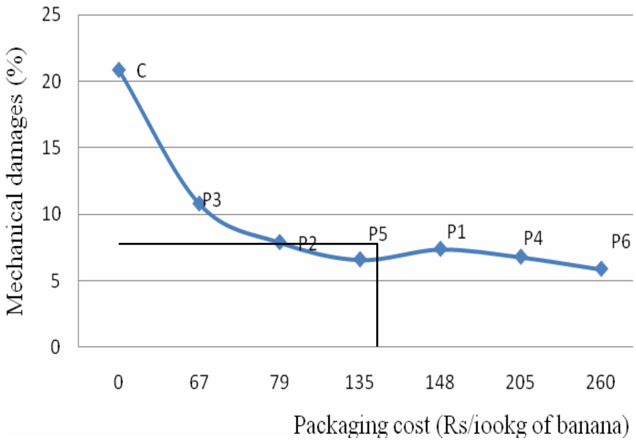

Fig. 8. Packaging cost and postharvest losses of banana

CONCLUSION

Use of styrofoam sheets with 8 mm and 10 mm as a cushioning material between the layers of banana bunches was found to be a better method for banana bulk transportation as whole bunches. However, there was no significant difference of damage between two thicknesses. Therefore, considering the technical and economical feasibility and the practicality of operation, laying of 8 mm styrofoam sheets in between banana bunch layers during truck loading prior to long distance transportation could be recommended.

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