VG516

Mechanical harvesting of fresh market tomatoes

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INDUSTRY SUMMARY

The mechanical harvesting of fresh market tomatoes project was undertaken on behalf of the Bowen Horticultural Automation Group during 1996. The project objective was to re-examine potential for harvesting fresh market tomatoes by machine. The group had identified tomato/vine separation as the major factor in preventing the development of a mechanical harvester and research efforts were directed at this problem.

The project examined seven methods of tomato/vine separation based on the concepts of shaking, stripping and viscous drag. Forces required to separate the tomato from the vine at different angles were measured. The bruising and puncture resistance of two different tomato varieties was examined.

Eagle variety tomatoes were found to be more suitable than Tornado for mechanical harvesting. They were more resistant to bruising and punctures and had a lower separation force. Allowable drop heights onto an unpadded, hard surface were calculated as 235 mm for Eagle and 110 mm for Tornado. Separation force was lower when the force was applied at an angle to the stem.

The force balanced shaker, commonly employed in processing tomato harvesters, offers the most efficient means of separation studied. By optimising the amplitude and frequency of shake, this method could be successfully used in fresh market tomato harvesters. Amplitude of shake was more important than frequency for tomato removal. It appears that the actual separation method used is less likely to cause mechanical damage to the tomatoes than the handling process before and after separation.

In July 1996, FMC Corporation imported the Sandei tomato harvester from Italy and subsequently trialed it on farms in Victoria. This machine successfully harvests the tomato vines from plastic mulch covered beds and separates the tomatoes from the vine. Mechanical damage caused by this harvester was due to drops and impacts rather than the separation process. FMC have indicated their intention to develop the harvester to the point where it will be suitable for harvesting fresh market tomatoes. This is an appropriate course for future development of a machine for the industry for several reasons; the Sandei is a commercial machine already in production which avoids the need for ground-up machine development; FMC will fund development costs and carry out development engineering; if necessary the machine could be fitted with an alternate separation system.

Future research and development may be required relating to delivery of tomatoes from the harvester to field trailers and a systems approach to the overall bulk handling operation.

TECHNICAL SUMMARY

Two varieties of fresh market tomatoes, Eagle and Tornado, were tested for their suitability for mechanical harvesting. Eagle required less force to separate the tomato from the stem than Tornado (34.3 N and 39.5 N respectively at green maturity stage). The separation force was significantly decreased in both varieties and tomatoes were more likely to be separated completely from the calyx as the angle of application force to the stem increased. No relationship between calyx attachment area and separation force was evident. Differences in separation force between maturity stages was not sufficient for use as a basis for machine selectivity. At lower energy inputs, a separating mechanism that causes the separating force to be applied at an angle to the stem will have a greater likelihood of success.

Eagle was less susceptible to bruising and puncturing than Tornado. For a threshold bruise of 64 mm^3 and an energy input of 1 J, Tornado recorded 20% bruising compared to 0% in Eagle. The acceptable level of bruising will dictate maximum drop height for different varieties at different maturity stages. Green mature Eagle and Tornado should withstand drop heights of 235 mm and 110 mm respectively, onto an unpadded hard surface, in 95% of events. No relationship between bruise volume and energy was evident for the energy levels tested.

Separation of tomatoes from the vine was identified by industry as being the main constraint to harvester development. Seven methods of tomato separation based on the concepts of shaking, stripping and viscous drag were investigated to determine which, if any, warranted further development.

For shaking, results showed that separation was more dependent on amplitude than frequency of movement. Tomatoes with short pedicels and relatively stiff peduncles are more likely to separate at lower amplitudes and frequencies due to higher energy transfers. Stripping trials showed that this concept may be developed further using pinch rollers to directly strip the tomatoes from harvested vines. Viscous drag is impractical since vine velocity required for effective separation is too high.

The force balanced shaker methods for effecting separation were the most practical and offer the greatest potential for success with appropriate development and optimisation of shaking parameters. The actual separation method used is less likely to cause mechanical damage to the tomatoes than the handling processes before and after separation.

Modification of the Sandei harvester (imported by FMC in 1996) offers the most expedient option for development of a suitable fresh market tomato harvester. It employs a reciprocating belt system which could be fitted with a force balanced shaker drive to more fully test the concept developed in trials. Future investigation may be required into to delivery of tomatoes from the harvester to field trailers and a systems approach to the overall bulk handling operation.

1.0 INVESTIGATION OF PROCESSING TOMATO HARVESTING MACHINERY

1.1 Introduction

Machinery used for the harvesting of processing tomatoes in Victoria was examined to determine if it could be adapted or modified for harvesting fresh market tomatoes (FMT). Of particular interest were the principles employed for plant pick-up, fruit/vine separation, fruit handling and the forces imparted to tomatoes by the harvesting machinery. For vine/fruit separation all of the harvesters examined used a force balanced shaker, driving a drum equipped with fibreglass fingers. Although this system appears to be quite rough on processing tomatoes it warranted further investigation because of its high separating efficiency. The pick-up fronts examined showed little scope for successful adaptation to FMT. Similarly the bulk handling systems used were deemed unsuitable for FMT.

The axial fruit removal force (FRF) for different varieties of processing tomatoes was measured for comparison to FMT grown in the Bowen district. This force was found to be approximately half that measured for FMT in preliminary trials conducted on the Atherton Tablelands.

Attempts to determine acceleration forces subjected to tomatoes in machines using an instrumented sphere were abandoned after the sphere became unserviceable.

1.2 Instrumented Sphere

The instrumented sphere (IS) comprises accelerometers, a microprocessor unit with memory and a rechargeable battery, enclosed in a spherical shell. Changes in direction (acceleration) due to impact forces are measured and stored in memory. Subsequently, areas in the machine where mechanical damage is likely to occur can be identified (in combination with video footage or time data). Passing the IS through the different machines would have identified typical inherent forces which could then be related to potential damage levels in FMT. However, after several passes through the Pik Rite harvester, the IS was rendered unserviceable

1.3 Processing Tomato Harvesters

Currently, there are four main manufactures of tomato harvesters operated in the USA; FMC, Blackwelder, Button-Johnson and more recently Pik Rite. The general configuration and principle of operation of machines is similar. Australian producers typically import used tomato harvesting machinery from the USA due to small areas of production and the high cost of new machines. About 50% of the machines in Australia are Blackwelders.

Functionally, the two basic areas of machine operation are the systems employed for vine pick-up and fruit separation.

1.3.1 Vine Pick-up

FMC

A reciprocating sickle bar operating below ground level at approximately 1 Hz is used to sever the vine. This mechanism caused a large amount of soil and clods to be fed onto the pick-up conveyor. Subsequent attempts to remove the clods resulted in an estimated 10% loss of tomatoes from the harvester. It is probable that the knife section would experience a high wear rate due to soil contact. A twin overhead chain/finger system was used to assist the passage of tomato vines to the separator due to the steep inclination of the pick-up conveyor.

Blackwelder

A spear point, running below ground level is used to sever the tomato vine. Vine feeding onto the conveyor is aided by a rubber bat reel. No overhead aid was required to assist the vine up the conveyor. The owner had modified the pick-up front by removing the leading edges and claimed that this assisted pick-up by preventing the build up of plant material.

Button Johnson

A spear point, running below ground level is used to sever the tomato vine. The pick-up comprises a chain conveyor and twin overhead chain/fingers and is almost identical to that employed on the FMC.

Pik Rite

Twin, counter rotating discs were used to sever the vine below ground level. Vine gathering was aided by belts running in conjunction with the cut-off discs. Once severed, the vine was carried into the separating mechanism by a rod conveyor with every sixth rod raised approximately 20 mm.

1.3.2 Separator

Various mechanisms have been used previously for tomato/vine separation; eg. reciprocating horizontal chain, offset crank, and straw walker type systems. However, all modern machines are now fitted with force balanced shaker systems. Force balanced shaker systems (FBS) utilise rotating eccentric masses constrained to produce an oscillating torque about a centre support shaft. The forces generated by the rotating masses balance each other and produce angular oscillations of the main shaft with minimal vibration transmission to the supporting structure (Studer *et al.*, 1982). The separator generally consists of a drum (mounted axially to the oscillating centre support shaft) with fibreglass fingers attached to it. On some machines the separator drum is fitted with a separate positive drive.

FMC

The separator comprises a single, free-wheel, FBS drum with the tomato vines being drawn underneath the drum by a driven belt system. The detached tomatoes fall to a conveyor below. In other free-wheeling FBS systems, (eg. those used in berry harvesters) movement of the machine relative to the fixed plant causes overall rotation of the FBS shaft. In the tomato harvester, material flow is insufficient to rotate the FBS drum and the driven belt system is required to maintain feed to the separator. The FMC was observed to achieve a high degree of fruit separation, although some detached tomatoes were passed through the machine with the vine mass.

Blackwelder

The separator comprises a single, driven, FBS drum. The tomato vines are passed underneath the separator drum and detached tomatoes fall to the belt conveyor below. This arrangement is similar to those employed on the FMC and Button Johnson machines. The larger size drum increases the amplitude of the oscillation compared to the Pik Rite.

Button Johnson

The Button Johnson FBS system is almost identical to that of the Blackwelder due to commonality of components. Performance was also similar to the Blackwelder since 100% separation was not achieved and a significant proportion of ripe tomatoes were passed through the machine. The owner/operator believed this was due to inexperience with a relatively new machine.

Pik Rite

The separator comprises two, driven, FBS drums. The tomato vines are passed over the drums at a rate determined by the speed of the positive drive motor. The frequency and amplitude of finger vibration is determined by the angular speed (rpm) of the rotating masses. Although the drums are smaller than those on other machines, the time available for separation is maintained since there are two drums (greater surface area). By feeding the vines over the top of the drums the fruit drop height is approximately 800 mm which could cause significant fruit damage. The Pik Rite was observed to achieve better fruit detachment than the Blackwelder when operated in the same crop.

1.4 Bulk Handling

All harvesting operations employed the same bulk handling system, ie. small wooden bins provided by the processing company were carried on a field trailer, towed by a tractor which chased the harvester. The delivery conveyor from the harvester dropped tomatoes from up to 1.5 m above the bed of the empty bins (depending on the skill/diligence of the operator). In-field and on farm roads, trailers were towed at the highest speed achievable by the tractors. This caused significant bouncing/vibration and soil from the tractor tyres was thrown into the following bins of tomatoes.

While most tomatoes in bins exhibited little sign of external damage, the generally rough handling process, ie. harvesting and haul out, caused the tomatoes to break down rapidly. This breakdown is significant and requires that processing tomatoes sold in the markets for home sauce production be hand picked by contractors to increase shelf life.

Current practice for handling machine harvested processing tomatoes is unsuitable for FMT.

1.5 Field Losses

The tomato industry development officer estimated that up to 15 to 20% of the crop was lost during harvesting. This does not include damaged tomatoes in bins (postharvest). Categories of loss were identified and estimated as follows:

5% - tractor and harvester running over adjacent rows (not harvested);
5-10% - machine losses due to sorting eg. soil belt, electric eye, etc;
5% - fruit remaining attached to vine and passed through machine.

1.6 Fruit Removal Force

Two varieties of processing tomatoes were tested for axial FRF using a load cell and datalogger. Variety H8704 is recognised as being one of the more difficult varieties to separate the fruit from the vine and had a FRF of 13.6 N. One of the more common varieties. H9280 had an average FRF of 10.7 N. These values can be compared to those measured for the Tornado variety of 25.2 N in preliminary trials. This suggests that while a machine may achieve 90 to 95% separation in processing tomatoes it would be significantly less effective in FMT.

2.0 TOMATO REMOVAL FORCES

2.1 Introduction

Fluck (1970) and Alper *et al.* (1984) have tested both processing and FMT to determine the force required for separation of the fruit from the vine, ie. FRF. They found differences between varieties and in some instances between maturaties. In citrus, Hield *et al.* (1967) found that the FRF was reduced if applied at an angle of 45° from the stem axis. It was assumed this was due to causing a tensile failure over a reduced area of the fruit/stem attachment area which then progressed rapidly through the remaining area.

Tests were conducted to determine if Bowen district grown tomatoes displayed varietal or maturity differences with respect to FRF and to assess the effect of varying the angle of application of force on FRF. With the varieties tested, results showed it would not be possible to use maturity to increase the effectiveness of mechanical harvesting or as a basis for harvester selectivity (ie. prevent mature red fruit from entering the harvester by pre-detachment from the vine or pass immature fruit through the separator without detachment). FRF was observed to decrease as the angle of application of the separating force increased. This suggests that any pick-up mechanism will have to produce forces less than these threshold values to prevent pre-harvest losses. Likewise any separating mechanism that induces a separating force at an angle to the stem axis may have a greater separation efficacy and permit reduced separation forces resulting in less mechanical damage. It could also increase the level of complete calyx detachment, further reducing the potential for mechanical damage.

The results of these tests can be applied to design and characteristics of future machines such as separator speed, optimum presentation of vine and fruit in the separator and allowable forces during pick-up.

2.2 Method

Tensile force required to separate fruit from the vine was examined for two commercial FMT varieties, Tornado and Eagle and to a common processing variety, Zenith, over a range of fruit maturaties:

a. immature green - fruit not ready to be harvested
b. green mature - fruit at normal harvesting stage
c. breaker - fruit between beginning to colour and ¼ colour
d. red - fruit at full ripe stage

and at three angles relative to the stem axis:

a. 0°
b. 45°
c. 90°

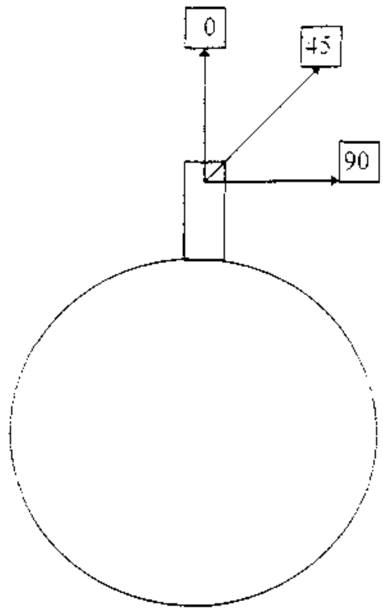

Figure 1: Angles of application of force to tomato stems.

The force was applied manually by means of a small claw attached to a 50 kg load cell. Using a datalogger, the maximum force applied through the load cell was recorded. The stem separation point, calyx diameter and fruit mass was also noted.

2.3 Results and Discussion

Results were analysed to determine the effect of maturity and angle of application of the separation force on FRF. Each variety was assessed separately. Data analysis required a $ln(x+1)$ transformation. Results of FRF tests are shown in Tables 1, 2 and 3 for the three varieties Eagle, Tornado and Zenith, respectively.

Table 1: Mean FRF (N) - angle of application and maturity - Eagle

Force Angle	*MaturityStage*			
	Immature	***Green Mature***	***Breaker***	***Red***
0°	32.26 h	34.32 h	26.68 gh	20.88 g
45°	11.20 ef	13.29 f	11.38 ef	7.73 de
90°	5.57 cd	1.35 a	4.37 bc	3.25 b

back transformed means - means with the same letter are not significantly different at P=0.05

Table 2: Mean FRF (N) - angle of application and maturity - Tornado

Force Angle	*Maturity Stage*			
	Immature	***Green Mature***	***Breaker***	***Red***
0°	43.38 g	39.46 g	32.51 fg	24.85 ef
45°	18.90 cde	14.24 c	20.74 de	17.32 cd
90°	6.57 ab	5.94 ab	4.88 a	7.35 b

back transformed means - means with the same letter are not significantly different at P=0.05

Table 3: Mean FRF (N) - angle of application and maturity - Zenith

Force Angle	*Maturity Stage*			
	Immature	***Green Mature***	***Breaker***	***Red***
0°	n/a	8.90 d	8.60 cd	8.22 cd
45°	n/a	7.75 cd	6.35 cd	5.80 c
90°	n/a	0.99 a	1.14 a	3.25 b

back transformed means - means with the same letter are not significantly different at P=0.05

Recorded FRF was higher for Tornado than Eagle for all combinations of maturity and force application angles of 0° and 45°. FRF for FMT varieties was 3 to 4 times greater than the processing variety Zenith. These results are similar to those obtained by Alper *et al.* (1984), who recorded a range of 21 to 32 N and 15 to 28 N, for 5 jointless varieties of FMT at the green mature and red ripe stage respectively.

The FRF for Eagle and Tornado was significantly lower at force application angles of 45° than 0° and also significantly lower at 90° than 45° (Tables 1 and 2). For Eagle and Tornado, FRF generally decreased as tomatoes matured though this was only significant for red fruit compared to immature and green mature for force application angles of 0° and 45°.

The point of separation was noted for each tomato tested. For force application along the stem axis (0°), 73 % and 79 % of the calyx were removed completely from Eagle and Tornado respectively. These results were significantly less than those recorded for 45° and 90° force application angles, which resulted in 100 % calyx removal for both FMT varieties. When the calyx was not removed, it was usually due to the stem exhibiting tensile failure. The separation point for Zenith depended on tomato maturity and the force application angle.

Mass and stem attachment area were measured to determine if they affected FRF. Only immature Eagle tomatoes showed a significant relationship between FRF, mass and area. FRF increased with mass and attachment area. No relationships were evident in Tornado.

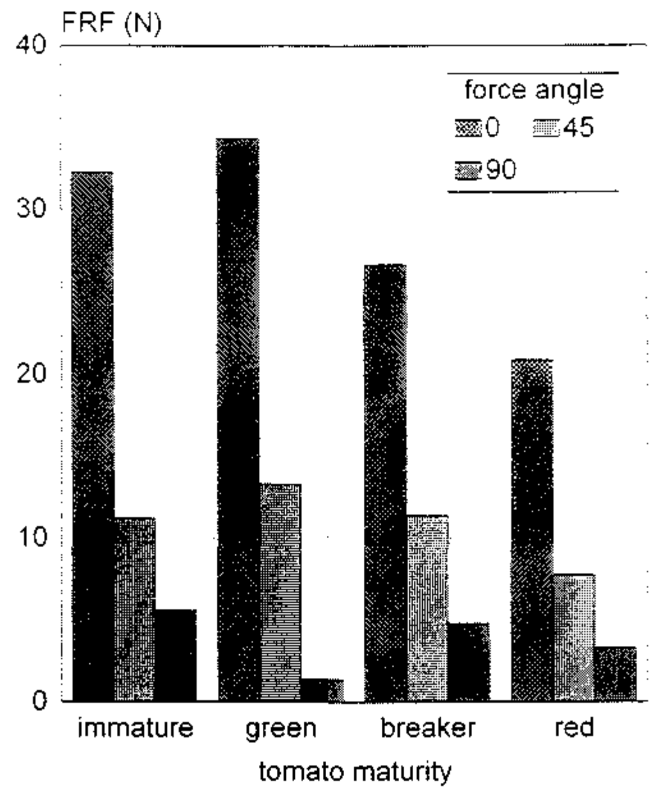

Figure 2: Effect of tomato maturity and angle of applied force on FRF - Eagle

2.4 Conclusions

For Eagle and Tornado, FRF is significantly decreased as the angle of separating force increases, independent of maturity stage.

For Eagle, tomatoes at the red maturity stage have a significantly lower detachment force than green tomatoes at angles of applied force of 0° and 45°. Tornado only exhibited this difference for applied force at 0°.

For Eagle and Tornado, immature tomatoes do not have a significantly higher FRF than other maturity stages excepting (in some instances) the red maturity stage.

The processing variety Zenith, had a much lower FRF than the FMT varieties Eagle and Tornado.

Separation of the vine from the tomato is significantly more likely to occur at the tomato when the separating force is applied at angles of 45° or more.

No general, significant relationship was found between the FRF and the mass of the tomato or between the FRF and stem attachment area for tomatoes of harvest maturity. Therefore, selection for smaller calyx attachment area will not necessarily reduce the force required for fruit/vine separation.

2.6 References

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3.0 BRUISING AND PUNCTURE RESISTANCE OF TOMATOES

3.1 Introduction

Four main types of damage are generally associated with the handling of fresh produce; cuts and punctures, compressions, impacts, and vibrations (Wills, *et al.*, 1989). Compression, impact and vibration damage, result from the dissipation of energy imparted to the fruit. It is instantaneous but may not be obvious until a secondary reaction such as discolouration due to enzyme reactions occurs. Holt, Schoorl and Muirhead (1983) further describe the nature of mechanical damage in terms of the actual physiological response:

> *It is characterised by cell bursting in bruising; separation of tissue along shear surfaces in slip; tearing apart in cracking and by scuffing and scoring in abrasion.*

Mechanical damage from cuts and punctures can be alleviated by removing sharp protrusions and edges which cause the damage. Bruising damage caused by the bulk handling of fruit during harvest, packing and transport is less easily prevented due to the inherent nature of the systems which cause impact and compression loads between fruit and fruit and between fruit and hard surfaces.

While considerable research into the mechanisms of apple bruising has been conducted, little work appears to have been carried out with tomatoes. Thompson, Lopresti and Anning (1996) have examined bruising in tomato packing lines.

Machine harvesting of FMT subjects the fruit to forces that may cause bruising and punctures. Threshold values of input energies that will damage tomatoes are required to evaluate and improve machinery design. Experiments were conducted to determine if a relationship between impact bruising, maturity, and the level of input energy could be established and to measure the resistance of various varieties to skin puncture. A further experiment was also conducted to determine the effect of multiple impacts on bruising.

No relationship could be determined between bruise volume and energy for the energy levels tested though red maturity stage tomatoes were shown to bruise more easily than green or breaker stage tomatoes. Based on the results of bruising trials, allowable mature green stage drop heights of 235 and 110 mm were calculated for Eagle and Tornado varieties respectively. Eagle was more resistant to bruising and puncturing than Tornado and would therefore be more suitable for machine harvesting.

Future evaluation of harvesting machinery should be conducted using a tomato variety that will increase the chance of a successful outcome.

3.2 Method

Two varieties of FMT, Eagle and Tornado were harvested at three different maturity levels; green mature, breaker, and red. Tomatoes of each maturity level were subjected to impact energies of 0.25 J, 0.5 J, 1.0 J, and 2.0 J. The impact was imparted by dropping a hard 45 mm diameter sphere weighing 98 g down specific lengths of 50 mm diameter PVC tube onto tomatoes positioned on a flat padded surface. Multiple impacts were effected by repeatedly dropping the sphere onto the same point on the tomato surface. Ten tomatoes of each variety and maturity stage were used in the single impact tests. Only Eagle was assessed for multiple impacts.

After impact testing, red and green/breaker tomatoes were stored for 7 and 14 days respectively at 16°C prior to assessment. Measurement of bruising resulting from the tests included the diameter and depth (after dissection) of bruising. A severity rating for bruising was based on the five point scale developed by Studer (1981) where 1 implies no damage recorded and 5 is the most severe.

Resistance to skin puncture was measured using a standard 8 mm diameter plunger fitted to a hand penetrometer. Force was manually applied to the penetrometer until skin failure occurred. Ten tomatoes of each variety and maturity were used for each test.

3.3 Results and Discussion

The test method used for impacting was devised to allow rapid testing of a large number of tomatoes. It avoided the need to individually weigh and identify each tomato but resulted in problems when determining the actual energy converted to bruising.

The total energy available for impact can be calculated from the drop height and sphere mass. Whilst the majority of the energy will be dissipated in the initial impact, several smaller impacts may also occur before the impacting sphere comes to rest. Additionally, the padding placed between the tomato and the hard surface will also dissipate some energy. Therefore, the bruise energy is less than the total energy and this method is not truly indicative of the energy causing bruising. However, it can be used to compare varietal differences and the effect of multiple impacts.

Holt and Schoorl (1977) successfully modelled apple bruises based on an idealised bruise, where the bruise took the form of a spherical section. Based on this finding the depth and volume of a bruise can be calculated for a measured diameter of bruise as depicted by the curve shown in Figure 1. Bruise depth in tomatoes was found to be highly variable and generally much higher than for the spherical model, especially for red maturity stage (Figure 1). When applied to tomato bruises the model was not found to be representative due to the non-homogeneous nature of the tomatoes. Bruise volumes for tomatoes were calculated using an elliptical model based on the measured diameter and depth.

Industry accepts that some bruising is inevitable due to handling. Accordingly, the results shown in Figures 1 and 2 are for bruise volumes greater than a threshold value of 64 mm^3, which is equivalent to a bruise 10 mm in diameter and 1 mm deep at the centre.

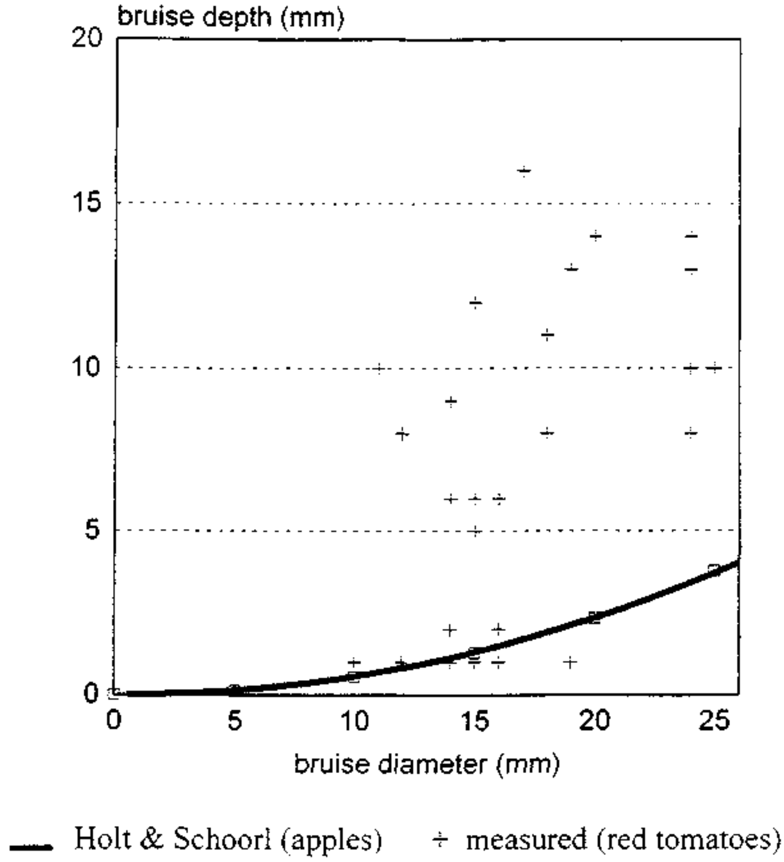

Figure 1: Depth of bruising at given bruise diameters.

Figures 2 and 3 show the percentage of tomatoes with bruising after being subjected to the four impact energies. Red tomatoes are more prone to bruising at all the energy inputs compared to tomatoes at either the green or breaker maturity stages. Eagle variety tomatoes at the mature green stage appear much less likely to bruise than Tornado. Anomalies in the results for breaker stage Tornado suggests that sample size should be increased to account for tomato variability.

The effect of multiple impacts (represented as total energy input) on tomato bruising is compared to that for single impact energy for Eagle tomatoes in Figure 4. For green and red maturity stage tomatoes, respective bruising levels are generally the same for equivalent levels of energy input (single or multiple impact). For breaker stage tomatoes there appears to be significant difference in bruising levels dependent on the number of impacts. For equivalent input energy, breaker tomatoes exhibited 80 to 100% more bruising occurrences when subjected to multiple impacts than for a single impact.

Thompson, Lopresti and Anning (1996) found that green Tempest variety tomatoes were able to withstand a drop height of 550 mm onto a padded steel surface before displaying signs of damage. The allowable drop height before damage occurred on an unpadded steel surface was reduced to 350 mm. Note that Tempest variety tomatoes would be more like Tornado than Eagle.

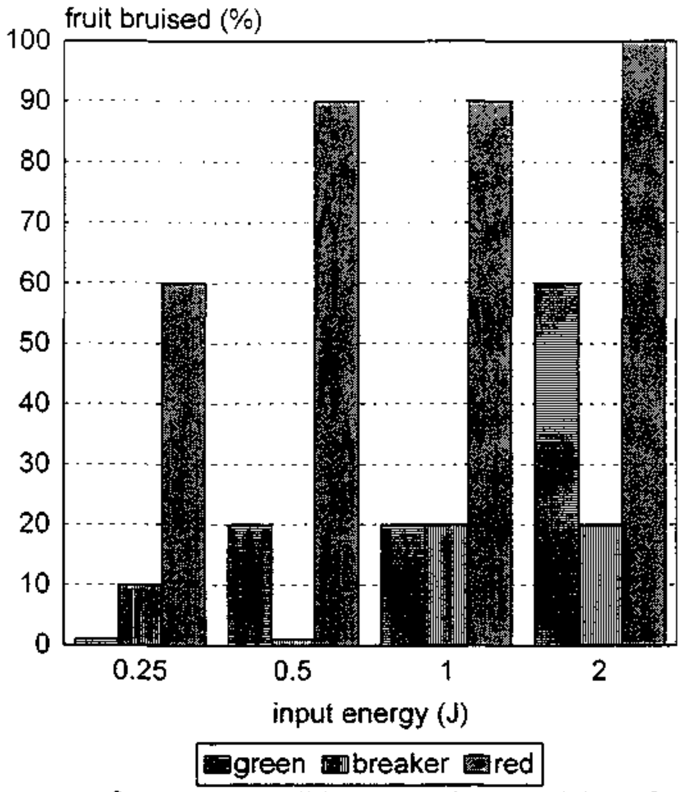

Figure 2: Percentage of tomatoes exhibiting threshold bruising after impacting at 4 energy levels - Tornado.

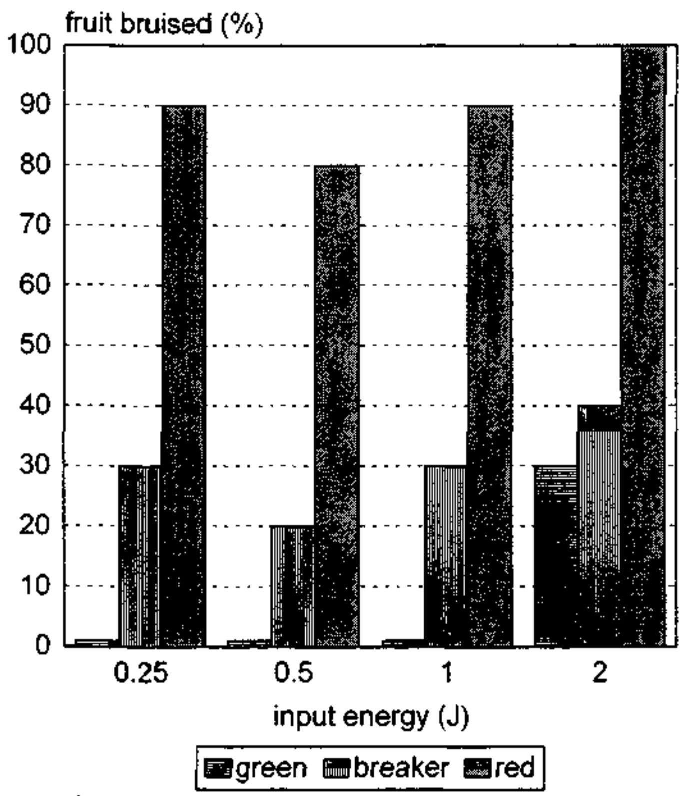

Figure 3: Percentage of tomatoes exhibiting threshold bruising after impacting at 4 energy levels - Eagle.

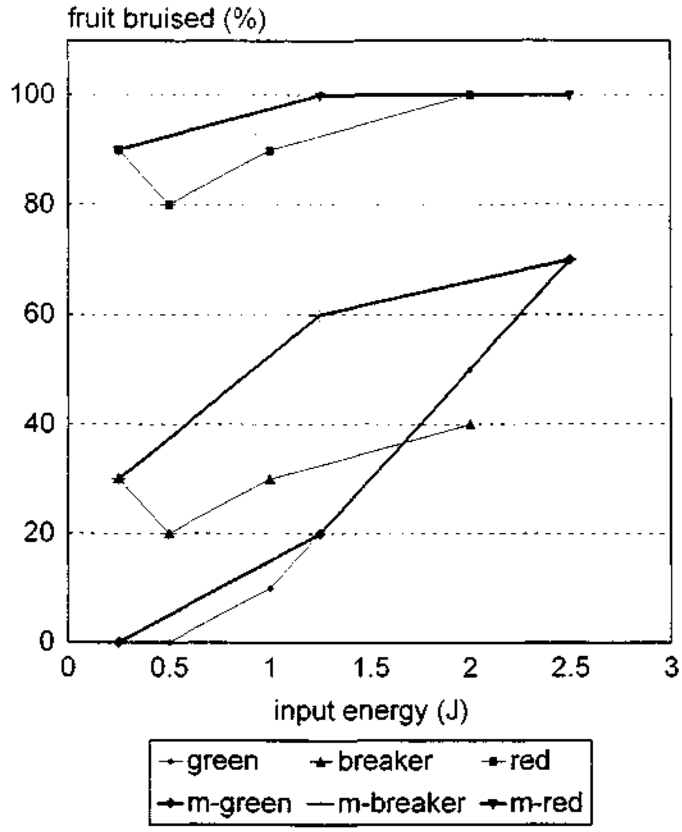

Figure 4: Comparison of % bruised tomatoes after single and multiple impacts.

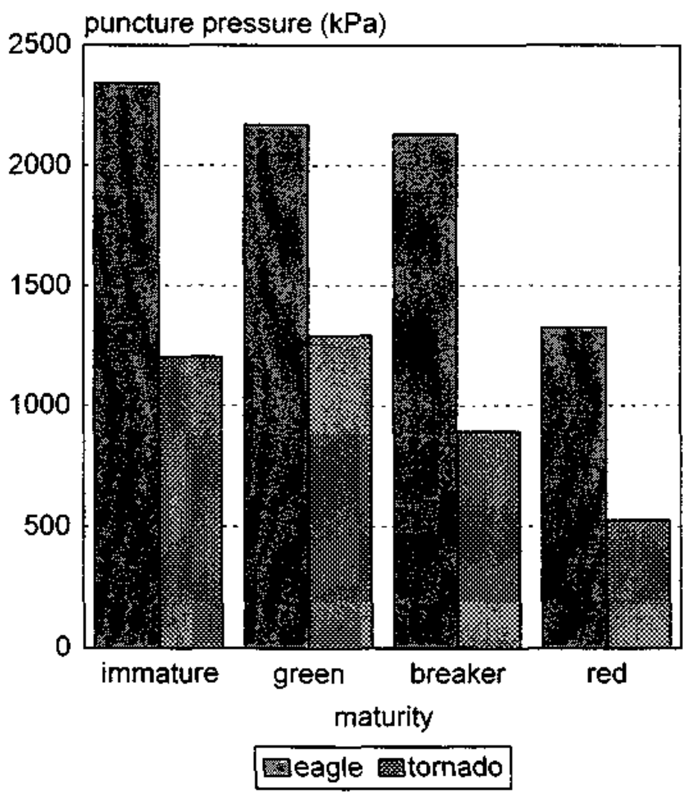

Figure 5: Average pressure required to induce puncture failure.

Figure 3 shows that green mature Eagle tomatoes can withstand a 1 J impact under the test conditions before bruising is initiated. Assuming test conditions approximate a drop onto a padded surface as used by Thompson, Lopresti and Anning then it is possible to calculate a maximum allowable drop heights based on both the average mass (50% of tomatoes bruised) and 95% mass (5% of tomatoes bruised). For an average mass of 193 g the calculated drop height is 520 mm; for a 95% mass of 259 g the drop height is 390 mm.

Thompson, Lopresti and Anning also showed that allowable drop height was reduced by about 60% for an unpadded steel surface. Assuming a similar response for Eagle tomatoes, the allowable drop heights are reduced to 310 and 235 mm respectively (for a hard unpadded surface). These allowable drop heights would be further reduced by about 50% for Tornado variety tomatoes.

At lower energy input levels where no bruising occurred, impact energy was dissipated by elastic deformation At higher energy levels, dissection of bruises revealed that impact energy was converted to bruise energy in several forms. Plate 1.1, shows internal cracking of the pericarp but little surrounding tissue damage, indicating that most of the impact was dissipated by the cracking action. Plate 1.2 shows a displacement and yellowing of the locule gel but little tissue damage suggesting that while the impact was in the elastic deformation range of the pericarp, physical displacement of the surface resulted in sub-surface damage. Plates 1.3 and 1.4 show major tissue damage where the pericarp cells have burst. In Plate 1.3, impact has caused a plastic deformation of the tomato surface. Plate 1.5 and 1.6 show green tomatoes after multiple impacts of 5 x 260 mm (1.25 J) and 20 x 260 mm (5 J) respectively.

For apples, Holt and Schoorl (1977) found that for a given amount of energy absorbed, bruise volumes were larger and damage more severe for slow compression loading than for impact loading. This was due to the difference in strain rate (rate of deformation). In this study of tomatoes, only impact tests were conducted and it is not known what effect compression loading would have. However, observations of FMT at wholesale markets showed obvious compression bruising due to the handling chain. Testing for compression damage thresholds in FMT would provide useful information for improving bulk handling of tomatoes between the field and packing shed. There is a need for further investigation of compression damage of FMT even outside the context of mechanical harvesting.

Puncture pressures required to drive the penetrometer plunger through the skin of Tornado and Eagle variety tomatoes at different maturity stages, are shown in Figure 5. The pressure required to cause failure in Eagle is approximately twice that of for Tornado at all maturity stages. Lukanenko (1984) has suggested that for tomatoes to be suitable for mechanised harvest, they should withstand a puncture pressure of at least 1870 kPa. This value is exceeded by Eagle at the green and breaker maturity stages (2171 kPa and 2131 kPa respectively). All puncture pressures recorded for Tornado fall below Lukanenko's value.

3.4 Conclusions

Tomato varieties Eagle and Tornado exhibit clear differences in terms of resistance to bruising and puncture. For machine harvested FMT, Eagle would be more suitable than Tornado, since it has a higher threshold to mechanical damage.

Tolerable bruising levels dictate the maximum drop height at respective maturity stages. For a ninety five percent level of green mature fruit exhibiting no bruising, Eagle and Tornado tomatoes should tolerate drop heights of 235 and 110 mm respectively, onto a hard unpadded surface.

Red maturity tomatoes bruise more easily than green or breaker maturity tomatoes, even at low levels of energy input.

No relationship was found between bruise volume and energy for the energy levels tested.

3.5 References

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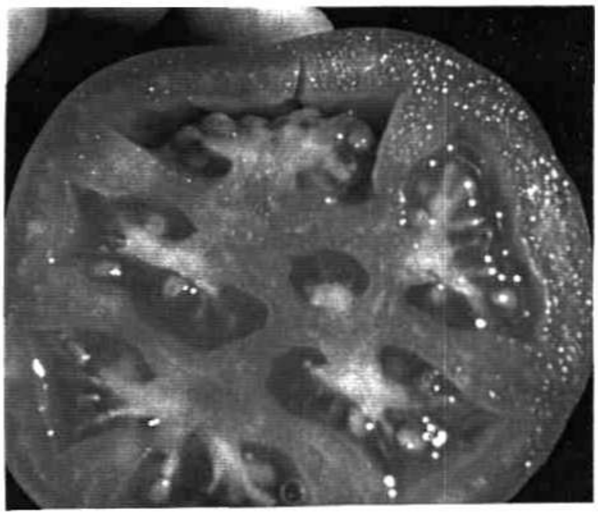

Plate 1.1: Pericarp cracking.

Plate 1.2: Yellowing of locule gel.

Plate 1.3: Plastic deformation of surface.

Plate 1.4: Water soaked tissue.

Plate 1.5: Multiple impact trial - 5 x 250 mm.

Plate 1.6: Multiple impact trial - 20 x 250 mm.

4.0 SEPARATING MECHANISMS FOR FRESH MARKET TOMATO HARVESTERS

4.1 Introduction

Since the 1960's many attempts have been made to develop a machine capable of harvesting FMT within acceptable limits of fruit damage. The three issues with respect to machine harvesting are:

- vine pick-up off plastic mulched beds
- tomato/vine separation
- bulk handling of harvested tomatoes

Of these three, growers of the Bowen Horticultural Automation Group identified the tomato/vine separation problem as the limiting factor in development of a local FMT harvester.

Processing tomato harvesters have used a variety of separating mechanisms during the past thirty years. Early models used an offset crank mechanism similar to those used for straw walkers in combine harvesters. Separator mechanisms then moved to hydraulically driven, reciprocating chains and other similar devices before incorporating force balanced shaker (FBS) systems. FBS systems are now commonly used for many crop harvesting machines where a shaking action is applied. eg. coffee.

Several types of separators have been trialed in FMT. (Hood *et al.* 1974; Deen *et al.* 1970; Stout and Ries, 1960) with varying success. More recently Studer (1982) adapted the FBS for tomatoes and it was quickly incorporated into commercial processing tomato harvesters. However, it has had limited testing in FMT harvesters. Alper (1984) used a continuous, reciprocating conveyor at a 45° incline to successfully harvest FMT without significant damage.

Diener, Mohsenin and Jenks (1965) noted three modes of fruit movement induced by shaking:

- pendulum mode, where the fruit swings from the stem
- tilting mode, where the fruit swings around the stem attachment point
- rotation mode, where the fruit rotates about the axis of the stem

Garmen, Diener and Stafford (1970) also noted a fourth mode of fruit movement where the stem buckles and vibrates with little fruit movement. Young (1986) found that frequencies below 40 Hz appeared to excite tilting, pendulum and combination type modes in pome fruits. He also found that stem buckling mode did not generally lead to instantaneous fruit detachment.

Lorenz and Hanna (1962) found that at certain frequencies of shake the efficacy of tomato/vine separation could be optimised. They proposed that this was because an inverted, vertically suspended, tomato vine approximated a spring mass system and that optimum separation would be achieved at its natural frequency.

Lorenz and Hanna also outlined considerations for design of mechanical tomato harvesters as follows:

> *Separation of fruit and vine may be considered the important element of a practical mechanical harvester, but the physical properties of the plant and the fruit impose restrictions on the mechanical system that accomplishes this separation. With these in mind, separation can be considered from the standpoint of basic principles such as shaking, centrifugal force, high linear acceleration or deceleration of the vine, raking, combing, viscous drag, and stripping. Each of these principles has advantages and limitations. It then becomes a matter of optimising a principle with respect to (a) the physiological factors of the fruit/vine system and (b) the characteristics of other machine elements necessary to a practical unit.*

In this project, trials were conducted to assess the potential of tomato/vine separating concepts based on existing processing tomato machinery, techniques outlined in literature and input from the BHAG. Test rigs were fabricated to trial the following seven concepts:

1. inverted, vertical vine shaker
2. roller-stripper
3. roller-shaker
4. vine over FBS drum
5. vine under FBS drum
6. belt FBS
7. separation in water

Inverted, vertical vine shaking (IVVS) was found to be effective for tomato/vine separation however drop heights (about 1200 mm) associated with this system are excessive (typically equivalent to 2 J energy input). This problem may be overcome by padding surfaces or separating fruit above a water trough, however another obvious difficulty is the need to align and invert vines before entering the separator. Whilst practically, mechanisms for this purpose could be developed the overall suitability of this method must be questioned with respect to the bulk flow mechanisms currently used.

The roller-stripper concept was demonstrated to be feasible but requires tomato vines be broken into smaller units to enable successful feeding between the rollers. It is unlikely this separating mechanism could be adapted to bulk flow systems required for mechanical harvesting due to vine feeding and orientation problems.

The roller-shaker concept tested has some merit for tomato/vine separation. Originally the concept was proposed to overcome the poor efficacy of tomato separation due to stem damping of shake energy which was apparent during initial trials with the IVVS. However, this phenomenon was not evidenced during project trials. The roller shaker has problems in common with the IVVS and in addition presents the difficulties of feeding vines into the separator and coping with the amount of material being presented to the separator during bulk flow. Trials show that potential exists to examine the use of suitable pinch rollers as a direct stripping mechanism.

The vine over FBS drum achieved about 65% separation but caused tomato damage due to excessive drop heights and the aggressive action of drum fingers. The short resident time of vines in the separator leads to lower separation efficacy. Halving drum size and using multiple drums may reduce mechanical damage to acceptable levels while maintaining separator effectiveness. Modifications to this system should be examined.

The vine under FBS drum separator had a separation efficacy of about 75%. It is likely to cause less mechanical damage to FMT than a vine over drum separator due to the reduction in fruit drop heights. Vine feeding and throughput would be improved by using a positive drive on the FBS drum and a belt conveyor system. It is proposed that multiple, smaller diameter drums would cause less mechanical damage to tomatoes and improve separation.

The FBS belt separator in its current form failed to effectively separate tomatoes from the vines. This is probably due to poor energy transfer from the belts to the tomato stems. Tomatoes were observed to 'bounce' backward and forward but failed to separate from the stems. This system should be investigated further after increasing shake amplitude to at least 50 mm and increasing the number of lugs on the belts. The addition of extra belts would improve the vine support and conveying capacity of the separator.

Fruit separation in water by viscous drag was trialed as a technique that would reduce mechanical damage by preventing impacts. It was found that shaking inverted tomato vines submerged in water was not practical. An alternative concept would be to float vines on the surface of a water trough and provide a suitable amplitude movement by either overhead multiple FBS drums or a reciprocating belt system. Producers found during the 1996 season that not all tomatoes floated when they were transferred to a water based unloading facility. Therefore, any water based separation system would require a retrieval system able to cope with both sinking and floating tomatoes.

4.2 Inverted, Vertical Vine Shaker

This trial separator rig (Plate 4.1), comprised a variable speed electric motor driving a vertical crank to which the tomato vines could be attached. The stroke length of the crank could be adjusted. Two varieties of FMT (Eagle and Tornado) and one processing variety (Zenith) were tested to determine the efficacy of tomato/vine separation for varying frequencies and amplitudes of shake. For each combination of frequency and amplitude, five vines were shaken for 5 seconds (nominally) excepting for Zenith where only shaker amplitude was tested due to a shortage of suitable vines. The test frequencies were 9.2, 16.7 and 29.2 Hz at amplitudes of 11, 27 and 53 mm. It was not possible to test higher frequencies due to machine limitations.

Results from the three varieties were analysed separately. Fruit removal for Eagle increased significantly as amplitude and frequency increased as shown in Tables 4.1 and 4.2. The complete amplitude *x* frequency interaction for Tornado is given in Table 4.3

and illustrated in Figures 4.1 and 4.2. From Table 4.3 a significant response to frequency is shown only at the lowest test amplitude of 11 mm, however, there was a significant response to amplitude at all frequencies especially at amplitudes below 27 mm. Similar results were obtained for Eagle. The processing variety Zenith, tested only at a frequency of 16.7 Hz, recorded significantly reduced fruit removal at only the lowest shake amplitude of 11 mm (Table 4).

For IVVS then, tests demonstrated that increasing the amplitude of shake over the range of shake frequencies tested, more effectively separated tomatoes from the vine than increasing frequency; eg. from Table 4.3, only 35% of tomatoes were removed from the vine at the high frequency, low amplitude treatment (29.2 Hz x 11 mm) compared with 98% removal from the low frequency, high amplitude treatment (9.2 Hz x 53 mm). A shake amplitude of at least 27 mm is required for effective fruit separation in the FMT varieties tested. At shake amplitudes greater than 11 mm, frequency had little effect on separation efficacy.

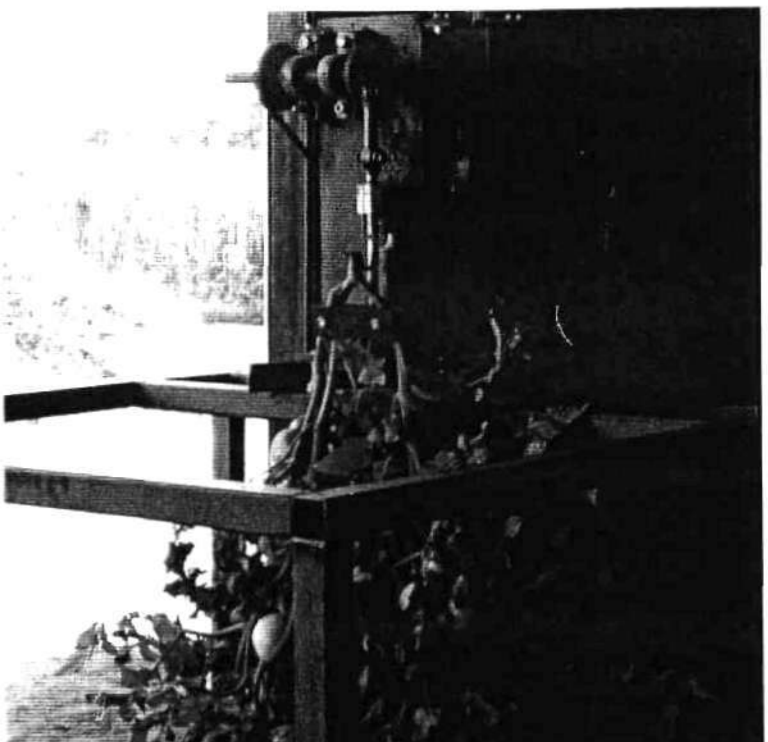

Plate 4.1: Inverted vertical vine shaker.

Table 4.1: Effect of amplitude of shake on tomato removal - Eagle variety.

Amplitude (mm)	*Mean No. tomato removed (%)*
11	23.5 a
27	74.2 b
53	98.4 c

means followed by the same letter are not significantly different, P=0.05

Table 4.2: Effect of frequency of shake on tomato removal - Eagle variety.

Frequency (Hz)	*Mean No. tomato removed (%)*
9.2	63.8 a
16.7	61.8 a
29.2	70.4 b

means followed by the same letter are not significantly different, P=0.05

Table 4.3: Effect of amplitude and frequency of shake on tomato removal Tornado variety.

Amplitude (mm)	*Frequency (Hz)*		
	9.2	16.7	29.2
11	8.6 a	33.9 b	34.9 b
27	88.7 cd	88.5 cd	81.3 c
53	98.4 d	97.1 d	100.0 d

means followed by the same letter are not significantly different P=0.05

Table 4.4: Effect of amplitude of shake on tomato removal - Zenith variety.

Amplitude (mm)	*Mean No. Tomatoes removed (%)*
11	35.7 a
27	64.3 b
53	83.0 b

means followed by the same letter are not significantly different, P=0.05

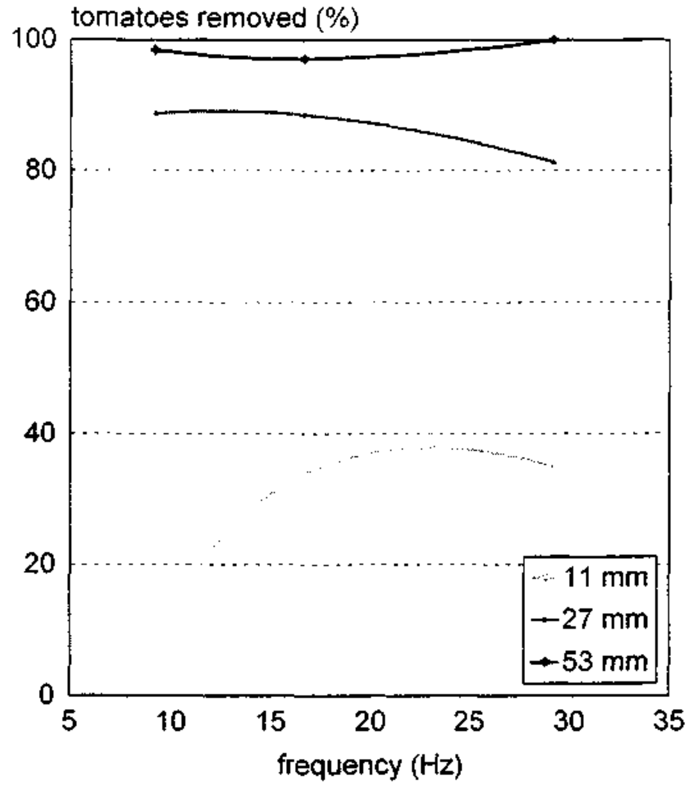

Figure 4.1: Effect of amplitude on Tornado tomato removal for a given frequency.

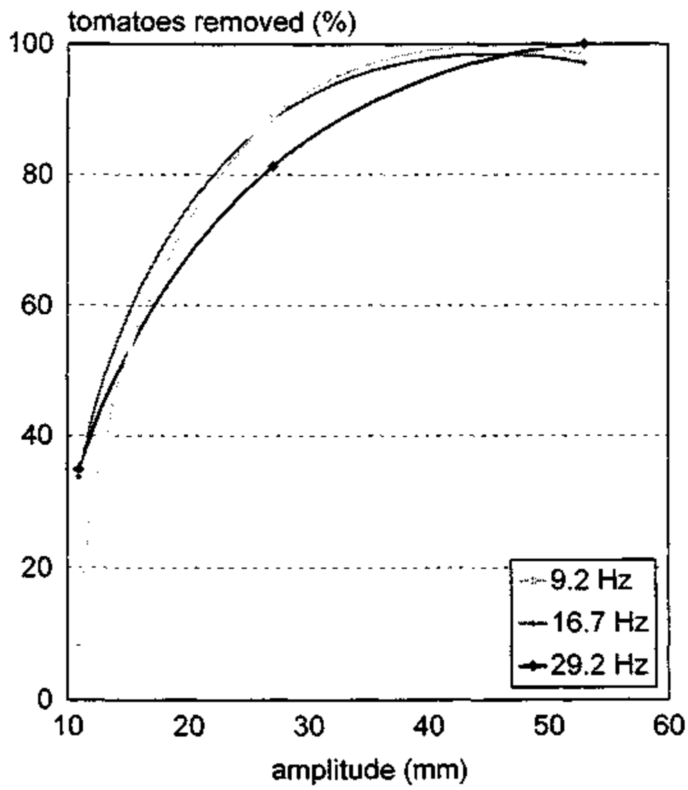

Figure 4.2: Effect of frequency on Tornado tomato removal for a given amplitude.

4.3 Roller-Stripper

A mechanism to strip tomatoes from the vine may reduce mechanical damage since energy required for fruit removal (Section 2) is less than for the various modes of (vine) shaking and avoids impacts from the shaking mechanism. An additional advantage is that most of the tomatoes would be separated from the stem at the tomato surface.

A stripper mechanism was constructed as shown in Plate 4.2. Padded stripper bars spaced 45 mm apart were positioned above two hydraulically driven rollers. Vines with tomatoes attached were fed stem first between the bars and grasped by the rollers. The polyurethane rollers were driven at a surface speed of 160 $mm.s^{-1}$ and were machined to increase their ability to grip the stem. The rollers were trialed at spacings of 10 mm, 5 mm and a negative distance attained by intermeshing their machined surfaces.

With the test rig, trials demonstrated that only a single stem could be successfully fed through the stripper at one time. When the rollers were operating correctly they drew the tomato stem between the stripping bars, separating tomatoes from the stem. The test rig could not accept numerous small stems simultaneously and was incapable of accepting a complete tomato vine.

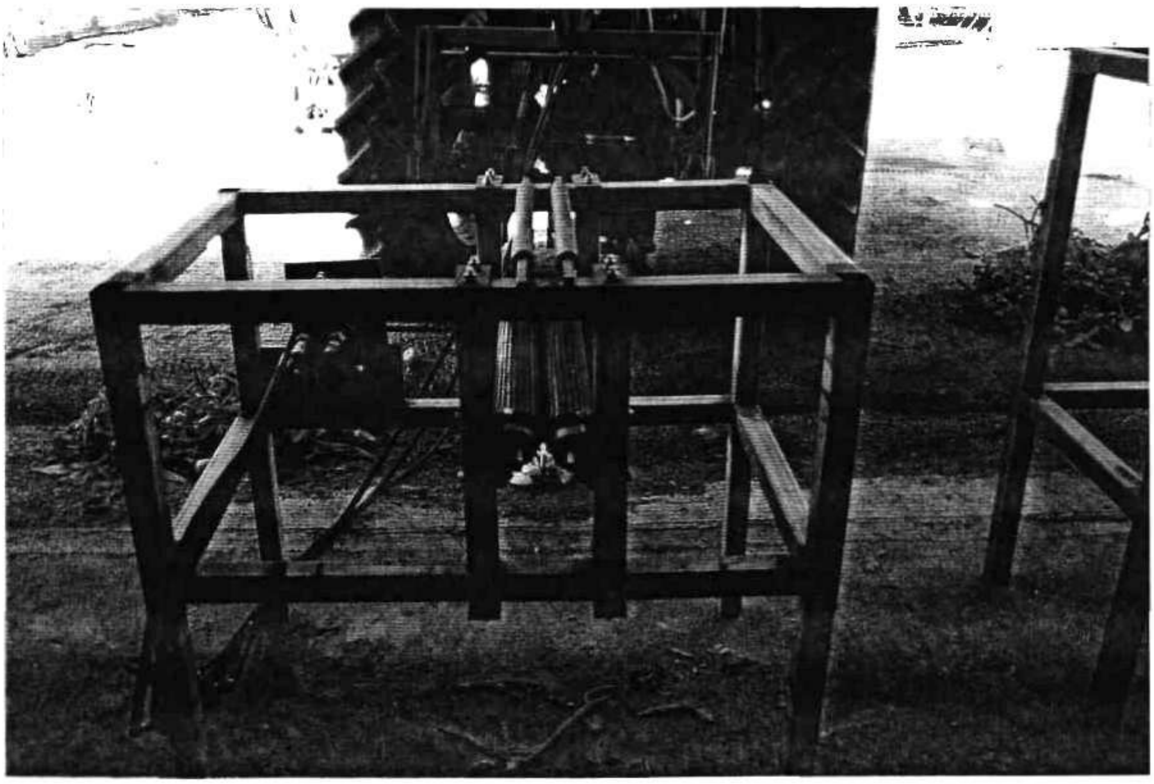

Plate 4.2: Roller-stripper tomato separator.

At roller spacings of 5 and 10 mm, the gap between rollers is less than the thickness of vine stems. Despite this, the rollers failed to grip the stems effectively since upon entering the rollers the stems were crushed releasing plant juices which further reduced the ability of the rollers to grip the stem. When the machined surfaces of the rollers were intermeshed, the rollers were able to grip the fibres of the crushed stem and draw the vine between the stripping bars. However, a build-up of crushed vine material eventually led to further problems with gripping the incoming stems.

The speed of the rollers was determined by their ability to grip the stem. By trial and error, a rate of 160 mms^{-1} was selected and was the highest rate that allowed the stripper to function. This is an extremely slow feed rate and requires about 16.5 s to pass 1 m of vine between the rollers.

The trials proved that the concept of stripping tomatoes from the vine using padded stripping bars and rollers has some potential. With the arrangement tested, tomato vines would need to be broken into smaller stem units to enable stems to be fed successfully between the rollers. Using a suitable scraper would possibly eliminate the problem of trash build-up.

4.4 Roller-Shaker

Preliminary experiments conducted with the IVVS suggested that energy input to tomato vines was not transferred to the vine extremities due to energy absorption (damping) within the tomato stems. This resulted in a decrease in tomato separation efficacy which was exacerbated as the distance from the shaker mechanism increased. The roller-shaker mechanism is based on the premise that if tomato vine shaking could occur as the stem length decreased, tomato separation would be more effective.

A roller-shaker separator was constructed using two hydraulically driven, pneumatic rubber tyred rollers and a cam shaker mechanism. The speed of the tyres and cam shaker could be varied. The roller-shaker test rig is shown in Plate 4.3. Tomato vines were fed between the rollers at a rate determined by the tyre speed. The amplitude and frequency of shaking were determined by the speed of the cam driving the shaker mechanism. Tests with the IVVS (Section 4.2) showed that increasing shaker amplitudes above 11 mm significantly increased the efficacy of tomato separation. Consequently the internal cam was set to provide a maximum amplitude of shake for a given input drive speed. Problems of gripping the tomato stem (described in Section 4.3) were overcome by operating each of the rubber tyred rollers at different pressures ie. 20 and 25 psi.. This pressure difference allowed different diameter stems to be gripped with only minor crushing.

Stem feed rates of 100 and 250 $mm.s^{-1}$ were tested at shake amplitudes of 20 and 45 mm. The 20 mm amplitude corresponded to a shake frequency of 10 Hz and the 45 mm amplitude to a shake frequency of 5 Hz. The shaker mechanism did not allow shake amplitude to be varied independently of shake frequency.

The 100 $mm.s^{-1}$ feed rate is extremely slow but allows sufficient time for tomato separation from the stem. Separation was more effective at the higher shake amplitude despite the low shake frequency. The 250 $mm.s^{-1}$ feed rate was too fast for this separator even at the 45 mm shake amplitude. At this feed rate some tomatoes were not removed from the stem before reaching the rollers although as they came into contact with the rollers they were easily detached from the stem. However, tomatoes removed in this manner, showed signs of skin abrasion caused by the rollers.

The separator was not capable of accepting whole tomato vines and was tested using only single stems. The limited gripping action of the rollers could not cope with heavier whole vines and the large amount of green material on a freshly harvested vine caused blockage problems as it was passed between the rollers.

The roller-shaker concept does have some promise for tomato/vine separation however has problems in common with the IVVS ie. excessive drop heights and the need to orientate and invert the vine. Additionally, the 100 $mm.s^{-1}$ feed rate attained with the trial separator would need to be increased about tenfold for the system to be commercially viable. The trials demonstrated the possibility of using suitable pinch rollers in a direct stripping configuration.

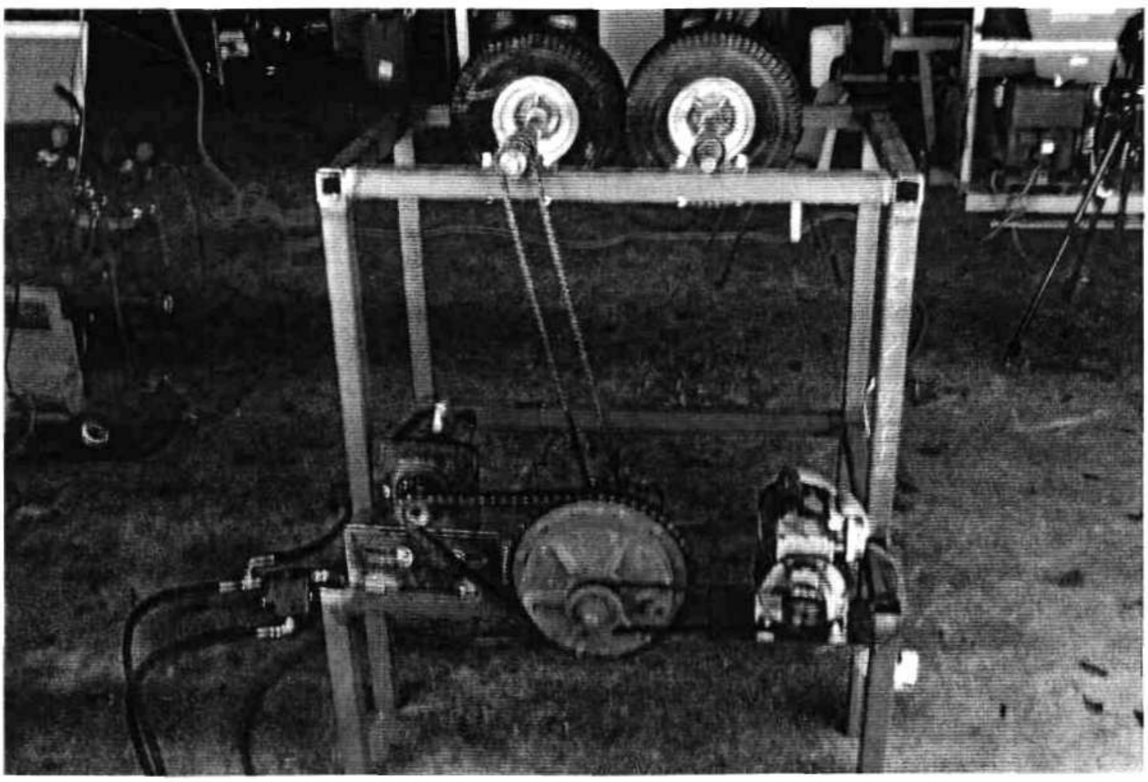

Plate 4.3: Roller-shaker tomato separator.

4.5 Vine Over Force Balanced Shaker Drum

FBS systems employed in a vertical configuration are currently used on several types of berry and coffee harvesters. Modern processing tomato harvesters have adopted the FBS technology by utilising a horizontal drum set-up and passing the tomato vines either over the drum (Pik Rite) or under the drum (Button Johnson and FMC) as discussed in Section 1.

A vine over FBS drum separator was constructed for testing to determine its potential for FMT separation. The FBS drum consisted of a series of fibreglass fingers attached to a central support shaft. The outside diameter of the drum was 1125 mm. Finger oscillation was induced using an FBS driven by a variable speed motor. The drum was also driven by a second variable speed motor. The amplitude of oscillation (or shake) was measured by locking the positive drive and using callipers to measure amplitude at the finger tips. Over the FBS drive speed range (400-700 rpm), measured amplitude was nominally 110 mm. The vine over FBS drum separator is shown in Plate 4.4.

Table 4.5 shows the average percentage of tomatoes removed by the vine over FBS drum separator for two frequencies of shake.

Table 4.5: Percentage of tomatoes removed at two different frequencies.

Amplitude (mm)	*Frequency (Hz)*	*Tomatoes Removed (%)*
110	6.7	63.6
110	11.7	66.3

The number of tomatoes removed increased only slightly when the shake frequency was increased from 6.7 Hz to 11.7 Hz for a corresponding approximate doubling of energy input.

Tomatoes separated by this method are subjected to a drop height of about 1300 mm with resultant damage levels similar to those discussed in Section 3. Damage to some tomatoes due to direct impact with the fibreglass fingers was severe. In some instances, when the tomato vine was dropped onto the FBS drum and a tomato came into immediate contact with a finger moving in the opposite direction, that tomato was projected several metres and suffered severe bruising.

A major problem with this separator is the short contact time of the tomato vine with the FBS drum (residence time). When the vine is fed onto the drum it can only physically remain in contact with the separator through approximately 120° before it drops beneath the drum (Figure 4.3). For the operating conditions tested, this equated to a contact time of about 1 s.

Short residence times mean that a large volume of tomato vines can be delivered and processed through the machine, allowing higher harvest speeds. However, the action of the separator is severe and creates excessive mechanical damage in FMT.

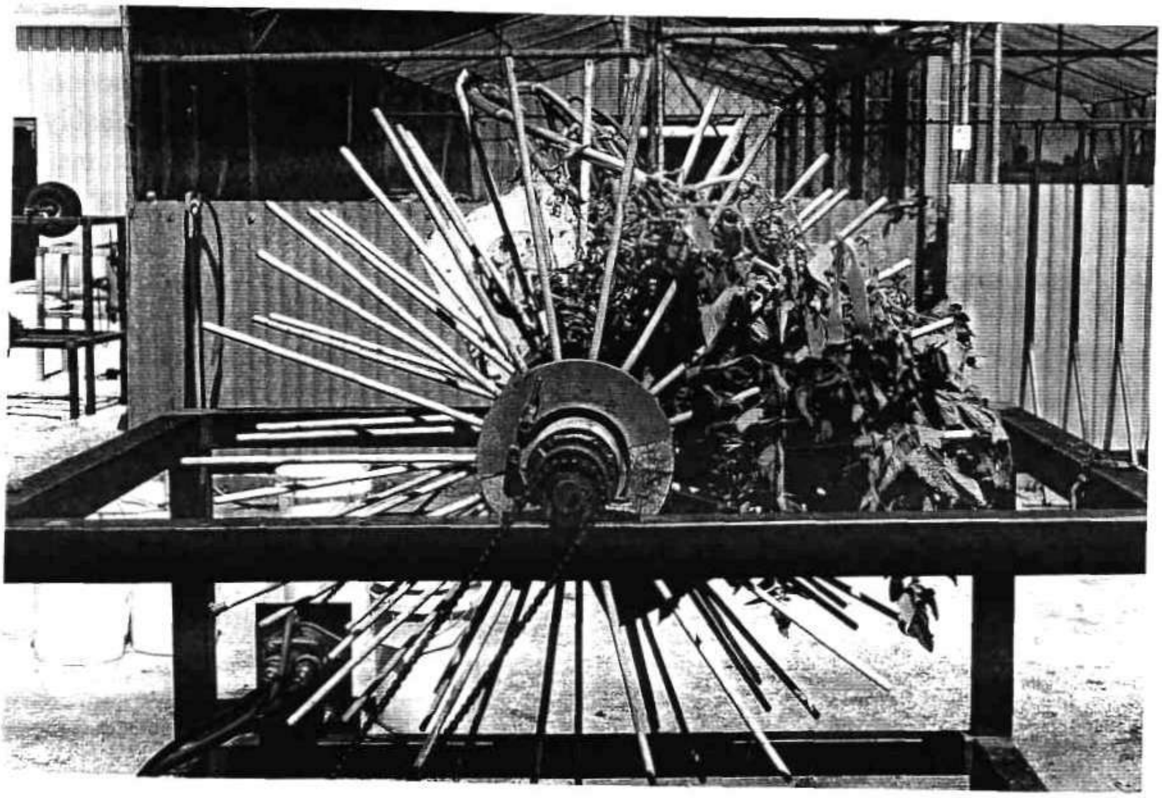

Plate 4.4: Vine over FBS drum.

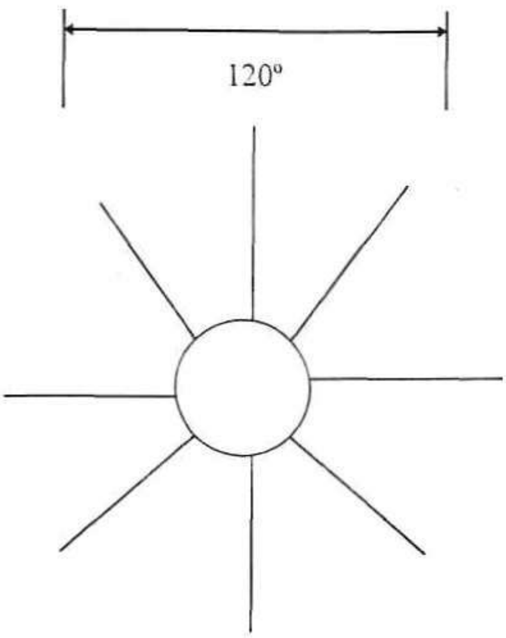

Figure 4.3: Contact area of vine over FBS drum.

Halving drum diameter would reduce input energy by one half and also reduces drop heights while maintaining a shake amplitude of approximately 55 mm at a shake frequency of 11.7 Hz (found to be highly effective with IVVS in Section 4.2). However, this would reduce the residence time to about 0.5 s with a consequent reduction in separating efficacy. The Pik Rite harvester has adopted smaller FBS drums, probably to reduce mechanical damage. To compensate for reduced residence time, dual drums are used.

4.6 Vine Under Force Balanced Shaker Drum

Most FBS processing tomato harvesters employ this type of separator. Button Johnson machines incorporate a positive drive on the FBS separator while FMC utilise a free wheeling FBS and belt conveyor system. A vine under FBS drum separator was constructed by placing a vine support structure similar to that of Studer (1982), beneath the FBS separator used in Section 4.5. The vine under FBS drum separator is shown in Plate 4.5.

The FBS drum was driven at 700 rpm giving a shake frequency of 11.7 Hz and a shake amplitude of 110 mm as in Section 4.5. Tomato vines were fed between the drum and the vine support structure. Vines generally failed to clear from the support even when additional vines were added to create a continuous feed situation. An average of 75% of tomatoes were removed in this separator which was about 10% higher than for the vine over FBS drum discussed in Section 4.5. This increase is probably attributable to vines stalling in the separator, increasing residence times.

Mechanical damage caused by drops was low compared to the over drum system due to the reduced drop heights. The under drum system is superior to the over drum system in this respect. However, severe damage was noted where impacts had occurred between fingers and tomatoes. As described in Section 4.5, the use of multiple, smaller diameter FBS drums would be expected to reduce damage from finger impacts while increasing the separation efficacy. The addition of a positive drive on the FBS drum and a belt feed system to the separator would improve removal of threshed vines from the separator.

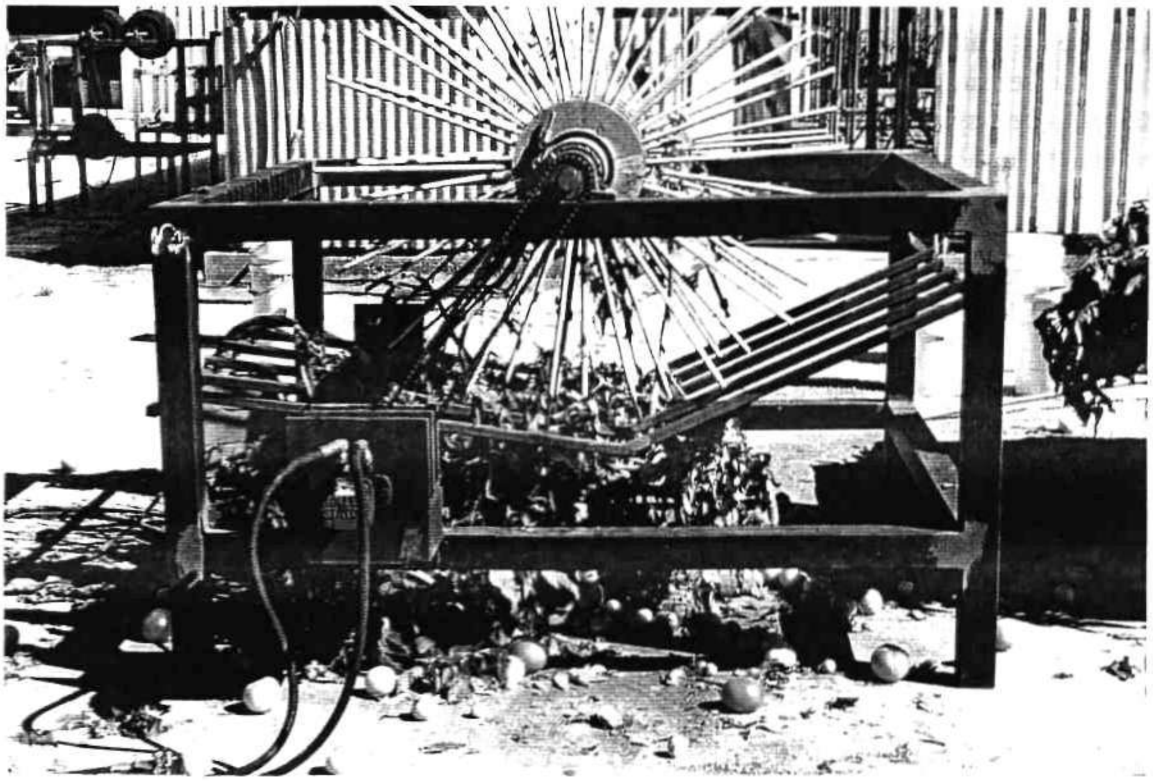

Plate 4.5: Vine under FBS drum separator.

4.7 Belt Force Balanced Shaker Separator

Reciprocating chain systems were used in some early tomato harvesters, while the new 'Sandei' harvester imported by FMC, uses a reciprocating belt system. As stated earlier, the use of multiple FBS drums to increase vine residence times in the separator should increase separator efficacy. Therefore, it was proposed to combine these two principles to test a belt system where an FBS provided an input force to the belts. Residence time would then depend on the belt speed and length, while allowing a high frequency of shake to be developed.

An FBS belt separator was constructed using the FBS system previously described and two positively driven timing belts. The timing belts were 50 mm wide and 2.5 m long, which gave a separator length of approximately 1000 mm. The belts had 75 mm lugs attached and were driven by a variable speed motor. This FBS belt separator is shown in Plate 4.6.

The FBS was driven at 700 rpm which transferred a nominal oscillation amplitude of 30 mm to the belts (determined by the diameter of the belt timing pulley attached to the FBS shaft). The belts were positively driven at a speed of 300 $mm.s^{-1}$. The use of timing belts ensured that the full shaking action was transferred to the belts from the FBS shaft.

The two belts used were incapable of supporting whole vines making it necessary to break the vines into smaller stem components. The system performed poorly, even with the smaller plant segments. Vine support and conveying capacity would have been greatly improved by the addition of an extra belt and by reducing the gap between belts to about 150 mm. The shake amplitude and frequency (30 mm and 11.7 Hz respectively) should have been adequate to separate most tomatoes based on the results of Section 4.2. However, very few tomatoes were separated from the stems and it appeared this was due to poor energy transfer from the belts to the tomato stems. Tomatoes were observed to 'bounce' backward and forward but failed to separate from the stems.
This concept should be investigated further after increasing the shake amplitude to at least 50 mm and improving vine support and conveying capacity by adding extra support lugs to the belts.

4.8 Separation in Water

Most of the mechanical damage in tomatoes removed by the IVVS is caused by excessive drop heights inherent in this system. It was suggested by members of the BHAG that the vine shaking could be carried out in water thereby eliminating drops. Additionally, viscous drag forces induced could be the principle mechanism for tomato removal. This suggestion was supported by the comments of Lorenzen and Hanna (1962) who stated:

> *Moving the vine through a fluid such as water, where the density is high enough to develop sufficient force at reasonable velocities, will remove the fruit in the gentlest manner.*

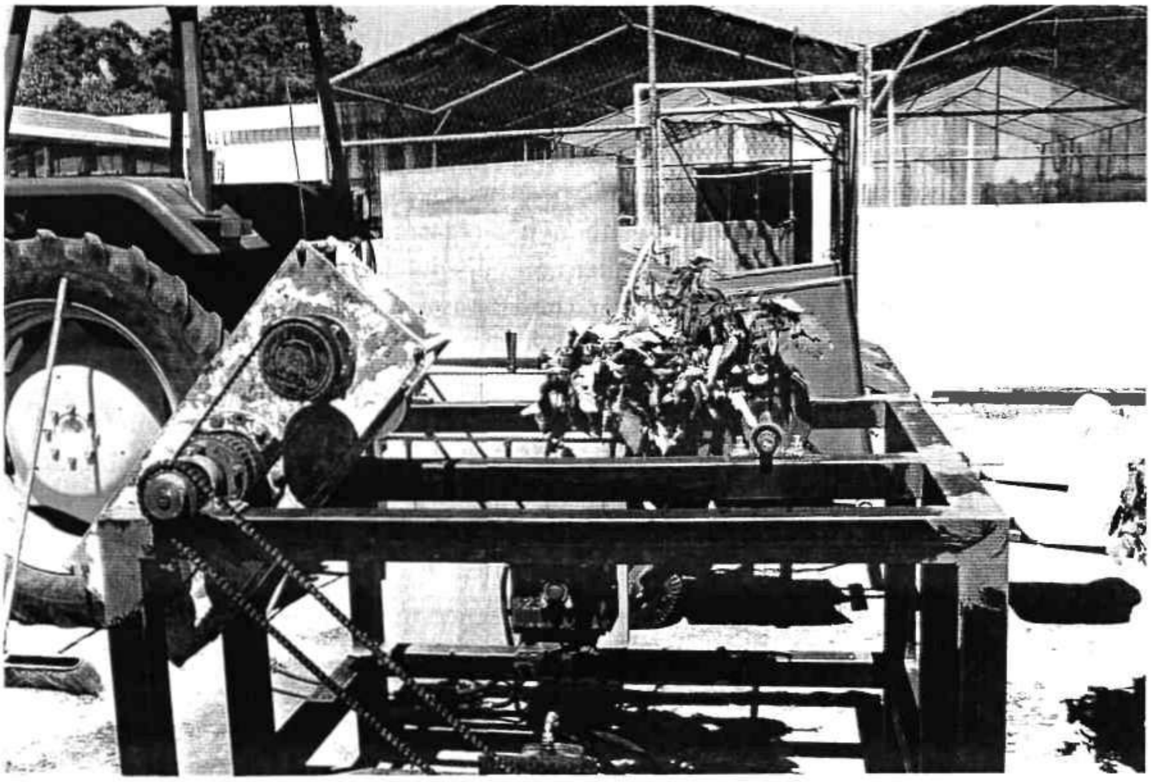

Plate 4.6: FBS belt separator.

The IVVS described in Section 4.2 was positioned over a water tank. Tomatoes were attached to the IVVS by the section of stem exposed above the water line (about 300 mm) as shown in Plate 4.7. The separator was operated at a shake amplitude and frequency of 53 mm and 16.7 Hz .

Free floating tomato vines were found to adopt a similar orientation to their growth habit, ie. generally horizontal and spread out. When the butt of the stem was attached to the separator, the vine re-orientated to a semi-vertical, inverted position and was observed to 'parachute' due to the buoyancy of the tomatoes and vines.

When the IVVS was operated, only those tomatoes above the water line were removed since this section of the exposed stem was shaken vigorously. Movement of the vine and tomatoes below the water was severely damped due to viscous drag and buoyancy. On one occasion a vine was detached from the separator and manually shaken in the water tank with an amplitude of 200-300 mm, resulting in 10 tomatoes being removed from the vine. The vine was then removed from the water tank and again manually shaken, resulting in a further 31 tomatoes being separated from the vine.

Since the tomatoes and vines floated in an orientation similar to their growth habit , the IVVS was rotated through 90° to produce a horizontal movement. Crude fingers were attached to the separator and protruded 200 mm below the water line. During testing in this configuration the vine was not attached to the separator but allowed to float freely in the tank. The separator was operated at the same amplitude and frequency used earlier. This arrangement is shown in Plates 4.8 and 4.9.

This method also failed to remove tomatoes from the vine. The vine was observed to move more vigorously than when oriented vertically, however significant movement was not transferred to the tomatoes. Although increasing the amplitude of movement may cause the vine to break-up into smaller components due to the action of the fingers, this method for tomato removal in water shows more potential for development than IVVS.

Any method attempting to use viscous drag as a separating force for tomato removal would require large amplitudes of movement due to the growth habit and elastic nature of the vine. By reference to Figure 4.4, if the vine is held at point *A*, this point would have to be moved past point *B* before tomatoes at *B* began to move. Elasticity in the stem would also have to be overcome as shown by the spring analogy in Figure 4.5. This means that the point at which the vine is attached to the separator has to be moved a distance x, equal to one half the diameter of the tomato vine, plus a stem straightening distance y, before force is exerted on all of the tomatoes.

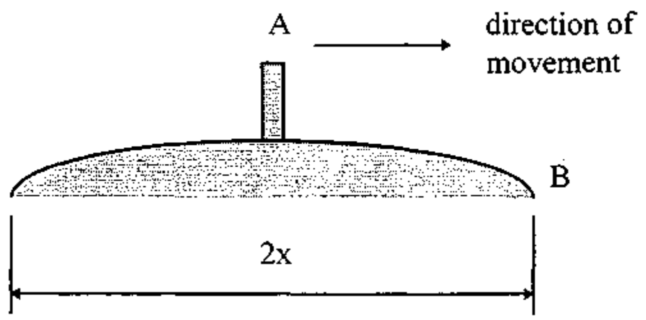

Figure 4.4: Distance of movement required to overcome vine diameter.

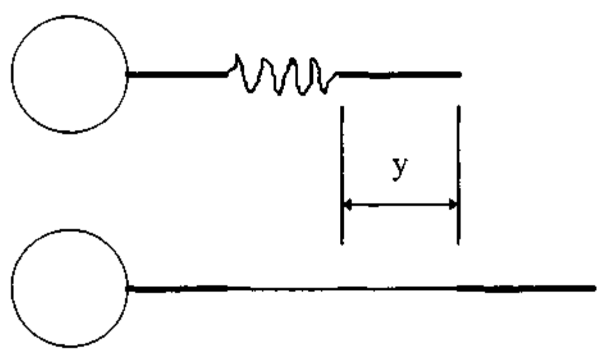

Figure 4.5: Distance of movement to overcome stem elasticity.

Plate 4.7: IVVS with tomato vine attached, positioned over water tank.

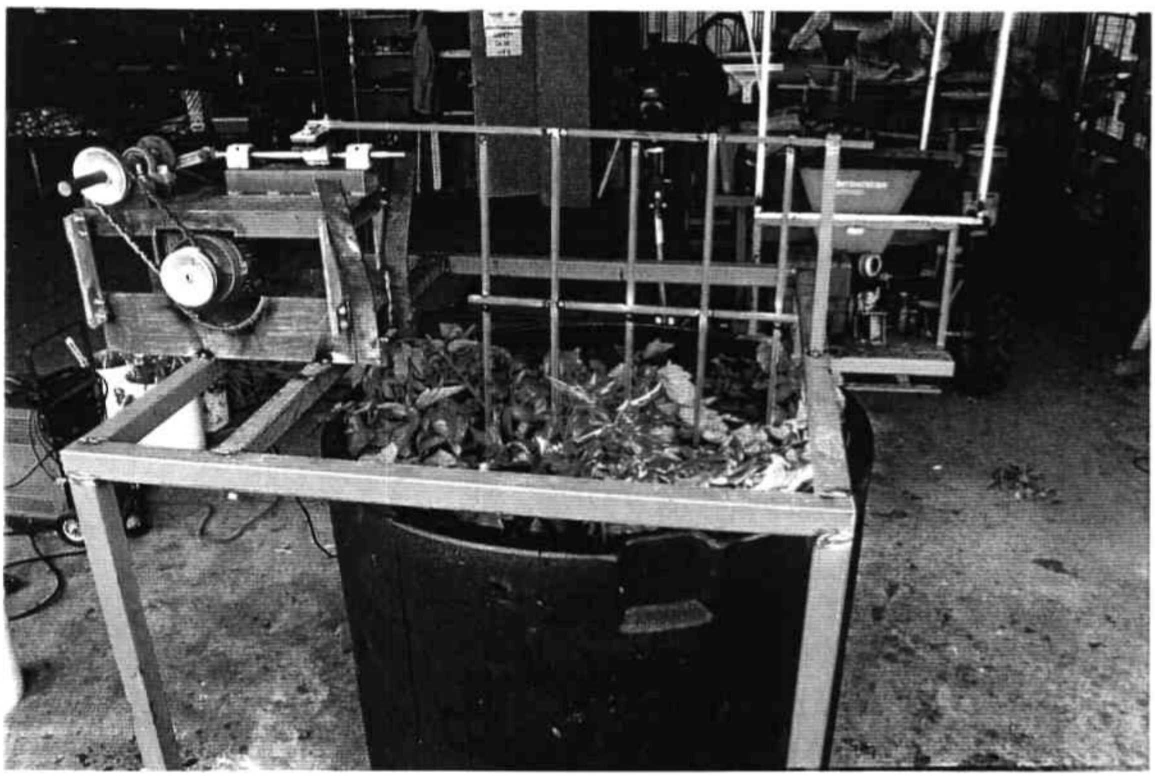

Plate 4.8: Horizontal drive and fingers positioned above water tank.

As stated previously, Lorenzen and Hanna (1962) believed that viscous drag forces could be used for tomato/vine separation. They assumed a drag coefficient of 0.35. Viscous drag force can be found from the equation:

$$C_D = \frac{F}{0.5\, p\, V^2 A}$$

where: C_D - drag coefficient
F - drag force
p - density of water
V - velocity of tomato
A - cross sectional area of tomato

Assuming a tomato diameter of 65 mm and a FRF of 30 N then the required tomato velocity is 7.2 $m.s^{-1}$. At this velocity it is probable that the tomato vines would break-up.

Additionally, allowing a reasonable distance for separation with such a system of about 2500 mm and a further 1000 mm at each end for delivery and discharge of vines, requires a minimum trough length of 4500 mm. Assuming a trough width of 2000 mm and water depth of 500 mm means that the trough has a water capacity of 4500 *l* and weight (excluding materials) of 4500 kg.

It is unlikely that a machine incorporating such a trough would be suitable for field operations from a consideration of dimensions and weight alone. However, it may be possible to use this separation method based on a mobile separating unit which could be positioned at a central location in the paddock and supplied with whole vines. Alternatively such a unit could be positioned at the packing shed.

Plate 4.9: Separator fingers positioned amongst tomato vine.

4.9 References

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5.0 PICK-UP FRONTS FOR FRESH MARKET TOMATO HARVESTERS.

5.1 Introduction

Of the four types of processing tomato harvesters examined in Victoria, all machines severed the tomato vines below the soil surface using a range of mechanisms to sever the plant, such as fixed sweeps, counter rotating metal discs and reciprocating knives. FMT in the Bowen district are grown on plastic mulch beds and it will be necessary to develop a pick-up front capable of lifting and severing the plants without causing mechanical damage to the tomatoes or machine blockages due to the plastic mulch entering the harvester.

Shaw (1984), notes that numerous attempts by researchers to sever the vine beneath plastic mulch beds have been unsatisfactory. He determined that the tomato vine should be cut above the plastic, and developed a pick-up front using a combine harvester knife section and three staggered 'Draper' styled rubber belts. However, the rubber conveyor belts could not effectively convey dense green tomato foliage into the harvester and it was necessary to substitute them with rod conveyors. He found that the knife fingers offered sufficient protection to prevent damage to tomatoes from the knives and went on to claim of the pick-up front he developed:

> *Fresh market tomato harvesters using this plant cutter are commercially available for use in Florida.*

To operate successfully above plastic mulch, the tomato vines must be lifted clear of the cutting mechanism before the stems can be cut and the vines moved onto a conveyor. A lifting device was fabricated to assess its potential for lifting tomato vines from the plastic mulch bed and allowing the stem to be severed without damaging the tomatoes.

5.2 Pick-up Front Lifters

Ten lifters based on conventional combine harvester crop lifters were constructed from plywood to allow easy shaping. A low profile rounded nose was incorporated on each lifter to prevent damage to the tomatoes it may contact and to prevent tearing of the plastic mulch. Additionally, the lifters were pivot mounted which allowed a small amount of 'float' in case of ground contact.

An initial lifter spacing of 50 mm was trialed to determine if it would be possible to use the lifters in a stripping capacity. It was envisaged that the tomato vine would pass between the lifters but tomatoes would be stripped from the vine. However the multi-branching habit of tomato vines meant that vines could not pass between the lifters. If such a stripping concept were to be pursued it may be necessary to desiccate the crop before harvest to remove excess foliage.

Increasing lifter spacing to 150 mm allowed the tomato vines to progress up the lifters. The vines tended to block the lifters after a short distance because there was no mechanism to cut or convey plants. Such an arrangement should be successful if a complete front was developed. If blockages were a problem, an overhead chain or similar device could be added to assist movement of the vines. Garthe and Persson (1991) used an overhead, cam operated, gathering system to hook plants and lift them onto the conveyor while Shaw (1984) used a rubber bat reel. The recently imported 'Sandei' tomato harvester utilises two sets of crop lifters (similar to conventional combine harvester crop lifters) and a crank arrangement to provide a progressive lifting action. This system successfully lifts, cuts and conveys tomato vines from the plastic mulch bed.

The performance of pick-up fronts operating above plastic mulch beds would be improved by the addition of an automatic height controllers.

5.3 References:

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6.0 RECOMMENDATIONS

6.1 Development of the Sandei Harvester:

The arrival of the Sandei harvester provides the opportunity for further development of a machine already in commercial production. This avoids the requirement to design a complete machine to address only specific areas such as crop pick-up and fruit separation which were identified by the BHAG. The Sandei has demonstrated capability for harvesting tomatoes off plastic mulch beds and delivering vines to the separator. Whilst the separator does not meet all the requirements of FMT harvesting, it effectively separates tomatoes from vines and FMC have indicated willingness to fund and resource further development of the harvester.

Obvious problems that need to be addressed with this machine are the padding of all fruit contact surfaces and the elimination of excessive drops and unnecessary protrusions. The addition of an automatic height controller to the pick-up front would be beneficial. Additionally, a FBS mechanism fitted to the drive of the existing reciprocating belt system should be trialed. Adaptation of farming practices to better suit harvester requirements will also be of benefit; eg. matching bed width to pick-up front spacing and forming more evenly levelled beds.

6.2 Tomato-Vine Separation

If future work is to be undertaken by the BHAG, then the following separation methods should be investigated further:

FBS belts: the most appropriate method of testing this concept on a commercial scale is to fit a FBS system to the drive of the belt separator currently utilised on the 'Sandei' harvester.

FBS drums: utilising multiple, smaller diameter drums with positive drive and feeding vines under the drums using a belt system similar to that on the FMC harvester.

Water separation: if viscous drag removal is pursued, use of a trough and overhead reciprocating belt system with suitable separation distance or, multiple, small diameter, positive drive, FBS drums with vines floated under the drums is recommended.

Pinch rollers: suitable arrangements could be investigated.