Management to Reduce Post Harvest Losses in Tomatoes

Final Report for VG326

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Summary

Losses of fresh market tomatoes due to post-harvest disease are estimated to cost North Queensland growers of the order of $5 million per year. Following physical and attitudinal surveys of the problem a multi-faceted project was undertaken to focus on managing risks during pre and post-harvest stages of the industry.

Growers identified the use of excessive nitrogen fertiliser and irrigation as factors predisposing tomatoes to post-harvest breakdown. Experiments found that tomatoes grown under increased irrigation were more susceptible to challenge from *Geotrichum candidum* (yeasty rot), a major post-harvest pathogen in tomatoes. However, while there was a trend towards more breakdown with higher rates of nitrogen application , it did not reach significance at the 5 % level.

Any factor which caused even minute damage to the integrity of the tomato cuticle resulted in major increases in susceptibility to post-harvest organisms. Such factors included climatic effects (poor pollination due to cold conditions and skin cracking in moist weather), potato tuber moth attack and abrasion after harvest. Entry of fungi into fruit occurred more readily via wounds than by moisture infiltrating into fruit.

Market outturn assessments showed that the incidence of fruit rots was often property specific, indicating the problem could be minimised. These assessments identified bruising as the most common major defect in North Queensland tomatoes at the central wholesale markets. In cold storage of tomatoes for up to four weeks, bruising was found to be significant and to precede systemic post-harvest rots.

The results of these studies have been directly communicated to growers during the associated on-farm investigations. A number of improvements in management practices have since been adopted, including

- altered patterns of nitrogen fertiliser usage in tomato crops so that most is applied as a basal dressing and minimal amounts via trickle irrigation during crop growth
- improved knowledge and control of irrigation by the increased usage of soil moisture monitoring devices
- reduction in abrasion by washing buckets regularly to remove grit and watering farm roads to reduce dust
- improved post-harvest handling to reduce bruising , including unloading fruit into water
- monitoring and control of fruit sanitation systems in packing sheds
- a general increase in hygiene in packing sheds.

In addition a subsequent project investigated the sources of bruising using an instrumented sphere, with the aim of minimising this threat to quality.

Introduction:

Post harvest losses in fresh market tomatoes produced in North Queensland have been estimated at approximately 10% of the gross annual return of more than $50 million dollars. In 1987 surveys of market agents in Brisbane and Sydney indicated that Bowen tomatoes compared unfavourably with Bundaberg fruit in terms of shine, firmness, consistency, overall quality and presentation (Ledger 1987). A initial project at Bowen involved a physical and attitudinal survey of most of the commercial packing establishments at Bowen. It was found that there were opportunities to reduce these losses. For example, in 20% of establishments post harvest disease was reduced by treatments applied in packing sheds. By contrast in 45% of establishments post harvest practices increased the incidence of fruit diseases (Anning & Cole 1993). The profile of diseases was similar to that reported by Ceponis *et al* (1986), being dominated by yeasty rot (*Geotrichum candidum*) and bacterial soft rot (*Erwinia carotovora*). Other diseases included transit rot (*Rhizopus stolinifer*) and alternaria rot (*Alternaria alternata*). The detrimental effects of commercial post-harvest handling systems on tomatoes at Bowen was confirmed by Reid *et al* (1996).

Market Outturn Assessments : Tomatoes from a number of Bowen growers were assessed at the central wholesale markets in Brisbane, Sydney and Melbourne in 1993 and 1994. Interviews were conducted with agents/merchants in each market regarding their perceptions of quality problems. The most common defect was found to be bruising. The degree of bruising was property specific, indicating that there were opportunities to minimise this damage. A number of lines of tomatoes had post harvest disease, specifically yeasty rot (*G. candidum*). Since the majority of packing sheds in Bowen had no diseased fruit in the wholesale markets it was similarly suggested that this problem was able to be addressed.

Nutrition & Irrigation : One important pre-harvest threat leading to fruit breakdown was identified by growers as overuse of nitrogen fertiliser. Also problems were reported from excessive irrigation. In addition anything which damaged the skin of fruit, even at a micro level, appeared to allow entry of disease organisms; for example, minor weather changes and abrasion by grit after harvesting.

Two trials on DPI Qld's Bowen Horticultural Research Station in 1993 and 1994 were designed to investigate the effects of differences in nitrogen fertiliser, irrigation management and cultivar on susceptibility to post-harvest disease. In addition the relative importance of wounding compared to infiltration as an avenue for entry of post-harvest organisms was investigated.

Methods and Materials

Two experiments were conducted at Bowen Horticultural Research Station.

Experiment 1 : In 1993, nitrogen applications of 0, 60, 90 and 120 kg/ha as pre-plant basal or combinations of basal and side-dress through the trickle irrigation system, under both high and low irrigation regimes were applied to the tomato cultivars *Tristar* and *Tornado*. A split-plot design was employed with nitrogen / irrigation combinations as main plots and cultivars as sub-plots.

Heavy infestations of potato tuber moth (*Phthorimaea operculella*) in fruit at maturity rendered the first experiment unusable for yield purposes. However, samples of fruit from the range of treatments imposed were subjected to several post-harvest treatments related to disease susceptibility. Mature, green fruit of each cultivar were harvested from the zero and highest nitrogen applications and the high and low irrigation regimes. In each case fifty sound fruit and fifty fruit with minor damage from potato tuber moth were submerged for one minute in a water bath containing G.*candidum*. Inoculum was prepared by culturing an isolate from infected fruit on Bowen Horticultural Research Station for 7 days on potato dextrose agar. Agar was blended and a inoculum suspension was prepared and added to Bowen town supply water in a large plastic container. The inoculum concentration of *G. candidum* was 1×10^5 colony forming units per ml. In order to avoid infiltration into the fruit, the water was heated to 30°C which was 5°C more than the core temperature of the tomatoes. Fruit were ripened for four days at 20°C in an atmosphere of ethylene at approximately 10 ppm. To simulate the transport and marketing regimes, the fruit were held at 10°C for one week and 20°C for one week before measuring the incidence of disease.

Experiment 2 : Since there was no visual difference in the growth and yield of any of the nitrogen rates in the first experiment it was assumed that there was a high level of available soil nitrogen. A cover crop of forage sorghum was grown on the new trial area and two cuts of hay removed in order to deplete this soil nitrogen bank. A second experiment was carried out in 1994 but with a reduced number of treatments. A split plot design was used with four replicates. Main plots were nitrogen applications of 0, 60 and 155 kg/ha as a pre-plant basal and combination of basal and side-dress through the trickle irrigation system. Sub- plots were high and low irrigation regimes. A single cultivar, *Tornado,* was used.

Containerised seedlings were field planted in early June 1994 and fertigation treatments commenced in mid July and continued until harvest. One week prior to harvest, petiole sap nitrate was measured by the rapid method employing the use of nitrate test strips and a 'nitrachek' meter. Samples from the four replicates of each treatment were bulked to give an average nitrate-N level for each treatment. Harvesting commenced in early September and continued through September, a total of three harvests being carried out. Fruit from the datum area of each plot were weighed and counted at each harvest and graded into marketable and unmarketable fruit.

Sixty fruit at the mature green to light pink stage were harvested from each of 4 replicates. Harvested fruit were then heated in ovens until fruit temperature was 35°C. This was designed to simulate the temperature to which fruit is commonly exposed at harvest in local crops in the main harvest period of September-October.

Twenty fruit were submerged in an inoculum of *G. candidum*, the causal organism of yeasty rot, at a concentration of 1 X 10^5 colony forming units per ml. In order to create conditions suitable to infiltration of water into tomato fruit, the inoculum was cooled (using sealed bags of ice) down to a temperature of 20°C, while the core temperature of the fruit before immersion was 35°C. Fruit were dried and placed into clean, new commercial packing boxes.

Another twenty fruit were wounded at 4 locations on the fruit using a vaccinating tool which consisted of a disc (1 cm diameter) with several sharp projections which entered fruit to a depth of .5 cm. The vaccinating tool was dipped in a *G. candidum* inoculum of 1 X 10^5 colony forming units per ml. The wounding was used as a simulation of potential surface wounding to which tomatoes could be subject in the field. Fruit were placed into a clean, new commercial cardboard packing boxes.

The final twenty fruit were placed directly into clean, new commercial packing boxes without washing.

All boxes were packed into a cool store at Bowen Horticultural Research Station and a standard commercial ethylene treatment (approximately 10 ppm) was applied. Fruit were stored at 21°C for 4 days (to ripen) and then 25°C for 3 days (to simulate what could occur in the market situation). At the end of the 7 day period all fruit were examined for signs and symptoms of yeasty rot infections.

Results

Experiment 1

Tomatoes with minor damage from potato tuber moth had a significant increase in yeasty rot over those which were undamaged (Table 1). There was a trend towards higher disease incidence at high levels of nitrogen fertilizer. Neither cultivar nor irrigation regime produced significant differences in disease incidence.

Table 1 Percentage of tomato fruit with yeasty rot in Experiment 1 *

	Minor Insect Damage	**Undamaged**
Nil Nitrogen	34.6 ± 1.9	0.1 ± 0.1
High Nitrogen	47.1 ± 0.8	1.2 ± 2.1

* Data are means of four replicates

Experiment 2

1. Impact of treatments on fruit yield : Effects of the 1994 nutrition and irrigation treatments on marketable yield, average fruit size and the nitrate concentration of plant sap at harvest are shown in Table 2. Highest fruit yields were associated with both higher irrigation levels and higher nitrogen applications. Irrigation alone in the absence of applied N produced significantly higher yields at the high irrigation regime than at the low regime. For each N level applied, fruit yields were significantly greater at the higher irrigation regime. There was also a strong trend to increasing yields with increasing levels of applied N under both irrigation regimes. At the higher applied N level and the high irrigation regime, fruit yield was significantly higher than from all other treatments. Fruit size, however, was unaffected by N application, but was significantly larger under the high irrigation regime.

Petiole sap nitrate-N increased with increasing N application, irrespective of irrigation regime. However, petiole sap nitrate levels at harvest were still quite low when only basal N was applied. Levels increased rapidly when additional N was applied as a fertigation treatment. Under the low irrigation regime, petiole sap nitrate-N was more than twice the corresponding level in the high irrigation regime.

Table 2. Effects of nitrogen and irrigation on tomato marketable yield, fruit size and nitrate concentration of plant sap

Treatment	Marketable Yield/Plot (kg)	Av. Size (g)	Sap N prior to harvest (ppm)
1. Nil N. Low irrigation	48.9 a	157 a	195
2. Basal N. (60kg/ha), Low irrigation	55.2 b	160 a	252
3. Basal N + side N, (60kg + 95kg Total 155kg), Low irrigation	66.5 c	159 a	2500
4. Nil N. High Irrigation	59.4 bde	172 b	197
5. Basal N (60kg/ha), High irrigation	63.1 ce	172 b	265
6. Basal N + Side N, (60kg/ha + 95kg/ha), High irrigation	73.1 f	170 b	1090
LSD p = 0.05	6.1	8.3	

NB : Means in each column which do not share the same letter are significantly different.

2. Impact of treatments on fruit breakdown : The main factors of irrigation and inoculation type were significant (P 0.05) in the development of yeasty rot infections (Table 3). High irrigation regimes predisposed fruit to yeasty rot infections. Wounding prior to storage led to significantly higher infections than dipping in inoculum or no wounding. No consistent interactions between these factors were measured. There was a marked trend towards increased incidence of disease with increased nitrogenous fertilizer but it did not reach significance at the 5 % level.

Table 3 Effects of Irrigation, Nitrogen Fertiliser and Inoculation with *G. candidum* on the of Percentage Tomatoes with Yeasty Rot in Experiment 2[II]

Factor	**Level of Factor**	**Percentage of fruit with yeasty rot**	**P (0.05)**
Irrigation	normal	1.0(a)	
	high	10.5(b)	*
Nitrogen fertiliser	nil	8.5	
	basal	16.5	n.s
	basal + fertigation	24.0	
Inoculation	infiltration	3.0(a)	
	wound	14.5(b)	*
	nil	2.0(a)	

II Data are equivalent means following arc sine transformation.
Means which do not share the same letter are significantly different (P=0.05).

Discussion of Experimental Results

Neither cultivars nor contrasting irrigation regimes produced significant differences in disease incidence in the first experiment. However there was a consistent trend towards increasing breakdown with the highest rate of nitrogen fertiliser compared to nil nitrogen application. It is believed that the effect was masked by having high initial levels of available soil nitrogen. This was indicated by lack of measurable differences in growth and yield under any of the nitrogen regimes.

Effects of irrigation : Excessive irrigation increased the susceptibility of tomato fruit to breakdown, consistent with grower experience and observations by extension officers. For example, one visit to the Flemington Markets coincided with the condemnation due to post-harvest rots of five pallets of tomatoes from one Bowen grower. A traceback isolated the problem to accidental excessive irrigation. Similar results were obtained in Bundaberg where Cunningham (1993) found a close relationship between high levels of available soil moisture and reduced shelf life of tomatoes. Peet (1992) noted that, in the field, high moisture tensions suddenly lowered by irrigation or rain are the most frequent cause of skin cracking in tomatoes. Practices designed to minimise cracking were maintenance of constant soil moisture and avoiding high levels of available soil water.

Effects of damage to the surface of tomatoes : Fruit with minute damage from potato tuber moth were much more susceptible to breakdown. Similarly fruit which was abraded became susceptible to the challenge. By contrast undamaged fruit showed negligible disease after immersion in inoculum. Fruit were more susceptible to infection from wounds than from infiltration. This supports the assumption that the integrity of the cuticle is a key factor in post-harvest disease of tomatoes. A number of tomato farmers concentrate on reducing abrasion by employing practices including washing out picking buckets each time they are emptied at the packing shed, watering roads to reduce dust and minimising impact damage during packing. Our results indicate that reduction in surface damage will significantly reduce the threat of the main post-harvest disease, yeasty rot.

Effects of nitrogen fertilizer : Lack of a significant increase in susceptibility to yeasty rot of tomatoes with increasing nitrogen in the second experiment contrasts with commercial experience in the Bowen tomato district. Low concentrations of nitrate in sap at harvest may have been due to irrigation under the high regime leaching nitrate-N from the root zone. The level of 1090 ppm petiole sap nitrate-N at harvest under the high irrigation regime is much lower than the level aimed for (3000 - 4000 ppm) and is close to the concentration which crop consultants recommend to farmers (John Hall, personal communication). Consequently, the combined effect of excessive irrigation and excessive nitrogen at harvest was not achieved. Soil type may have influenced this anomaly as leaching would be reduced as clay content increased.

Tomato variety considerations : Current attempts to produce fresh market tomato varieties with higher Brix, aimed at improving flavour, may have unintended consequences in increasing the susceptibility to fruit cracking (Peet1992). A major advantage of this work is that the resultant tomatoes could be used in a dual role for fresh market and processing. If second grade fruit is sent to processing it has the potential to improve financial returns to growers and to improve the average returns from the fresh market. At the shed level there may need to be some modifications to systems of removing tomatoes from the receival dip to ensure rapid removal of fruit as a higher proportion is likely to sink due to increased specific gravity. Otherwise there is likely to be an increase in post-harvest breakdown due to infiltration associated with longer immersion periods under increased hydrostatic pressure (Showalter 1993). Our results suggest this poses a lower risk than does surface damage to fruit.

Effects of climate : The effect of weather on fruit shelf life remains difficult to manage. Occasional cold nights, commonly at or below 10°C for less than 5 days at one time, are associated with misshapen fruit due to poor pollination. Regular call-outs to farms indicated that the larger fruit produced in these conditions often showed post-harvest breakdown. Based on the results of trials 1 and 2, it is suggested that lack of integrity of the tomato surface allowed the entry of disease organisms. This conclusion is supported by a recent review of tomato cracking (Peet 1992) which found that excessively rapid fruit growth which produces large fruit results in more cracking, particularly where there are high differentials between day and night temperatures. Soft fruit are reported throughout the district at similar times, suggesting that the rapidly varying temperature regimes are responsible.

The frequency of call-outs to packing sheds as a result of post-harvest disease has been noted over this period to relate directly to weather. In particular, following wet weather (including small precipitations, eg 1 -2 mm associated with non-drying air conditions due to overcast skies) post-harvest rots can be predicted to occur within a week. These may be related to skin damage (both major cracking and minor crazing), apparently allowing the entry of pathogens. Following such events a strict protocol of treatment with chlorinated washes and/or guazatine (Panoctine®) on shed receival and after ripening is recommended.

An example of widespread weather damage occurred in mid June 1994. Symptoms included russeting around the shoulders of tomatoes followed by pitting after harvest on both field coloured and ethylene treated fruit. It is suggested that the effect of environmental extremes including cold nights and warm days interacting with alternating sunny and cloudy days produced micro-cracking of the cuticle. Dehydration then occurred. Within 10 days the problem had passed.

Shelf life of tomatoes : A series of trials were carried out concurrently with this project aimed increasing the storage life of tomatoes. The goal was to develop a protocol for reliable outturns of quality tomatoes after long term storage. This would improve the opportunities by export via sea freight. This work was carried out for a plastics company in collaboration with researchers at the Institute for Horticultural Development, Knoxfield.

Tomatoes were treated with guazatine or chlorinated wash at shed receival and post-ripening. Storage was at 10°C or 12°C either in standard cartons or using plastic "active packaging" bags to create a modified atmosphere. Outturn assessments (over four days at 20°C) were made after 2, 3 and 4 weeks storage.

Assessments indicated a significant amount of bruising to a degree which would render many tomatoes unusable after storage. This damage was not apparent until late in the ripening process. Unbruised tomatoes were quite firm on removal after 2 weeks of storage, being too firm for immediate consumption. Softening, over the four day simulated marketing period at 20°C, was rapid but fruit had acceptable firmness.

More fruit rots occurred in bagged fruit with yeasty rot (*G candidum*) being the most prevalent (Reid et al 1996). This indicated that the organisms were protected from the fungicides, probably beneath the surface of the fruit. The higher incidence of yeasty rot has been linked by Wells and Spalding (1975) to low oxygen concentrations such as were designed in the modified atmosphere. By contrast unbagged fruit had higher incidences of *Alternaria*, *Cladosporium*, *Colletotrichum*, *Rhizopus* and *Penicillium* species.

It was concluded that overcoming bruising would significantly improve the shelf life of tomatoes.

Extension and Adoption by Industry

Marketplace : Results of market assessments were communicated to each grower. Attempts were made to identify the causes at each establishment. Remedial action was decided upon in association with the grower/packer. In addition, the reports by an independent (DPI) person on problems with produce in the market place were seen as more credible (and actionable) than 'ad hoc' information from sellers. Marketing agents indicated that they appreciated having a third party to report these problems to growers as past experience showed growers distrusted agents' reports on quality. Also such reports could threaten continuation of commercial relationships.

Irrigation : A number of Bowen growers have recently installed Enviroscan units to improve their irrigation scheduling with the aim of achieving high yields without rendering fruit susceptible to post-harvest diseases. Once these are calibrated to the specific soil conditions they will allow farmers to avoid irregular watering which is implicated in fruit cracking and possible entry of organisms causing breakdown. The situation is complicated by the low permeability of clay soils on which the majority of Bowen tomatoes are grown and the relatively high salinity of many of the ground waters used for irrigation (commonly in the range 2000 to 3000 υS/cm). It is anticipated that by use of Enviroscan there will be a reduction in the frequency of occurrence of blossom end rot which regularly occurs with irregular watering in this soil/water association.

Fertilizer Usage: There has been a general reduction in the use of nitrogen fertilizer on commercial tomato crops, particularly in application via trickle irrigation. One indication of this specific change has been a reduced incidence of induced magnesium deficiency due to overuse of potassium nitrate, particularly on land which had been heavily fertilised with nitrogen for prior crops of green beans and sweetcorn. A number of growers of these commodities have modified their fertiliser practices as a consequence. In one case tomatoes are no longer produced due to the problem. Sap testing is widely used as guide and the desirable level at harvest is accepted as being at or below 1000 ppm. Previously the industry used a higher standard which was developed for the increased crop life of trellised tomatoes in the Bundaberg area.

Compatibilities of Chemical Treatments: Prior surveying (Anning and Cole 1993) identified a risk to tomato shelf-life when the regulations for access to specific markets required use of insecticidal dips or sprays. High colony counts of breakdown organisms were found in both dips and recirculated sprays. This is an obvious hazard as these insecticidal treatments are required to be the last wetting of fruit before dispatch to market. Without a protective fungicide there is a risk of coating fruit with a layer of micro-organisms. A similar suggestion was made by Johnson (!986) who recorded an increase in post-harvest disease in tomatoes which had received a washing treatment after application of guazatine. Compatibility trials have been carried out by QDPI Agricultural Chemistry Section. As a result the registered fungicide guazatine (Panoctine®) is now recommended for addition to post-harvest dimethoate insecticide treatment. This has become standard practice in a number of packing sheds. *Note that fruit being exported to New Zealand cannot be treated with this fungicide at present because it is not included in the specific protocol for tomatoes.*

Packing Sheds : Regular observations were made in many of the Bowen establishments. All processes in sheds were recorded, particularly any washing treatments. A wide variation occurred in these. Problems with chemical type, solution temperature and methods of application were identified and rectified with growers in a number of cases. Since the post-harvest investigations began in 1992 many packing sheds have installed chlorinated water baths to receive fruit from the field. A training program has been delivered to a number of the enterprises which have moved to this hygienic treatment. The result has been development of effective work instructions for monitoring the temperature, pH and chlorine activity (Redox potential) of chlorinated dips.

Growers indicated fruit which needed more than a 3 to 4 day period in a ripening room during the warmer months had regular problems with disease. This suggests that the fruit involved are immature and lack integrity of the surface cuticle or wax layer.

Benchmarking : In addition visits were made to observe tomato packing sheds in other districts, namely Bundaberg and Stanthorpe. Alternative systems of handling were investigated and the resultant fruit quality assessed. In each case Bowen growers were also present. The net effect of these exercises has been to focus the attention of the grower community on overcoming post-harvest problems in the quest for reliable quality. This operation has used an action learning approach for both the project staff and the tomato producers. As in the earlier survey it was found that use of strict hygiene and attention to detail during all operations allowed some growers to consistently minimise threats to quality.

Technology Transfer : A wide rage of techniques were used to inform and involve industry in this project. The most common method was as a one-to-one contact with tomato producers during visits to farms. Items were regularly placed in the local newspaper and on ABC rural radio. The results were used with producers involved in a series of quality management workshops.

Directions for Future Research

A trial is currently under way to investigate sources of bruising in tomatoes. It is being jointly conducted with IHD staff and a DPI officer (Anning). An instrumented sphere is being used to measure impacts throughout the handling processes on farms. It includes calibration studies of bruising effects of specific forces. The trial will allow causes bruising to be identified, quantified and consequently minimised.

There is a need to investigate the relationship between softness and climate at the detailed physiological level. Currently there is no information on minimising this effect. It is suggested that future studies investigate methods of minimising the entry of disease micro-organisms into damaged tomato cuticles. This may include the use of waxes, fungicides and/or biological antagonists. However it is unlikely that registrations for more post-harvest fungicides will be readily obtained. Therefore it is suggested that non-chemical methods be investigated for reducing post-harvest disease. These may include heating fruit. While irradiation may be considered for insect control, it has been suggested that the doses required to destroy decay organisms would damage tomato fruit (Heather 1986). A major benefit of such methods would be to widen access for Australian fresh market tomatoes to overseas markets. Associated detailed studies would include sources of infection and modes of transmission.

Any future studies related to pre-harvest effects on post-harvest quality need to employ rigorous monitoring of sap nitrogen and continuous irrigation monitoring equipment to achieve the desirable factors thought to be associated with post-harvest disease problems in tomatoes. There may be significant gains available from further investigation of irrigation and nitrogen fertilizer regimes which optimise marketable yield without compromising shelf life. Such relationships would need to be related to soil type.

Good calcium nutrition is important in prevention of cracking in tomatoes and most other fruits and helps to protect against blossom end rot. Deficiencies of calcium are often due to poor transport of the element to tomato fruit. There are many commercial products available which are sold for foliar application of calcium and studies have indicated that foliar applications can be partially effective (eg, Barke 1968). However there is a need to investigate the efficacy of different formulations and schedules of foliar calcium usage.

A manual of suggested best practices for minimising threats to quality is under development.

Financial and Commercial Benefits from This Work

This was a very cost effective project. For less than $10 000 it has provided the Bowen tomato industry with recommendations for managing the complex of interacting factors affecting post-harvest quality of their product. Adoption of the principles developed in this work by many growers has significantly improved their performance in the marketplace. Effectively this has repositioned their product by improving the confidence of wholesalers in its quality.

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