Improved strawberry postharvest handling in Australia with new technology (CALM) and cultivars

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Sydney Postharvest Laboratory

Project Number: BS05002

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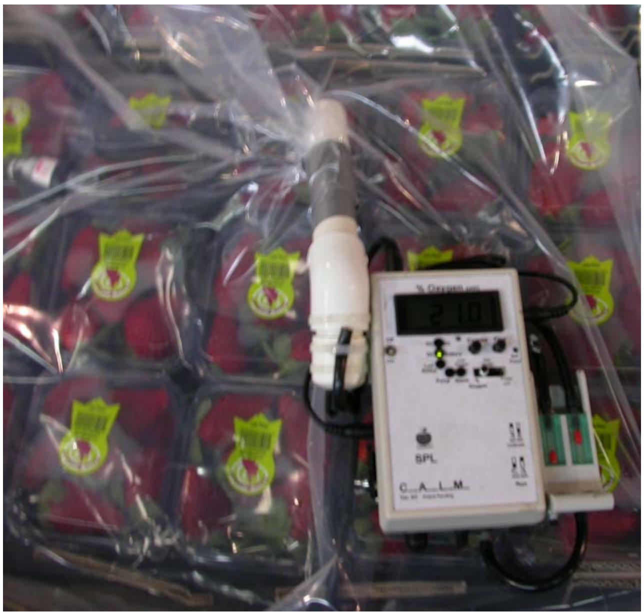

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Sydney Postharvest Laboratory
(10 June 2008)

HAL Project Number: BS05002

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Purpose of the report:

This report examines the quality of strawberries marketed in Australia, it also examines the performance of major cultivars grown in Australia. New handling methods involving controlled atmosphere storage are developed Strawberry CALM system, together with readily applicable methods of disease control. Implementing of these findings will allow premium fully mature/ripe strawberries to be picked and marketed to consumers, while ensuring that growers have little or no postharvest losses.

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Media Summary

Australia has a world class strawberry breeding program and new higher flavour local and overseas developed cultivars have been developed that can be grown in Australia. It has been suggested that the newer, higher flavour cultivars have higher losses during marketing. This has been examined in this work. For the first time in Australia a detailed comparison, was made of some of the major cultivars grown in Australia. Also postharvest quality with regards to rots and flavour of fruit was investigated as it was felt after the excellent breeding that postharvest quality was potentially a bottleneck that can adversely effect sales.

The project also examined the quality of strawberries commonly found in the market in several Australian capital cities. Problems with immature fruit (and consequently poor flavour) and rots were commonly found. The effect of individual grower was found to be more significant than district or cultivars on immaturity and rots. The higher flavoured and sweeter cultivars were not found in this research to be any more susceptible to rots and postharvest losses than cultivars with lower sugar content and flavour. This suggests that with adequate disease control, the newer sweeter strawberry cultivars can be marketed with no increased losses to the strawberry industry. It was found that fully mature and ripe strawberries (i.e. fully red with no white or green patches) had much higher flavour, sugars and aroma levels but that they were slightly more susceptible to rots than immature strawberries that are being marketed by some growers. Therefore some postharvest disease control is very important in marketing high flavour, fully mature strawberries. Rubygem, an Australian bred strawberry, was found to have high levels of the most important strawberry aroma compounds.

This project has developed new and improved postharvest handling methods for the Australian strawberry industry. This has occurred in two ways. Firstly, the CALM storage technology developed recently in Australia for chestnuts has been extensively modified and optimised for strawberries. The maintaining of a high carbon dioxide and low oxygen atmosphere around the strawberries has considerably extended their storage life. Secondly, new handling and disease control measures based on hot water or sanitisers have been developed that compliment the CALM technology. The two technologies combined together can greatly extend strawberry storage life and improve the deliverable quality of strawberries to the consumer.

Technical Summary

Australia has world class strawberry (*Fragaria virginiana* Duschesne) breeding programs and have developed new higher flavour local cultivars. There are also new overseas developed cultivars developed that can be grown in Australia. It has been suggested that the newer higher flavour cultivars have higher losses during marketing. This has been examined in this work. Also postharvest quality with regards to rots and flavour of fruit was investigated, as it was felt after the excellent breeding input, that postharvest quality was potentially a bottleneck that can adversely affect sales.

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It is recommended that the critical importance of harvesting fully mature strawberries be communicated to both growers and consumers, so that they can immediately start to reward growers marketing better strawberries. Also it is important that growers also include postharvest disease control strategies in their marketing including the newly developed CALM technology and other complimentary strategies such as hot water. Useful future work would include more detailed comparisons of the major cultivars for taste, using the optimal maturity stages and also evaluating with taste panels.

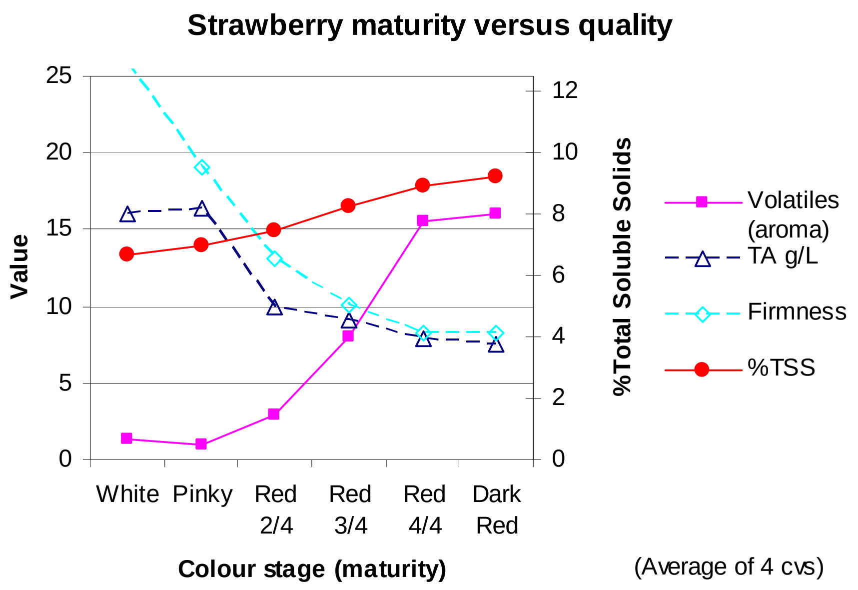
Introduction

Strawberries are a fruit that is especially valued for its sweet taste and aroma. However, the potential for high losses due to rots during marketing is a major concern for strawberry growers. This particularly so since the only commonly used method of postharvest disease control is refrigeration. The experience of strawberry growers seems to have been that if they grow sweeter strawberries and harvest them when at the stage of maximum ripeness, that levels of losses due to rots can be high. However, this supposition of growers has never been verified with scientific testing.

The result of this attitude is that while strawberry breeders have been breeding for flavour as well as yield, and have recently produced some cultivars with much improved flavour, growers are mostly often producing strawberries for yield and minimum losses during marketing. This frequently means harvesting less mature fruit which would seem to result in major compromises regarding flavour and aroma. Little is understood about the quality or maturity of strawberries marketed in Australia. This project will attempt to understand the current marketing situation. Further there has been no detailed postharvest quality comparison of strawberry cultivars grown in Australia

There is a considerable amount of literature describing methods by which strawberry rots can be controlled. These include chemical dips with iprodione (Rovral) (Washington *et al.* 1999), hot water (Karabulut *et al.* 2004), calcium chloride (Upadhayaya & Sanghavi, 2001) and MAP(Vicente *et al.* 2003) and inducing resistance to disease (Karjalainen *et al.* 2002). There is also a considerable body of information about the importance of harvesting mature fruit (Risser and Navatel 1997; Meanager *et al.* 2004).

This is illustrated in a composite figure, produced from the averages of two papers with precise maturity levels (as measured by colour and berry age on the plant) at harvest (Meanage et al. 2005, Risser & Navatel 1997). For the two positive characteristics of sweetness and aroma (or volatile levels of furanones, esters and lactones, which give the characteric flavour of ripe strawberries) it is apparent that the best taste is for strawberries that are 100% red or deep red. Much lower levels, especially of aroma, occur in strawberries that are even 75% red or less ripeness. The two more negative factors on flavour of firmness and acidity, both decrease rapidly with maturity. This decrease slows down and doesn’t change much after the 75% red stage of maturity.



There has been no detailed study of the relative flavour and quality parameters of strawberry cultivars in Australia. This research looking a postharvest disease susceptibility, %TSS (or Brix), sugar levels, volatiles and taste will help to fulfil an important need for this research.

This research also follows on highly successful research, where a simple and economic controlled atmosphere system has been developed for the Australian chestnut industry (CALM). The basis of the success on chestnuts is a high carbon dioxide and low oxygen atmosphere. Such an atmosphere is very beneficial for strawberries. This project aims to develop such a system, especially tailored for the requirements of the strawberry crop.

The significance to this research to the Australian strawberry industry is to enable a clear understanding of current marketing strengths and weakness. It will clarify wether some of the higher flavour new cultivars are actually more prone to postharvest rots. It will also explore whether the maturity of currently marketed strawberries is adequate.

The research will also develop new effective methods of postharvest disease controls for Australian strawberries. This will include a CALM system of controlling the atmosphere around the strawberries. It will also include a complementary method of disease control such as heat or sanitiser. This should enable a significant increase in strawberry quality to consumers with reduced postharvest losses to the Australian strawberry industry.

Materials and Methods

Fruit sources
Strawberries were obtained from a variety of sources. Many of the strawberries for the disease control experiments were obtained from sources close to Sydney as fruit could be used in experiments within an hour or two of being harvested. Both conventionally grown and hydroponically grown strawberries were used. For trials including larger quantities of strawberries and especially known cultivars, strawberries were obtained from a number of commercial growers in Queensland (including Sunray Strawberries, Coco & Sons) and Victoria (Kookaberry Strawberry Farm, Ozfresh). The specific cultivars included in this work were Camarosa, Albion, Festival, Gaviota and Rubygem.

Marketing Surveys
The market surveys that were carried out involved buying four punnets of each grower of strawberries present in each store surveyed. Stores sampled involved Coles, Woolworths, Independents and Farmers Markets. The fruit sources tested came from Victoria, Queensland, Western Australia and California. Occasional punnets were brought from South Australia, but not enough to analysis as a state.

Quality Testing.
Testing was done for %TSS on a minimum of 4 berries per punnet with usually 4 punnets used. Sugar content was analysed by first pureeing strawberries and freezing at -20C. The fruit puree was to a centrifuge tube o.5g with 0.5mls of ethanol, this was mixed and centrifuged. After filtering through a 0.5um filter, the sample was analysed for individual sugars by HPLC (LKB Bromma 2150 HPLC Pump) using an NH2 column with 75% acetonitrile and 25% water and an RI detector(LKB Bromma 2142 Differential Refractometer). Peaks were quantified against glucose, fructose and sucrose standards. At least three punnets were used for each sample tested.

Volatile testing was done by adding 3.5g of puree to 6.5mls of 35% $NaCl_2$ in headspace vials and then freezing at -20C. Samples for testing were brought to 40C and then volatiles accumulated on a SPME fiber (Divinylbenzene/Carboxen/Polydimethylsiloxane (DVB/CAR/PDMS)) for 15 minutes. They were analysed using a capillary Carbowax column with holding at 40C for 2 minutes and then increasing by 15C a minute up to 190C. The GC used was a Shimazdu GC17C with a FID detector and Shimadzu integrator. Peaks were quantified against standards of ethyl acetate, ethyl butanoate, methyl hexanoate, ethyl hexanoate and hexyl acetate. Other peaks were determined on the basis of retention time and testing several samples with GC/MS and identifying them using this technology.

Berry and Pathogen Testing
The assessment of rots was done by assessing either for presence, or absence of rot on each berry in a punnet. They were also assessed for severity of infection or rot on each berry where 1 = no rot, 2 = trace of rot (<=2%), 3 = slight amount of rot (~2-5%), 4 = moderate rot (~6 – 25%), 5 = severe rot (>25%). The percentage of infection refers to the average % of strawberries in a punnet with any infection at all. The storage regime for strawberries of 4 days at 0°C followed by 3 days at 20°C, was designed to give the strawberries a very severe test, with worse conditions than they would normally encounter.

If not assessed for severity, berries were assessed for percentage of the surface of each berry with blemish or rot. Also in some tests the type of rot was recorded for Rhizopus, Botrytis and Penicillium rots. The colour was recorded as % of skin red and % white. Colour stages were standardized against the CTIFL strawberry six stage colour standards (Risser & Navatel 1997). For all pathogen and quality tests, a minimum of three punnets were used per treatment.

Taste Tests

The taste testing was only done with six panel members rather than the more normal (and very expensive) 20 – 30 members, this smaller type of panel only can determine large differences between flavour and aroma. The taste panels were in addition to the original proposal and were kept small as they were not budgeted for. However, it was felt that it was beneficial to have some taste test results to correlate with other quality parameters and particularly with the volatile aroma analysis.

Results

Current Marketing of Strawberries in Australia

This research starts by examining the quality of strawberries currently marketed in Australia, including imported strawberries. This was done at a time of the year when strawberries from several Australian states and also overseas strawberries were available (April). There was found to be no major effect of store at which they were purchased on any taste & quality characteristics of strawberries. These were tested by obtaining all different grower strawberries available from four stores each of Coles (18), Woolworths (11) and Independents (17) (Table 1). Independent stores were slightly superior in terms of larger berry size, and higher levels of volatile produced. Woolworth strawberries were less ripe than Coles (less red colour).

Table 1 Effects of Chains of Supermarkets and Independent Stores on Strawberry Quality

				% Surface Area		Peak area/g		Taste Tests 0-10 scale		
Store	% TSS	% TA	Weight G	% Blemish	% Deep Red	Vol-atiles	Peak 4.26	Aroma	Flavour	Overall
Coles	8.52	1.02	36.3	12.5	76.3	61	390	6.97	6.45	6.82
Wool-worths	7.95	1.02	32.5	9.8	32.5	47	452	6.57	6.53	6.45
Independ-ent	8.2	1.01	49	13.3	49	115	1179	6.8	6.49	6.26
Significance	N.S.	N.S.	<5%	N.S.	<5%	<5%	<5%	N.S.	N.S.	N.S.

The numbers of strawberry samples tested were Queensland (23), Victoria (12) and California (11). There was a major effect of district of State, with Victoria fruit being less sweet (lower %TSS) and less mature or ripe with much more % of the skin with white colour (Table 2). The higher level of the volatile peak that had a retention time of 4.26min, suggests that this peak is associated with immature fruit and declines as the fruit ripens. (Based on subsequent research, it seems this peak is most probably 2-hexenol, which is associated with a green, grassy odour and taste.)

Table 2 Effects of District or Country of Origin

				Surface Area		Peak area/g		Taste Tests 0-10 scale		
District	% TSS	% TA	Weight G	% with Blemish	% with White	Vol-atiles	Peak 4.26	Aroma	Flavour	Overall
Queens-land	8.8	1.11	22.5	15.3	3.8	96	433	6.86	6.88	6.78
Victoria	7.8	0.96	24.2	11.5	19.7	97	2060	6.45	5.91	5.53
California	8.1	1.06	36	8.5	6.9	51	913	7.03	6.28	6.95
Significance	<1%	N.S.	<1%	<10%	<0.1%	N.S.	<10%	N.S.	N.S.	N.S.

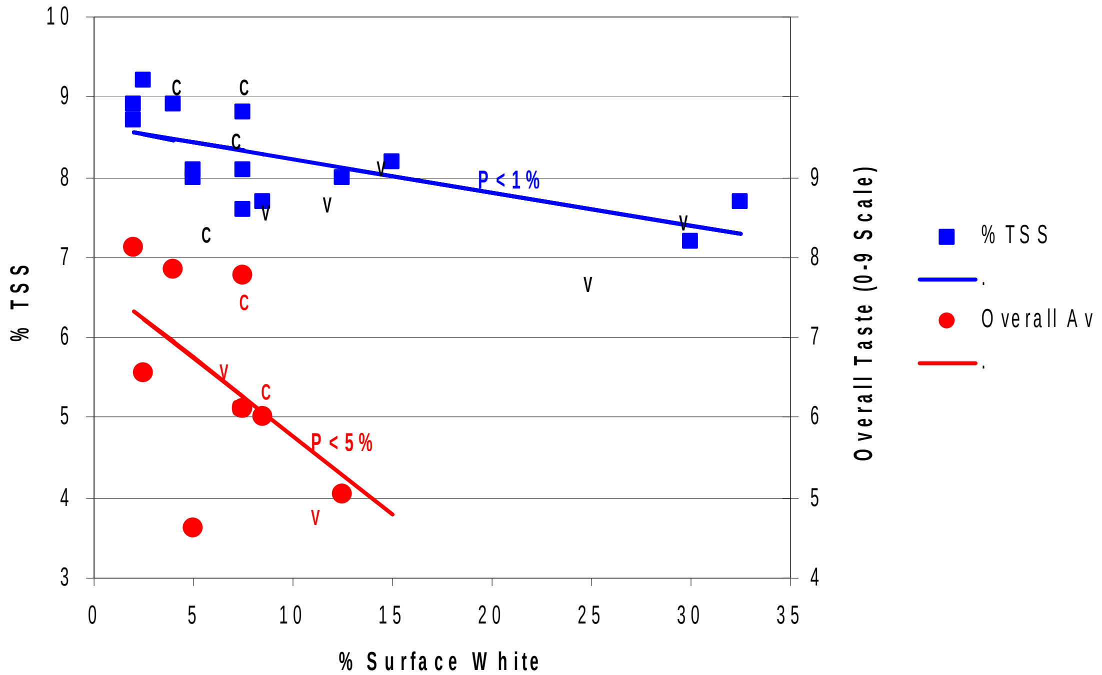
There was a large differences in quality, blemish and maturity for growers within each district (Table 3), with the variation between growers frequently being much greater than that between district. This is especially seen in Victoria, where grower 4 is producing quality mature fruit, while growers 2 and 3 are producing fruit of poor maturity. In Queensland grower 1 has fruit with much less %TSS (or sugar) than the other growers.

Table 3 Effects of Grower within District/ Country on Strawberry Quality

State	Grower	% TSS	%TA	% Blemish	Weight g	% Deep Red	% White	Volatiles Peak/g
Vic	1	8	1.03	15	27	32.5	12.5	67
Vic	2	7.7	0.9	7.5	18	12.5	32.5	
Vic	3	7.2	0.91	7.5	20	10	30	33
Vic	4	8.2	1	15	29	5	15	144
Vic	5	7.7	0.96	12.5	27	45	8.5	144
Qld	1	8.1	1.3	10	18	72.5	5	79
Qld	2	8.7	1.02	20	30	46.5	2	132
Qld	3	8.9	1.03	17.5	22	37.5	2	162
Qld	4	8.9	1.24	9	18	75	4	39
Qld	5	9.2	0.95	20	25	65	2.5	68
Cal	1	8.1	0.92	12.5	37	82.5	7.5	68
Cal	2	8	1.06	7.5	32	80	5	47
Cal	3	7.6	1.09	5	31	87.5	7.5	28
Cal	4	8.8	1.14	9	44	77.5	7.5	61
Range		7.2 - 9.2	0.92 - 1.24	5 - 20	18 - 44	5 - 87.5	2 - 32.5	28 - 163

When these results are examined in more detail (Figure 1) the percentage of the skin that was white was found to relate strongly in a negative way to %TSS and also very strongly in a negative way to overall taste. The poorer performance of Victorian growers is clearly seen. This relationship very strongly emphasises the important of harvesting strawberries at full maturity, without any significant white area, in order to achieve a good flavour. It also shows just how much flavour is compromised by harvesting at an immature stage to minimise losses to rots.

Figure 1 The relationship between % TSS and Overall Taste with % Surface White,for Strawberries (V=Victoria, Q=Queensland, C=California)



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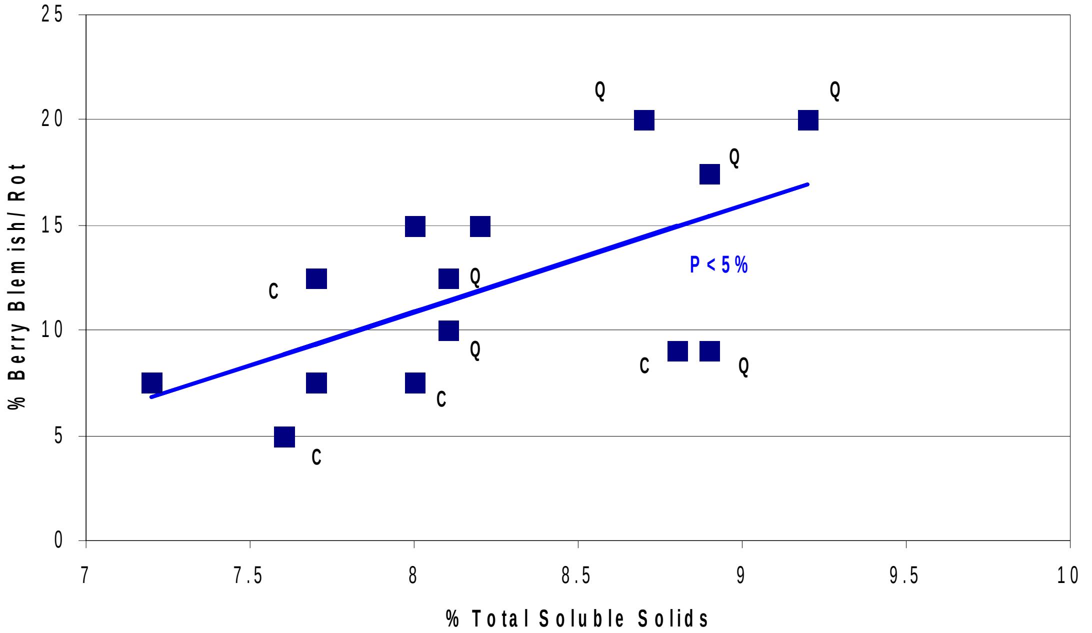
When the relationship between the level of sweetness as measured by %TSS and the level of blemish or rot is examined (Figure 2), there is a significant relationship, with sweeter strawberries having higher levels of rot and blemish. This is especially the case for Queensland strawberries. This shows that the best flavour strawberries need to have efficient disease control in order to deliver to customers in a premium condition. Victorian berries had overall the lowest levels of rots, which would be expected due to their overall less mature condition.

Figure 2 The relationship between levels of Blemish/ Rot and the % TSS for Strawberries (Q = Queensland, C= California, Rest are Victoria)



A similar exercise was carried out in late spring (late October) when fruit from all major strawberry producing states (QLD, VIC, WA) plus NSW were available (Table 4). The results between states found that Western Australian strawberries had a higher percentage of Premium berries (defined as berries with no rot or blemish on their surface). The % of full red berries was lowest for Western Australian berries and highest for NSW berries. As would be expected the % TSS for Victoria was slightly higher than when tested in previously autumn and the % TSS was almost one percent lower for Queensland berries. These tests also included a number of supermarkets and unlike the tests in autumn, there was found to be no differences between supermarkets for any parameters.

Table 4 The effect of state of origin on strawberry quality (October)

States	% Blemish Free Berries		% Full Red		% Rots	% TSS (Brix)	Total Volatiles Peak Area
NSW	50.3	A	85.4	b	1.03	7.70	1,204,268
QLD	48.9	A	74.8	ab	1.23	7.89	863,465
VIC	47.9	A	76.2	ab	1.02	8.13	1,358,839
WA	68.8	B	64.5	a	1.38	7.69	1,180,493
Significance	<5%		<5%		N.S.	N.S.	N.S.

Again the difference between growers was much more than any difference between States. The range between growers for % blemish free berries was extremely large - 14 to 98%, for % full red berries it was 11 to 96%, for % rots it was 0 to 9.1%, % TSS from 6.6 to 9.9% and total volatiles from 0.67 x 10^6 to 1.53 x 10^6. These differences are very large and show the huge difference in quality between a grower growing premium quality strawberries and a grower not paying attention to quality even within the one district..

Table 5 The effect of growers on strawberry quality (October)

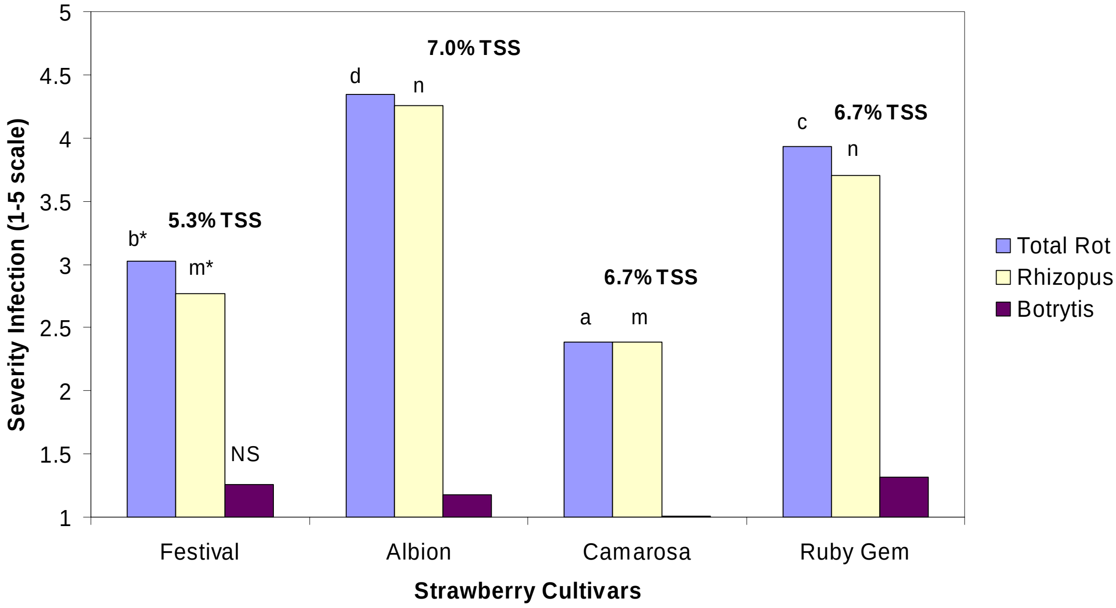
State	Grower Number	% Blemish Free Berries	% Full Red	% Rots	% TSS (Brix)	Total Volatiles
NSW	1	64	89	0	6.8	1.31 x 10^6
NSW	2	18	96	1.2	8.9	1.29 x 10^6
NSW	3	70	72	1.9	7.4	1.00 x 10^6
QLD	1	38	71	2.4	8.6	0.67 x 10^6
QLD	2	55	69	1.3	7.6	1.05 x 10^6
QLD	3	54	85	0	7.4	
VIC	1	38	92	0	9.9	1.15 x 10^6
VIC	2	14	84	6.1	7.6	1.53 x 10^6
VIC	3	46	55	0	8.1	1.39 x 10^6
VIC	4	59	75	0	6.6	
VIC	5	72	80	0	8.2	
VIC	6	58	71	0	8.4	
WA	1	53	72	0	8.0	1.25 x 10^6
WA	2	60	61	2.2	7.5	1.39 x 10^6
WA	3	43	53	1.7	7.7	1.17 x 10^6
WA	4	98	11	0	8.9	1.11 x 10^6
WA	5	71	59	6.7	7.9	1.27 x 10^6
WA	6	67	54	0	6.6	1.44 x 10^6
WA	7	65	45	1.8	7.4	0.60 x 10^6
WA	8	50	79	0	9.1	1.36 x 10^6
WA	9	89	44	4.4	6.7	0.90 x 10^6
WA	10	85	73	0	7.9	1.29 x 10^6
WA	11	66	66	0	6.9	1.11 x 10^6
WA	12	75	87	0	8.8	1.52 x 10^6
WA	13	80	85	0	9.6	1.19 x 10^6
WA	14	77	83	9.1	7.1	1.44 x 10^6
WA	15	67	62	0	6.8	1.11 x 10^6
WA	16	71	73	0	7.7	1,07 x 10^6
WA	17	71	58	0	7.0	1.00 x 10^6
WA	18	60	80	0	8.2	
WA	19	71	78	1.7	7.5	
WA	20	58	68	0	6.6	1.00 x 10^6

The Effect of Cultivar

Postharvest Disease

The effect of cultivar of postharvest rot susceptibility was tested in a trial with strawberries grown in Queensland (Figure 3). There are large differences with Camarosa having the lowest level of overall rots and of Rhizopus rot (see Photo 2). Festival was intermediate and Albion and Ruby Gem had the highest levels of rots. Also included in text for each cultivar on the Figure is the average %TSS, with Festival being lowest at 5.3% and Albion the highest at 7.0%. Consistent with previous results the cultivar with a highest %TSS had the highest level of postharvest rots. The levels of Botrytis rots were very low when the strawberries were assessed. It may be that due to the more aggressive growth of *Rhizopus* spp. at 20°C, that any *Botrytis* spp. fungi present were overrun. Penicillium rots were also assessed and but was very rarely observed <0.1% of berries.

Figure 3 The disease susceptibility of several strawberry cultivars grown in Queensland harvested in September - storage for 4 d at 0°C and 3 d at 20°C (also included is %TSS)



*Means followed by different letters are significantly different at k=100 (~5%) k Ratio LSD rule

Photo 2 Botrytis rot of strawberries

Photo 1 Rhizopus rot of strawberries

Photo 3 Camarosa cultivar

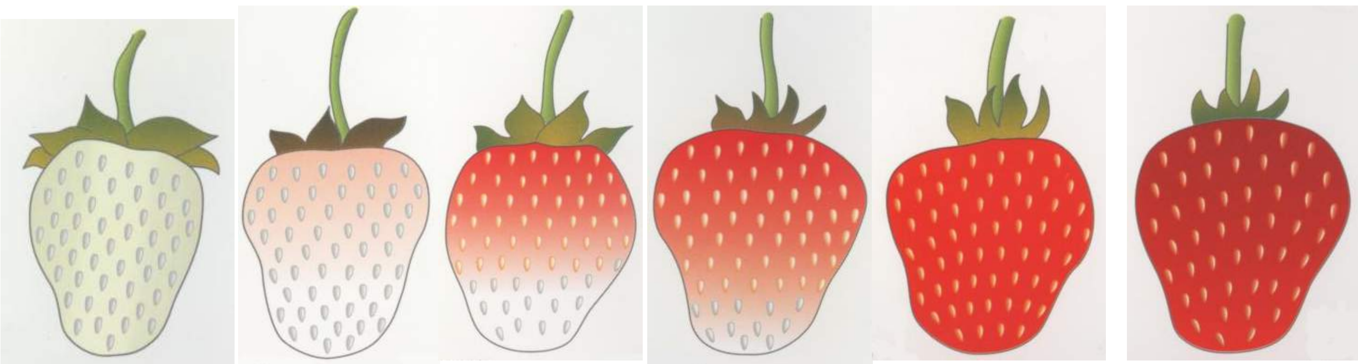
Photo 4 Albion

<u>Sugar Levels and %TSS</u>

Five cultivars grown in Queensland in September were tested for % TSS, sugars and volatile content. In this experiment we had available three maturity levels. However, the strawberry maturity stages developed at CTIFL in France has six colour stages. The colour stages of red/white, light red and full red in our results, correspond to the CTIFL colour stages of 3 / 4, 4 / 5 and 5 / 6. Unfortunately, two cultivars only had two maturity stages (Albion and Rubygem).

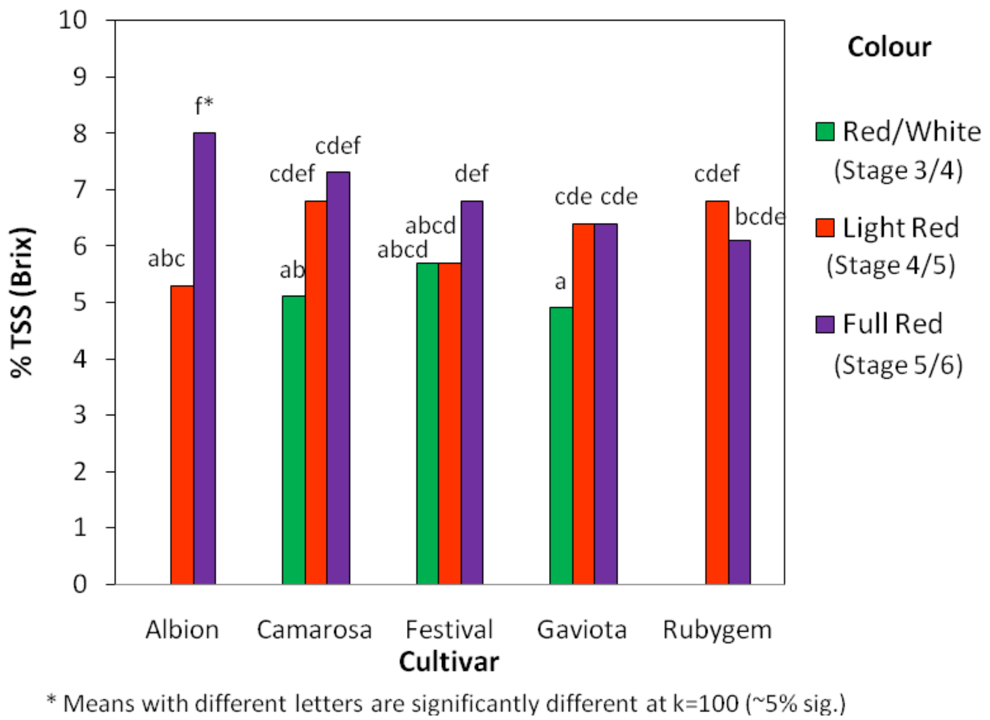
Figure 4 Strawberry Colour Maturity Stages (Risser & Navatel 1997)

Stage	1	2	3	4	5	6
Description	White	Pinky	½ Red	¾ Red	4/4 Red	Dark Red



While the overall %TSS doesn’t vary markedly between cultivars, there are marked differences between cultivars and maturity stages (Figure 5). Overall, there is a large increase in %TSS from the red/white stage to both red stages, with a much small difference between the two red stages.

Figure 5 The Effect of Strawberry Cultivar on % Total Soluble Solids



When individual sugars are measured and combined to give total sugars, there is a larger difference between cultivars (Fig. 6). Gaviota has now the highest overall level of sugar and this high sugar levels especially accumulates in the two red stages. Again there is overall a large increase from the red/white stage to both red stages, with a much small difference between the two red stages. These results show how important it is to harvest strawberries with no white areas.

Figure 6 The Effect of Strawberry Cultivar on % Total Sugars

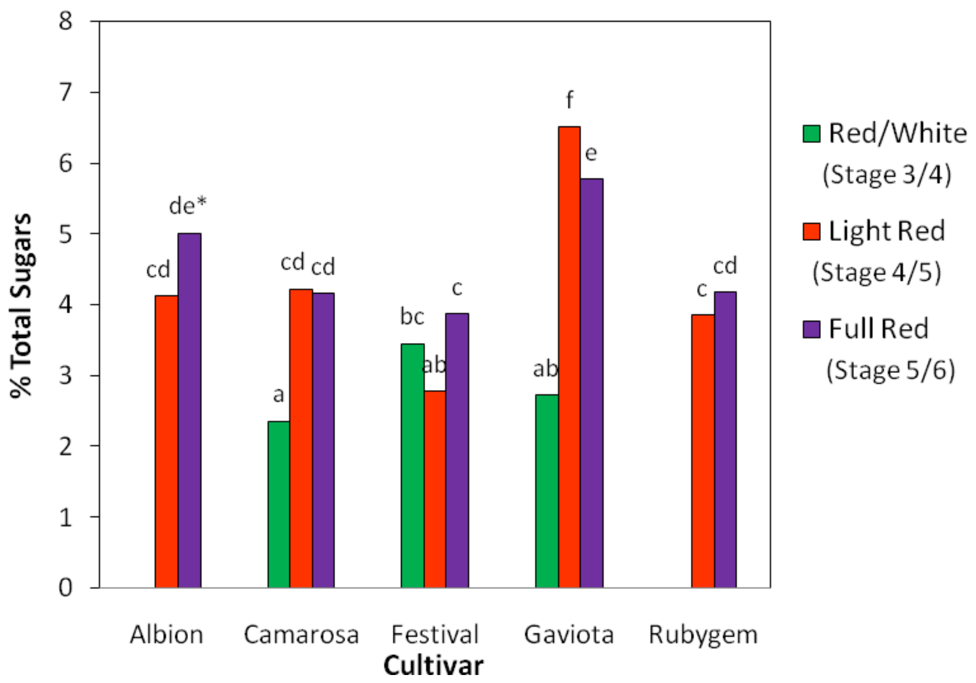
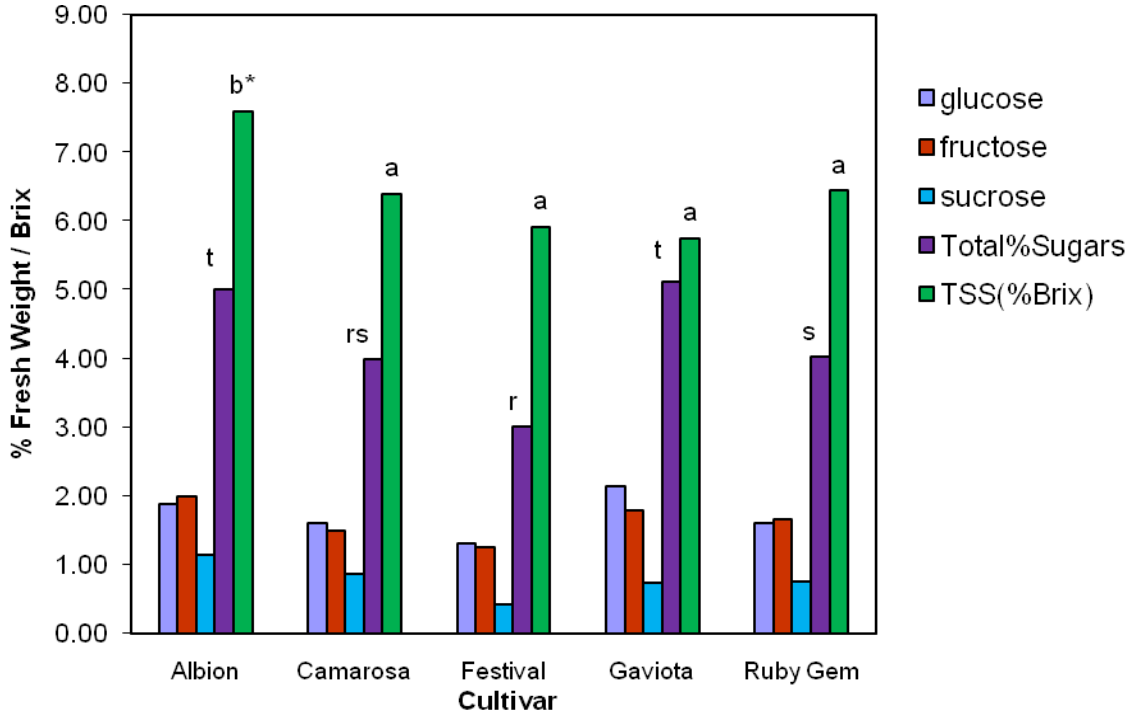


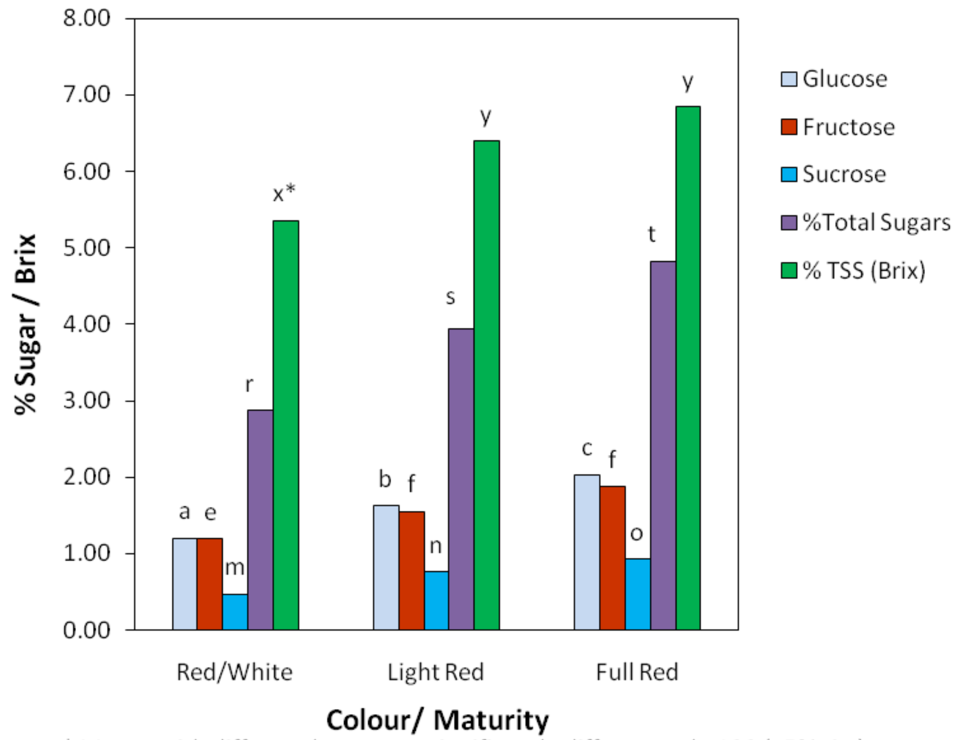
Figure 7 The effect of strawberry cultivar on sugars and % TSS averaged over maturity levels.



* Means with different letters are significantly different at k=100 (~5% sig.)

In Figure 7 we can see that when averaged over all maturity levels, the highest %TSS was Albion. Greater differences were shown for sugar levels, with the highest levels being in Gaviota and Albion and the lowest Festival. The overall pattern for individual sugars follows that for total sugars, except Gaviota has more glucose and fructose compared to sucrose than the other cultivars.

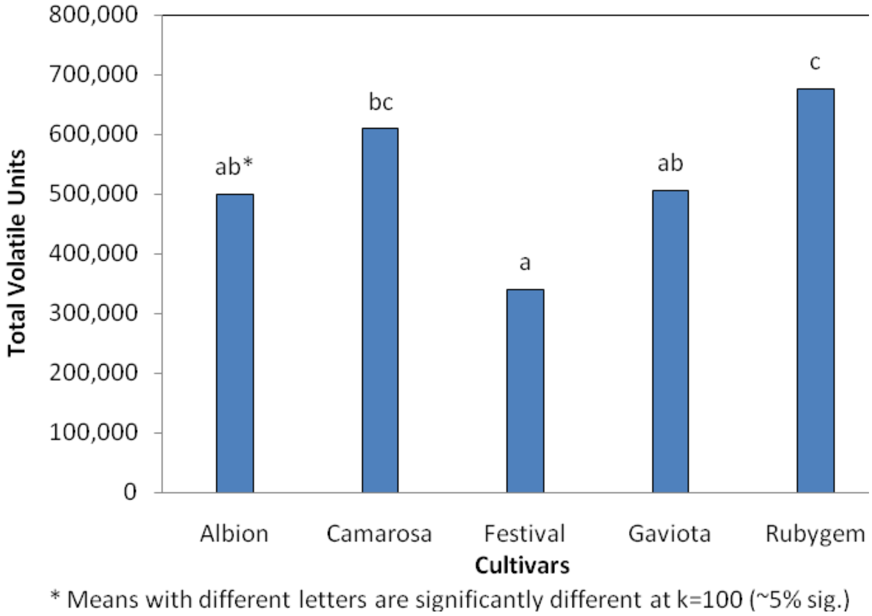
Figure 8 The effect of strawberry maturity on sugars and % TSS averaged over cultivars.



* Means with different letters are significantly different at k=100 (~5% sig.)

The effect of maturity when averaged over all cultivars is very dramatic (Fig. 8). For virtually every parameter there is a large and significant increase with each increase in maturity. This strongly suggests that the best stage for quality is Full Red (or CTIFL Colour Stages 5 and 6).

Figure 9 The effect of strawberry cultivar on levels of total major volatiles.



The strawberries were also tested for volatile levels by absorbing volatiles in the head space above macerated strawberries (in 35% salt solutions) with SPME fibers and separating compounds with GC. There was a difference in the combined total of major volatiles between cultivars (Fig. 9), with the highest levels being for Rubygem and the lowest levels being for Festival. However, when the effect of maturity on total volatiles was examined, there was no significant effect of maturity

Figure 10 The effect of strawberry maturity on levels of total major volatiles.

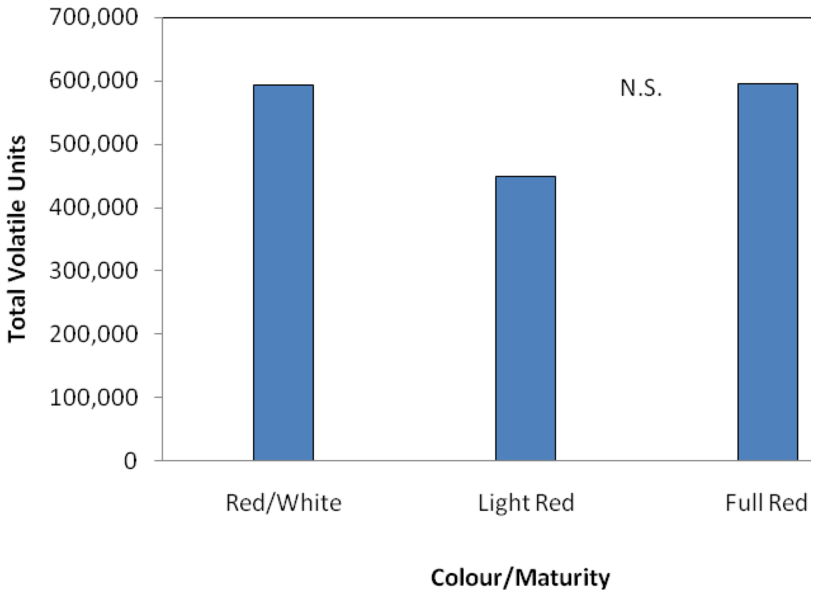
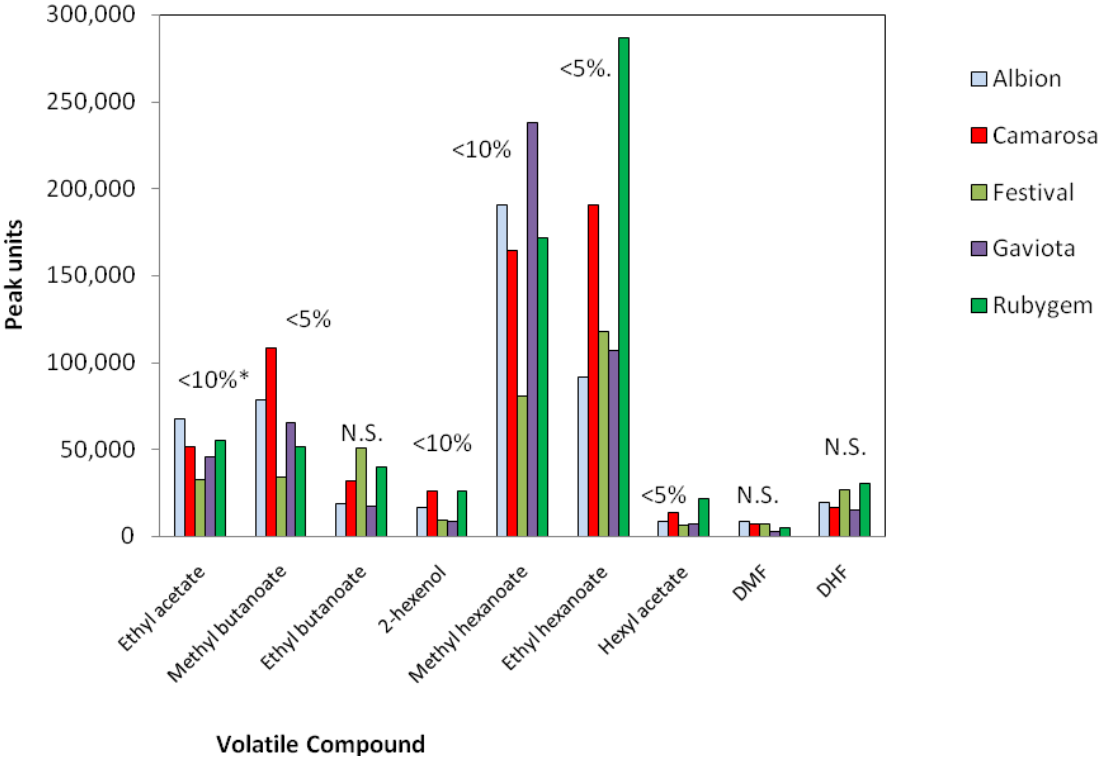
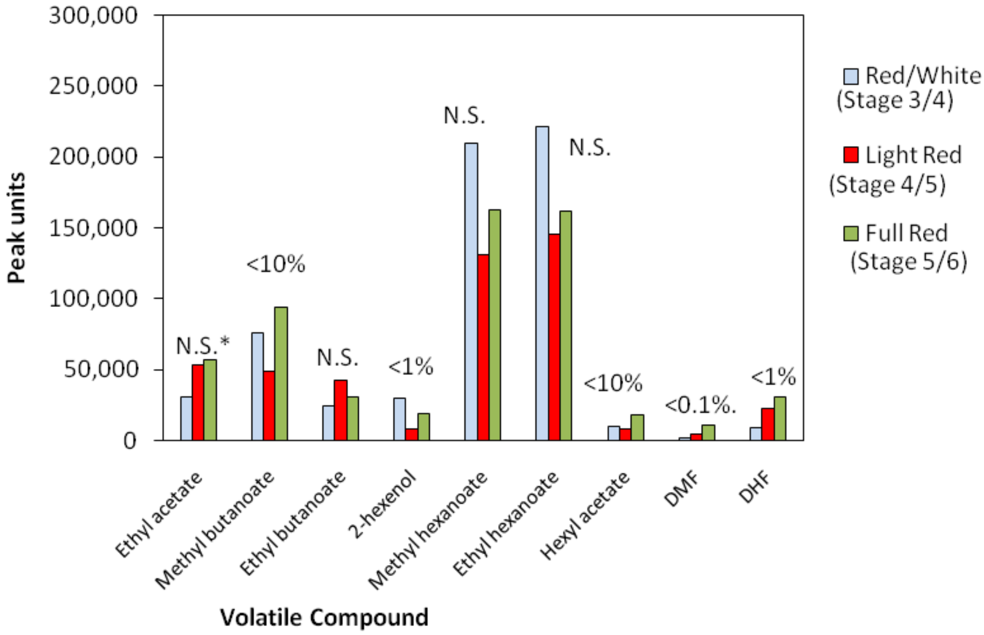


Figure 11 The effect of strawberry cultivars on levels of individual volatiles.



When individual volatile compounds are considered (averaged over maturity stages) in Figure 11, there is significant differences between cultivars - for methyl butanoate, the lowest cultivar was Festival and the highest Camarosa – for ethyl hexanoate, the lowest cultivar was Albion and the highest was Gaviota – for hexyl acetate, the lowest was Festival and the highest was Rubygem. Similarly, when individual volatile compounds were considered (Fig. 12), there were significant difference between maturity levels. The volatile 2-hexanol declined with increased maturity, while hexyl acetate, and especially DMF and DHF increased with increased maturity

Figure 12 The effect of strawberry maturity on levels of individual volatiles.



* Significance level of maturity variation within volatile compound

The volatile compounds in this research have been compared with regard to their peak areas. However, besides quantity volatile compounds have two important qualities than also need to be considered (Table 6). The first is the characteristic features of each volatile with regard to odour and taste, sometimes these characteristics can be pleasant, sometimes unpleasant, also they can sometimes be associated with immature green & grassy and sometimes with mature fruit (fruity). A further very important property is that the sensitivity of the human nose and palate varies enormously between compounds. For example human nose is about 2,500 more sensitive to two important compounds DMF (2,5-Dimethyl-4-methoxy-3(2H)-furanone) and DHF (2,5-dimethyl-4-hydroxy-3(2H)-furanone). than to methyl hexanoate.

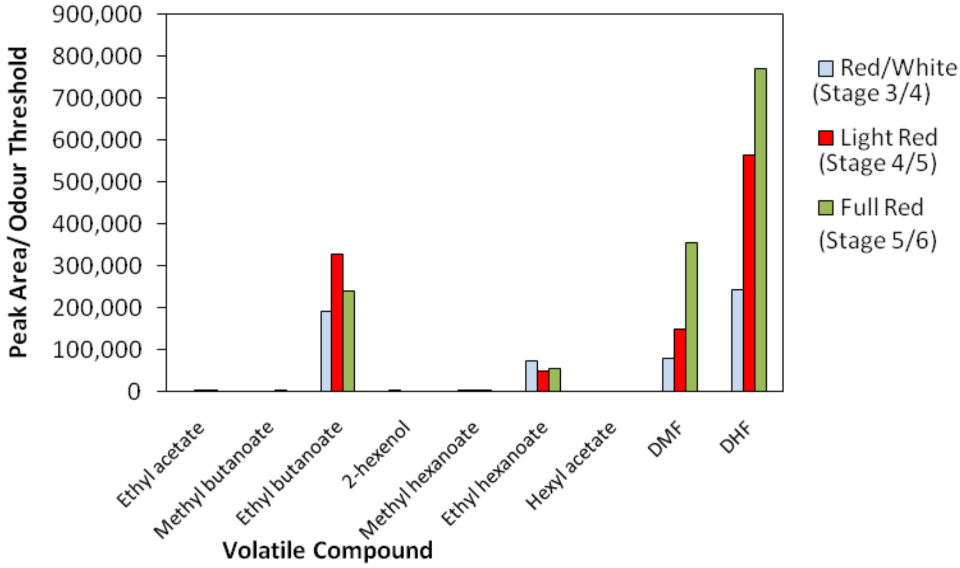
Table 6 Strawberry volatiles – characteristics and odour thresholds

Volatile Compound	Odour/ Taste Characteristics	Odour Threshold (in water ppb)[1, 2]
Ethyl acetate	pleasant, sweet-fruity	25
Methyl butanoate	fruity, ester-like, green	59
Ethyl butanoate	fruity, ester-like, sweet	0.13
2-Hexenol	green, grassy	17
Methyl hexanoate	fruity, ester-like	70
Ethyl hexanoate	fruity, ester-like, green apple	3
Hexyl acetate	green, fruity	2
DMF (2,5-Dimethyl-4-methoxy-3(2H)-furanone)	fruity, caramel, green	0.03
DHF (2,5-dimethyl-4-hydroxy-3(2H)-furanone)	sweet, caramel	0.04

[1,2] Ulrich *et al.* 1997, Jetti *et al.* 2007

When adjustments are made for the relative sensitivity of the human nose to the volatives present, we get a relative pattern across maturity as described in Fig. 13. This graph clearly shows that the most important compounds for strawberry flavour in these tests are DMF and DHF and to some extent ethyl butanoate. DMF and DHF have large increases between each maturity stages. Other researchers have frequently commented on the importance of these two compounds to the characteristic flavour of strawberries.

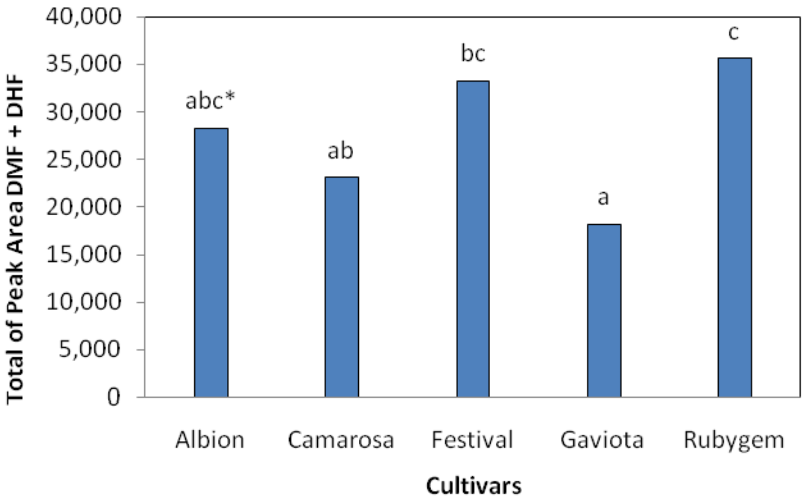
Figure 13 The effect of maturity on individual volatiles adjusted for odour threshold sensitivity.



* Significance level of cultivar variation within volatile compound

After determining the importance of these compounds in strawberry flavour, the difference between cultivars for these two compounds was examined (Fig.14). While Rubygem still is the highest compared to total levels (see Fig. 9), Festival moves from the lowest to second highest and Camarosa drops relatively to other cultivars. Gaviota drops from the middle to the lowest. This suggest high flavour levels for the Australian bred Rubygem compared to the other cultivars.

Figure 14 The effect of cultivar on levels of the important strawberry volatiles DMF and DHF

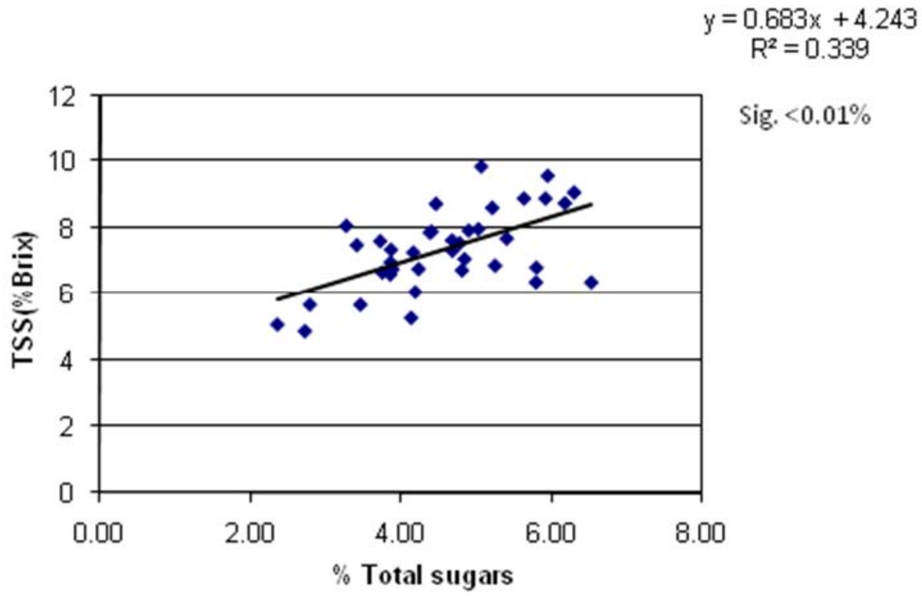


* Means with different letters are significantly different at k=100 (~5% sig.)

Relationship Between Quality Parameters

The relationship between % TSS and total sugars (glucose, fructose, sucrose) is examined in Figure 15. The relationship is very strong, however the relationship is certainly not 1:1 since %TSS is effected by many other factors besides sugars, i.e. organic acids, salts, soluble proteins etc. The greater relative range of % total sugars means this is a more sensitive, and accurate test to discriminate sweetness between strawberries.

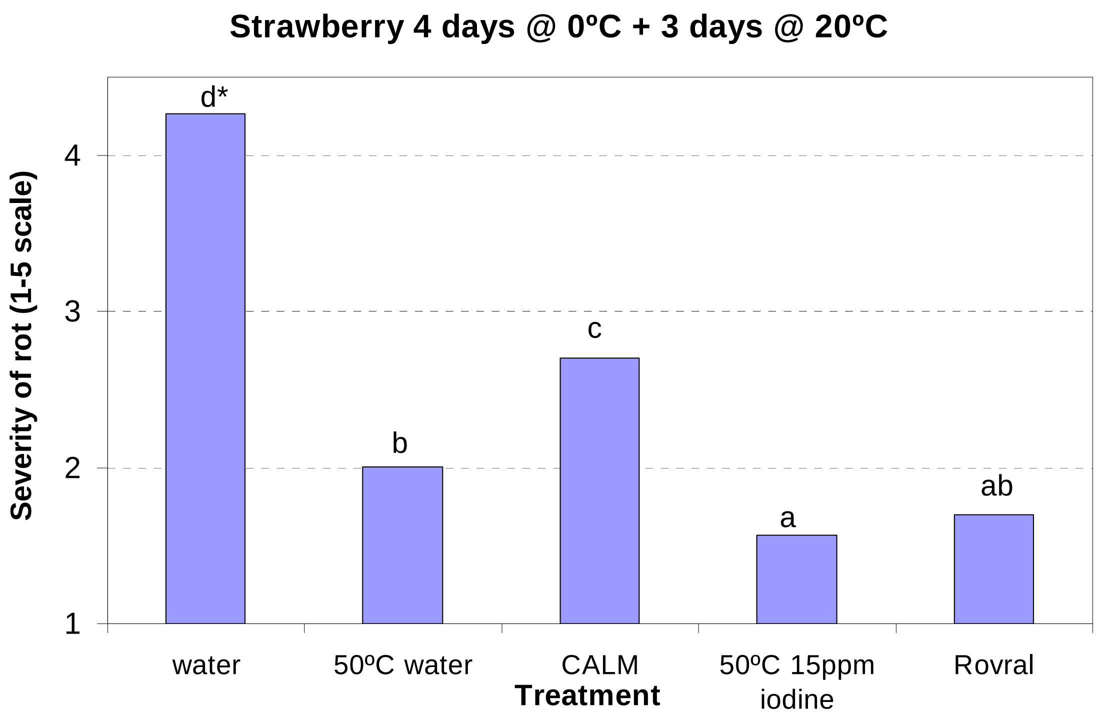
Figure 15 Relationship between %TSS and Total Sugars



Disease Control

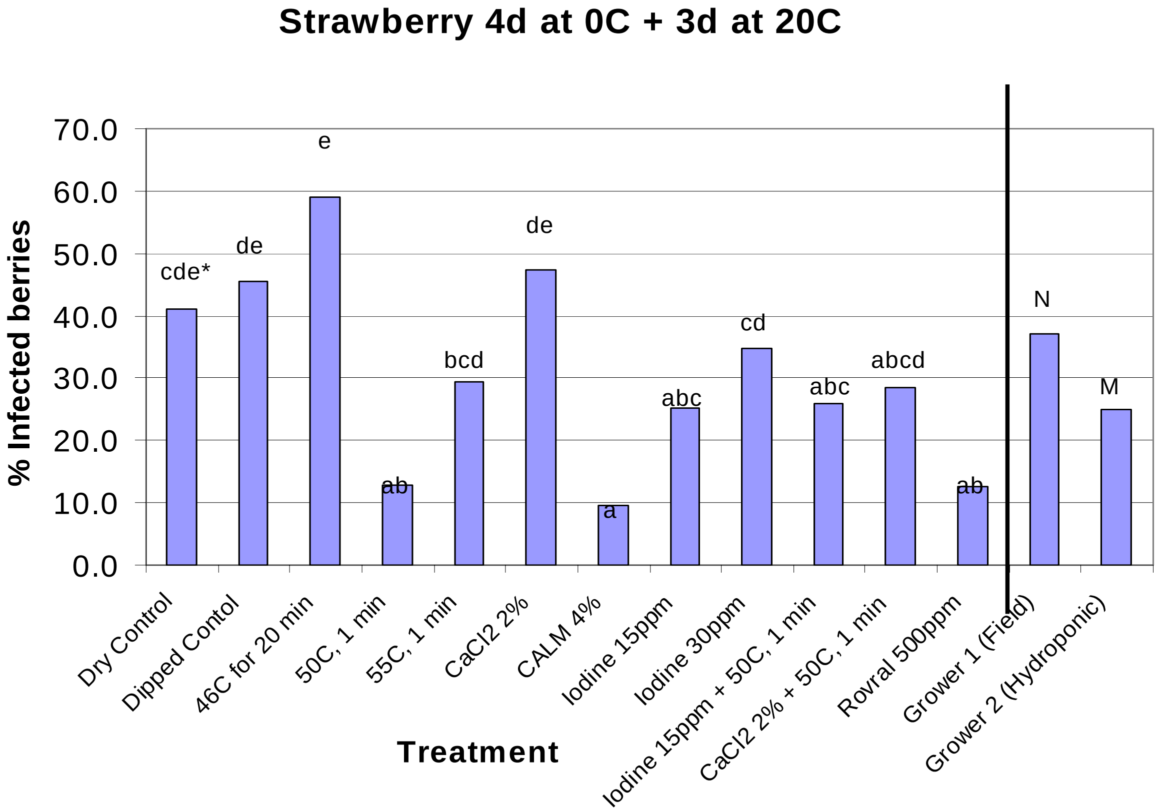
In order to permit the production of strawberries that are grown for flavour and also of cultivars with higher flavour, but shorter storage life, a range of postharvest disease controls were tested. The postharvest treatments tested were largely restricted to Generally Regarded As Safe (GRAS) treatments such as sanitisers, hot water and modified atmospheres. Four treatments were found to have large effects at reducing postharvest rots (Figure 16) – hot water (50°C for 1 minute), CALM (an actively controlled high CO2 environment around the strawberries) a combination of hot water and a santiser iodine at 15 ppm and a fungicide Rovral (iprodione at 500ppm. The CALM (Control Atmosphere Longlife Module) is an adaptation of a successful system developed for storage of chestnuts., that is being adapted for storage of strawberries.

Figure 16 Control of postharvest decay on strawberries using hot water (1m dip), sanitiser, CALM system or fungicide



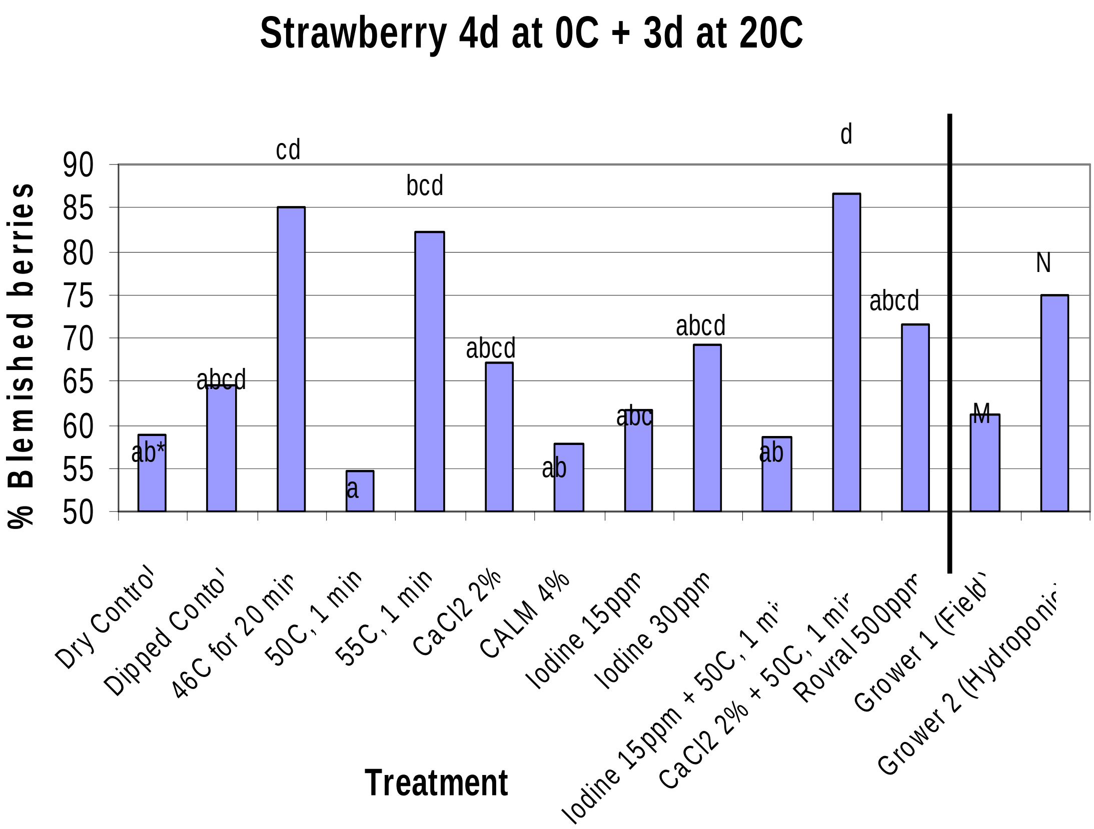
A large number of treatments was tested to control postharvest strawberry rots, strawberries used came from both hydroponic and field grown strawberries. (Figure 17) The most effective treatments were hot water (50ºC for 1 minute), CALM storage and the postharvest fungicide Rovral (iprodione). These three treatments gave excellent control of rots. Hydroponically grown strawberries had significantly lower levels of postharvest rots than field grown strawberries. Some treatments increased the level of postharvest rots, these were hot water at 48ºC for 20 minutes and 2% calcium chloride. The major reason for this is shown in Figure 18, where three treatments had a strong phytotoxic effect (or injurious effect) on the strawberries - 46ºC for 20 min, 55ºC for 1 min and 2% $CaCl_2$ + 50ºC for 1 min.

Figure 17 Control of postharvest strawberry rots after exposure to severe handling conditions



*Means followed by different letters are significantly different at k=100 level kLSD (~5%)

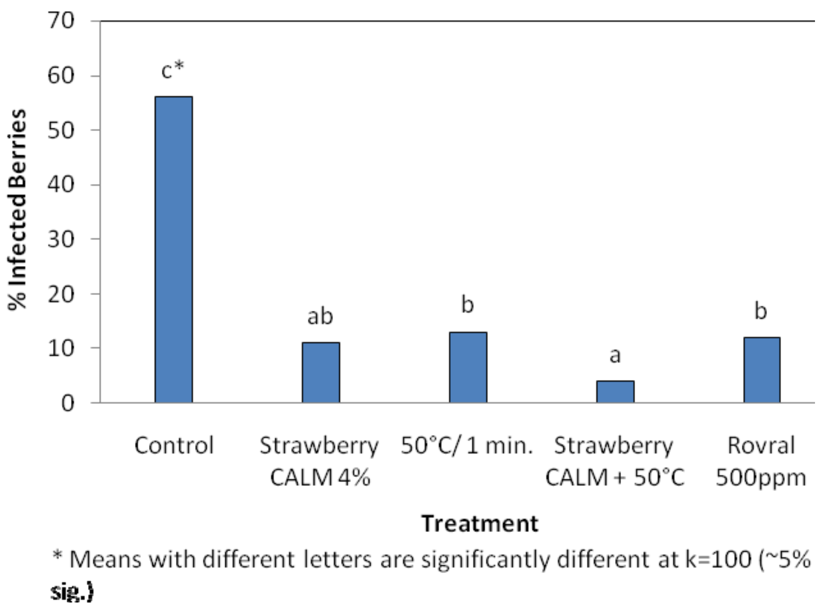
Figure 18 Level of blemish of strawberries after postharvest treatment and exposure to severe handling conditions



*Means followed by different letters are significantly different at k=100 level kLSD (~5%)

On completion of the final configuration of the strawberry CALM system (see next section) a storage trial was conducted using this system with high flavour cultivar Camarosa strawberries on trays on pallets and the strawberry CALM units running on batteries. After being packed they were transported and then held for 4 days at 0C and 3 days at 20C. The results are described in Figure 19. The best treatment was found to be the strawberry CALM system combined with 50C for 1 minute. Treatment with Rovral and 50C on its own were less effective than the combined CALM heat treatment. CALM on its own was intermediate between these treatments. All treatments gave very large and significant improvements compared to untreated controls.

Figure 19 Level of blemish of strawberries after postharvest treatment and exposure to severe handling conditions (4 days at 0C and 3 days at 20C) using CALM strawberry system pallets.



Electronics and Modification of the Chestnut CALM unit.

A modified chestnut CALM unit (see Picture 5) was used in the early disease control experiments (developed under HAL Project CH02003). This unit has a small detachable pump (Picture 6) that was powered from the unit, the unit itself is powered by a 12V DC plug pack. This use of 12V DC ensures safety in the cool room. However, while chestnuts are held in the one cool room for up to six months, strawberries spend only part of their shorter storage life of up to three weeks in a coolroom on the farm.

Picture 5 Chestnut CALM unit

Picture 6 CALM Pump

The running of CALM units on pallets with a totally DC powered system is shown in Picture 7.

Picture 7. Running of CALM units on chestnuts

A significant part of the postharvest life of strawberries can be during transport. Consequently a CALM unit for strawberries needs to be able to run both from a DC power supply and also from batteries both for the unit and for pumps will the system and strawberries are being transported under refrigeration. Design is underway towards this end of a unit that can run on both DC power and batteries. Since battery power is a limited resource, the unit will have to be very efficient. Consideration is also necessary for a simpler cheaper sealing system that can be readily included into the current strawberry industry and also for possibly a thicker plastic to compensate for the lower respiration of strawberries at 0°C.

<u>Electronics and Modification of the Chestnut CALM unit.</u>

Design has progressed well, with good power management from both battery and DC power, also the use of low power components has greatly reduced the requirement for power. The current design when running on batteries uses 4 AA batteries to run the CALM controller, which can run the unit for up to 7 days. The pump is run by separate batteries 2 D cells batteries, these batteries can run the pump continuously for 18 hours, which with expected on/off cycles, this should ensure the pump can run for up to 4 days by battery power. This performance on batteries is sufficient for almost all road transport journeys in Australia.

A large series of tests were performed with a range of circuit designs and refinement was required for a completely stable signal in a very low power consumption design. A total of 11 different circuit board designs were manufactured and evaluated as part of this testing Also an indication of battery status for both the Strawberry CALM unit was included and the air pump was redesigned.

It is planned to have the new strawberry units able to run either with the smaller chestnut pumps, or with the larger strawberry pumps that also include batteries specifically for the pump. By carefully planning, the one interface plug and the one set of mounting posts can be used for both pump types.

A copy of the latest circuit board and unit as at early 2007 is shown below (Picture 20a,b).

Photo 20a Circuit Board Layout Mid 2007

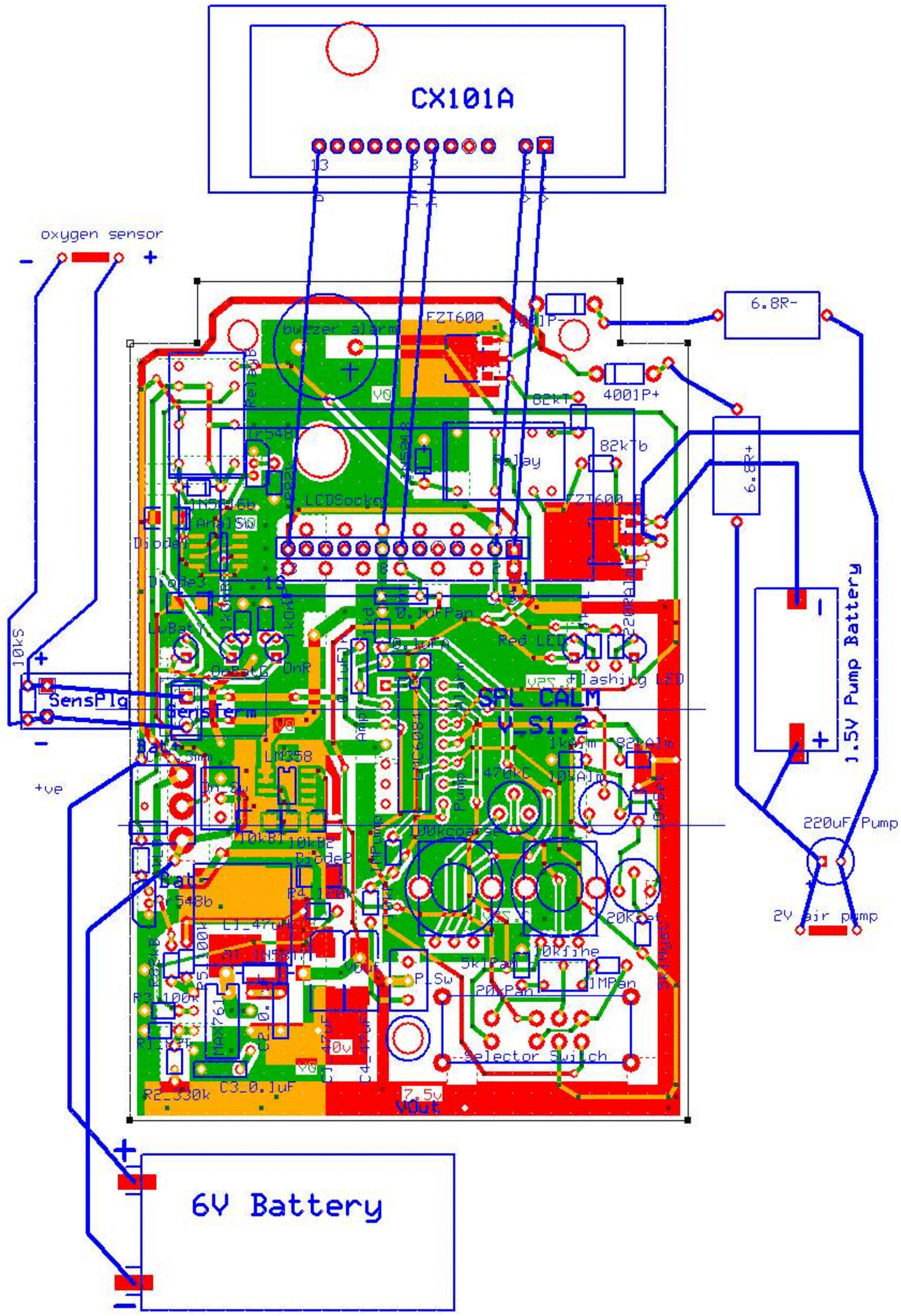


Photo 20b The strawberry CALM unit as developed at mid 2007.

Use of Tap for Oxygen Control

Minimising power is very important for battery powered equipment and the heaviest user of power by far in the air pump (uses >95%) of all power. Consequently a CALM tap was developed based on adapting a simple electronic watering system tap and adding a new control circuit (Fig. 21). Such a unit was developed and it ran well with a reduction of power by over 90% since a pulse of power was only used to turn the tap on and another pulse to turn the tap off. This CALM tap is shown in Figure 7, you can also see in the picture the 6.5mm opening in the tap that allowed air through when the tap is open. The unit was connected to the plastic bag by inserting the connection tube through a small hole made in the plastic and wrapping plastic around the tube and sealing with PVC duct tape (similar to CALM unit in latter photos). The CALM tap unit was connected to the CALM unit via a plug and cord and when oxygen was required the CALM unit closed a switch which opened the tap. The CALM tap was powered by two AA batteries, which should have a life of 9-12 months under normal operating system. An indicator light provided an indication of the need to replace the CALM tap batteries.

Figure 21. Circuit layout of CALM Tap controller.

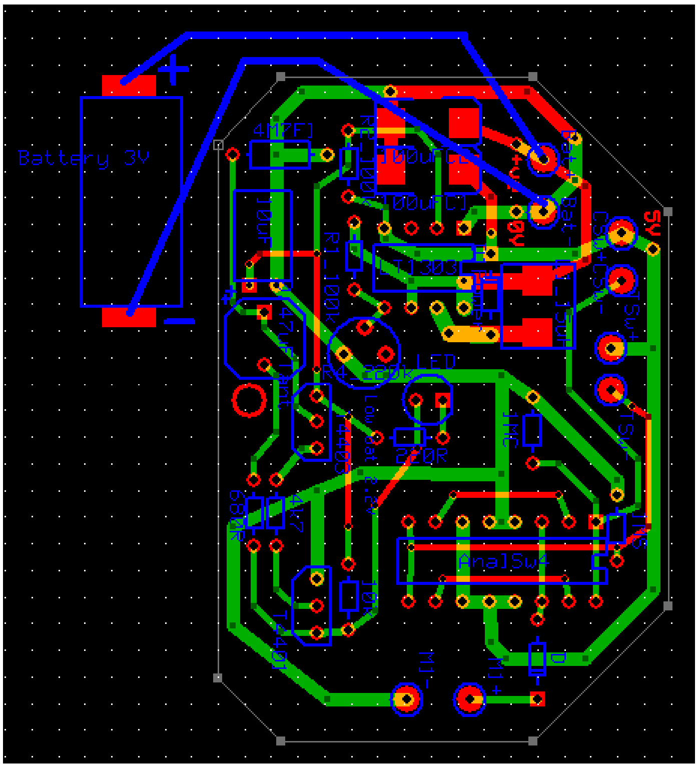
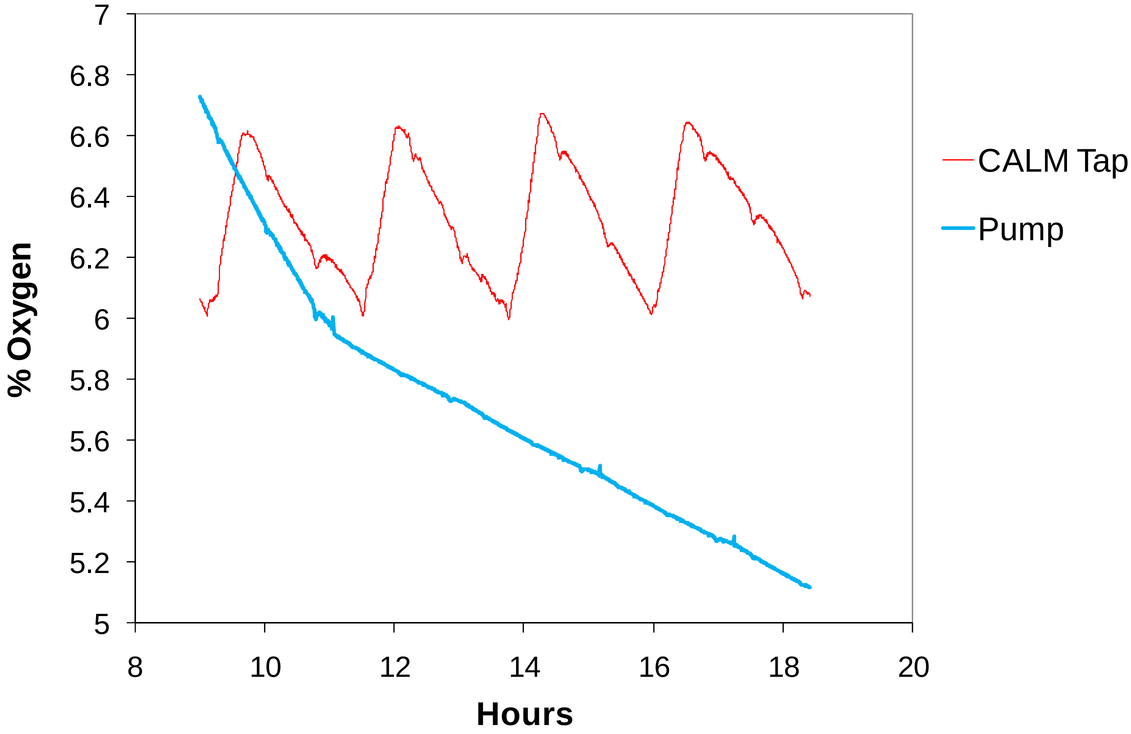


Photo 7 The CALM Tap

While the tap worked well in smaller scale tests. Unfortunately, when tested on a small pallet scale with three boxes of bananas at 20C to speed up the testing process, it was found that air movement through the tap was extremely slow. Shortening the tubing attached to the tap slightly increased the air movement. But even though the hole was of 6.5mm in diameter, movement of air through the hole was limited to a very slow diffusion. Even under the best conditions it was not possible to match respiration, with oxygen levels still declining (Fig. 21). Also shown on this graph is a CALM unit operating a pump. This controls oxygen levels to within a 1% range, with a rapid increase in oxygen when the pump turns on. However, when the CALM unit opens a CALM Tap instead, then the rate of oxygen reduction reduces slightly but the incoming oxygen doesn’t come anyway near to matching the respiration demand. To see wether air movement by convention was possible, one CALM tap was placed at the bottom of the pallet and one at the top, hoping to get air flow into the bottom tap and out through the top tap, however, this still made little difference.

Figure 21 Oxygen level in test pallet containing fruit (3 boxes ripe bananas at 20C) with CALM controller set to 6% and oxygen levels adjusted by CALM Tap or CALM Pump.

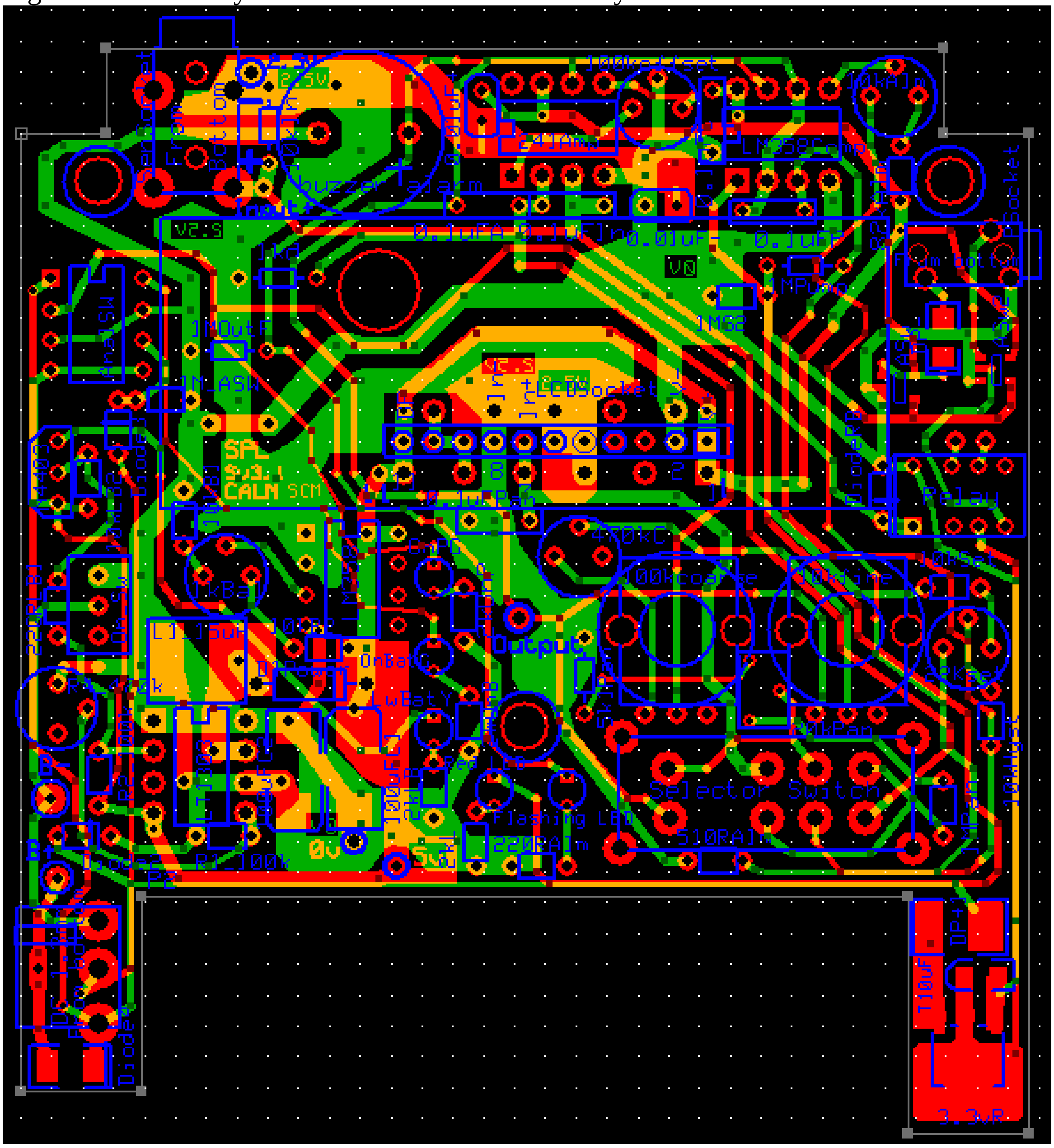


Strawberry CALM unit.

Many different variations of battery configuration and control circuitry were tested (11) and the final configuration was decided upon to fit in a small case, which matched the pump unit used in size.

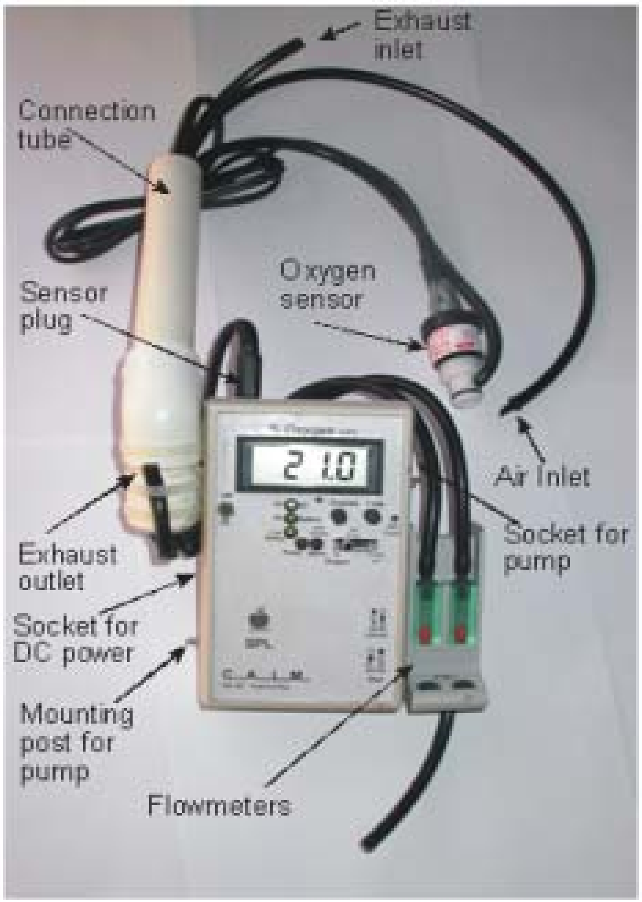
The board layout for the final configuration is described in Figure 22.

Figure 22. Final Layout of PCB Board for strawberry CALM unit.



The CALM unit (Fig. 22) is powered either by internal batteries (4 x AA) or via a 5V DC plug pack. All connection for external wiring is via three sockets (DC power, oxygen sensor input, pump controller output). Connecting plugs to these sockets via standard cables allows for simplicity of connections and for ready exchange of components. On the right side of the unit is a flowmeter and tap set, on the left of the unit is an airtight connection to the plastic bag surrounding the strawberries. Coming out of this connection tube are the cable and oxygen sensor, together with a tube allowing for calibration of the oxygen sensor (if required) without opening the plastic bag around the strawberries. There is also a long tubing, which is the air inlet providing the air required to maintain the oxygen level at the optimum level for strawberries – during operation a 1.5m extra tube is attached to enable fresh air to be delivered to the bottom of the pallet. To allow the surplus air to vent from the bag surrounding the strawberries there is an exhaust tube. Also on the unit are two mounting posts for attaching the pump.

Fig. 22 Strawberry CALM unit without pump attached.

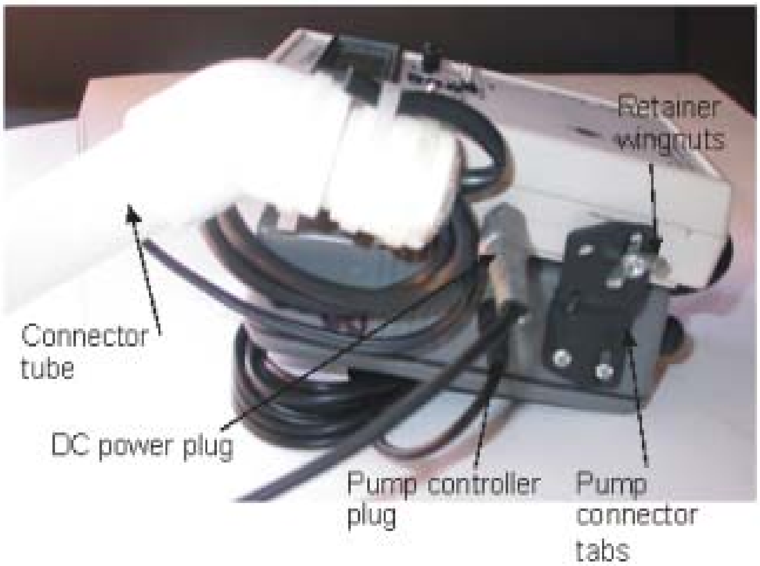


As mentioned previously, the air to maintain the required oxygen level is supplied by a pump. This pump can operate in two modes. If the CALM unit is operating by batteries alone, then the pump needs to have its own batteries (2 x D). This will allow the pump to operate continuously for about 20 hours, or at least 7 days under normal operating conditions. This time period would cover all normal transport by road or even export by air.   If the CALM unit is powered by a 5V DC plugpack, then the pump doesn't need batteries and draws its power directly from the 5V DC plug pack. The pump also has mounting tabs to allow connection to the CALM unit with two wing-nuts. The back of the pump unit is readily accessible while the unit is running, so that the pump batteries can be replaced simply if required.

Fig. 23 Strawberry CALM Pump Unit

In Figure 24, the CALM unit attached to the pump is shown side-on. The DC power cable and the Pump Controller cable are in the centre of the picture. The pump connects to the CALM unit via wing-nuts (one each side). The connector tube continues forward from the unit to enable sealing to the plastic bag around the strawberries.

Fig. 24 CALM unit connected to pump



The CALM unit is simply fitted to the strawberry plastic bag, by piercing the plastic bag with a pointed object, i.e. biro, screwdriver etc. The hole is then enlarged so that the oxygen sensor and tubes can be inserted through the hole. (The inlet tube needs first to have a 1.5m extension connected to enable the air to be pumped to the bottom of the pallet.). Once the tubes and sensors are in place, then the plastic is pulled outwards around the connection tube and firmly sealed with wide PVC duct tape. This provides a completely airtight seal.

Figure 25 Connection of the CALM unit to the Plastic bag surrounding the strawberries

The overall pallet of strawberries is shown in Figure 26. The plastic is sealed to a thin 3 ply sheet of plywood under the strawberries with a thin plastic angle attached to provide a vertical sealing surface. The sealing is again done with wide PVC duct tape. The top of the plastic tube is sealed by twisting the open end doubling it over and clamping with a large cable tie.

Figure 26 Side on view of strawberry pallet set up for strawberry CALM system

This configuration was found to give as good an airtight seal as the more complicated system used for chestnuts. It is obviously not as robust, however, it is only required to last for days or a week or two at most and not up to nine months as for chestnuts.

The final strawberry trial described in Figure 19 with Camarosa strawberries was tested using this system.

Discussion

These results show that the individual strawberry grower is the greatest factor in the final quality of the strawberries produced. This is more important than season, state of origin or even cultivar. However, it is not more important than the stage of maturity at which strawberries are harvested. There was found to be an overall quality variation between states, with regard to the time of the year. The quality was found to be better in the middle of the season for each state, rather than early of late in the season. This can be worth a full percentage point of %TSS or sweetness. However, it is also particularly at the end of the season from a district that individual grower performance becomes critical. The taste tests conducted did not find significant differences between states, this was felt to be largely due to the large differences in individual growers reducing the sensitivity of the tests. There seems to be a trend that the local produce ie farmer's market have higher levels of volatiles or aroma, while fruit that has travelled the longest distance ie imported, tends to have the lowest volatiles. This trend may be confounded by the use of different cultivars in California.

The harvesting of immature strawberries is a major problem for some growers and has been found to have very large detrimental effects of flavour and sweetness. Strawberries with any amount of white surface should be avoid by consumers! There is a large difference between cultivars with regard to susceptibility to postharvest rots and also strawberries with higher sugar levels and those being redder or more mature were found to be more susceptible to rots and blemishes. Hydroponically grown strawberries had significantly lower levels of postharvest rots than field grown strawberries, therefore this can be an important way of controlling infections.

For the best flavour and taste it is very important to harvest and sell strawberries to customers as red as possible. Some slight level of blemish needs to be tolerated by customers currently for them to get the best taste. When strawberries are overmature, the dark red stage can loose its bright, fresh appearance and become a dull dark red. This stage should be avoided during harvesting and marketing.

There were considerable differences found between cultivars with regard to postharvest disease susceptibility, with Camarosa the most resistant and Albion the least resistant. There was little overall difference between cultivars with regard to %TSS. Although when sugars were considered, there were major differences between cultivars, with Gaviota having the highest sugar levels and Camarosa and Festival the lowest. For total volatiles, overall the highest levels was for Rubygem and the lowest was Festival. However, when the most important strawberry flavour and odour compounds of DMF and DHF are considered then the best cultivars were Rubygem and Festival and the lowest was Gaviota. The biggest difference for all quality parameters was however maturity, with the final two maturity stages of light and full red being much superior to strawberries with any white. This is the case for %TSS, total and individual sugars, and especially the critical volatile compounds of DMF and DHF.

Several treatments were found to assist greatly with disease control (which as mentioned previously, is especially a problem for the much better quality mature berries). The best of these were CALM modified atmosphere, 50C water for 1 minute, iprodione (Rovral) dip and a combination of hot water and a CALM system. These tests were conducted under very severe conditions, so a very major reduction in rots would be expected under normal marketing. These disease control treatments and their benefits means that it is possible to harvest and market the best quality mature berries, without any significant loss due to postharvest rots.

The CALM technology has now been successfully developed for strawberries, so it in now a much simpler system to set up and can run from batteries for up to 7 days, or using DC power it can run for as long as required. The increases benefits of much lower postharvest disease and a much lower weight loss can achieved with using the CALM system alone. However, the maximum benefit is achievable when the CALM system is also combined with another disease control treatment, such as hot water.

The benefits of this project to the strawberry growers and consumers are that by careful attention to harvesting at the best maturity stages (ie no white at all) and purchasing only at this stage a dramatic improvement in eating quality of strawberries for Australian consumers is possible. The Australian cultivar Rubygem, was found to perform well compared to other cultivars, especially with regard to the most important strawberry flavour compounds DMF and DHF. There is therefore considerable potential for improving postharvest handling of strawberries. This will enable the production of cultivars and of maturities that maximise strawberry flavour and aroma, without any penalty to growers due to higher postharvest losses due to disease.

Technology Transfer

These results have been presented to the 2007 Australasian Postharvest Conference " Postharvest quality and disease control of Australian strawberries" S.C. Morris and M. Forbes-Smith.

It is proposed that these results also be published an industry newspaper such as "Good Fruit and Vegetables and also a horticulture journal, so that growers can become fully aware of the benefits of these findings. It is also proposed to write an article aimed at consumers, so that through consumer awareness demand will be generated for the better quality of berries that some growers are currently producing. During this project there has been consultations and collaborative research with several leading strawberry growers in Queensland, Victoria and NSW.

Recommendations

A key outcome of this project is to emphasis the extremely, critical importance of maturity to quality flavour and aroma. It is especially important to avoid any white areas on fruit at harvest. These findings need to be communicated to both growers and consumers. Once correct maturity strawberries are harvested, these are slightly more susceptible to rots, so it is important that disease control is also used by strawberry growers. This would be ideally the CALM system and hot water combined, or could be one of these on their own. Neither of these disease control systems requires government registration as postharvest treatments prior to usage. There are currently no registered postharvest treatments for strawberries in Australia, except for several sanitisers such as iodine of chlorine.

It is recommended that the results of this project be widely distributed to key growers and any others interested. The publicising or the new methods in Good Fruits and Vegetables will also further make growers aware of the benefits.

Further research into differences between cultivars and more detailed taste testing would be of benefit for the strawberry industry in the future.

Acknowledgements

We would like to acknowledge the help of Lewie Coco (Coco A & E & Sons), and Sunray strawberries from Queensland, Sam Violi and Elizabeth Wharton from Victoria and Rory Cave from the Flemington Markets. Also we would like to thank HAL for providing the funding for this project.

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