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Comparing genetic impact vs supply chain on consumer satisfaction

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Applied Horticultural Research

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AHR Confidential Report

HAL Project AH04026
"Comparing the genetic impact versus the supply chain on consumer satisfaction of strawberries in Australia"

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Media summary

This study, commissioned by the across-horticulture program, addresses the oft-debated question: “Is it the variety, or the way we handle it in the supply chain that most affects the consumer’s eating experience?”

The report emphasises that the answer will vary between products. However, in the case study of strawberries, the post-production factors accounted for nearly half, at 44%, of quality loss. What’s more, most of these factors can be managed using existing technology.

So are growers best to ignore the hype around new plant varieties? Not at all, according the report’s author, Jenny Jobling:

“Strawberry quality cannot be improved during supply chain handling and so the level of flavour and fruit quality at harvest must be high in order for it to be maintained through the supply chain”

Strawberries are just one example of a plant that may perform well under specific growing conditions, but poorly if these are changed.

For example, the short-day variety Camarosa can produce delicious fruit in Queensland and has stimulated strong consumer demand. Whereas in southern growing regions, Camarosa doesn’t perform well at all. This has frustrated quality-focused growers who lack an equivalent flavoured “day-neutral” variety for summer supply.

Breeding provides an opportunity to deliver consumers a year round supply of good quality strawberries. However, if you want to grow a crop at the limits of its natural temperature range, you can expect a very long wait for a breeding program to produce the answer.

This begs the question “Is 365-day supply realistic for produce?” Retailers are certainly bent on providing this for their customers, through global procurement if necessary. They will also continue to “raise the bar” regarding eating quality.

The choice seems to be: grow a given variety where it performs best, or find new varieties to suit particular production areas over a longer season. This is the rationale for many horticultural breeding programs. However, while producing a better tasting strawberry is part of the issue, maintaining that quality throughout the supply chain is also important.

Consumer dissatisfaction can be the result of two factors: poor flavour or a short shelf life. There are several interacting factors that cause this dissatisfaction. Many would argue that the quickest way to cut back the quality losses and reduce customer dissatisfaction would come from focusing on supply chain issues such as maturity at harvest, maintaining the cool chain and better packaging to reduce bruising. This report describes some proven technologies for strawberry postharvest handling that are scarcely applied in Australia such as the addition of CO_2 to reduce fungal rots during transport and handling.

However, for the longer term, breeding or introducing suitable varieties is essential to underpin fruit quality: Breeding can produce the following quality advantages

- a marketing advantage resulting from unique quality characteristics and product labeling
- unique plant pest and/or disease resistance or a unique combination of such resistances and
- varieties suited to specific regions that will give more consistent and higher performance for yield and/or quality.

In terms of allocating R&D investment to ensure the long term success of an industry, the industry must weigh up the costs, chances of success and rate of return in allocating investments between variety development and improved supply chain management.

This type of study could be done for other horticultural crops in an effort to objectively determine the relative investment that should be made into breeding and supply chain work. Both aspects are needed but for different industries the relative impact on fruit quality can vary.

Executive Summary

A review was conducted on the relative impact of genetic quality characteristics and the supply chain on consumer satisfaction of strawberries in Australia. This study is a valuable example of the analysis that should be done as one of the decision making tools for allocating investment between breeding and supply chain work. The conclusions and relative impact of the genetic quality characteristics and the supply chain found for strawberries in this report may not be typical for other horticultural products.

The data shows that the relative effect of cultivar is significantly greater than the variation due to harvest maturity, storage conditions and the supply chain for strawberries.

Varietal difference in flavour quality for strawberries as measured by the sugar to acid ratio is very large (up to 56%) and it is up to plant breeders to make use of that potential by breeding varieties that suit local conditions. The major reason for the complaints of poor quality strawberries is often due to the early season crops of the day-neutral variety Selva which does not always have the optimum sugar to acid ratio at this time. Breeders are working to find a superior quality day-neutral variety that suits Australian conditions.

At the same time postharvest handling and supply chain management must also be managed correctly so that bruising and grey mould growth do not cause significant losses. There is a considerable amount of information on the proper ways to harvest and handle strawberries but despite this there are still considerable losses throughout the supply chain.

Strawberry quality cannot be improved during supply chain handling and so the level of flavour and fruit quality at harvest must be high in order for it to be maintained through the supply chain. There is a potential for a 10% loss in flavour during marketing and a 29% loss in volume. Managing the supply chain is critical for a successful industry. However starting with the best possible variety increases the potential for success of any supply chain.

Summary of the relative impact of cultivar versus supply chain management on strawberry fruit quality.

Quality variation	Variation in sugar to acid ratio	% Quality change
Between cultivars grown under the same conditions	3.8 to 8.7	+ 56
With maturity at harvest	5.5 to 6.5	+ 14
After 9 days storage at 5^{o}C	5.5 to 5.0	- 10
Loss at the consumer level		- 18
Loss at wholesale markets		- 6
Loss at retail markets		- 5
Summary	Quality Component	% Quality lost in supply chain
Total loss for supply chain	Flavour loss	-10
	Volume loss	-29
	Combined loss	-39

Research and Development Guidelines

1. This type of study could be done for other horticultural crops in an effort to objectively determine the relative investment that should be made into breeding and supply chain work.

2. Continue to trial new varieties under different production regimes in different regions to establish the consistency of the variety under different conditions.

3. Continue breeding work to find a superior quality day-neutral variety that suits Australian conditions.

4. Encourage growers to maintain best postharvest practise to ensure shelf life. The information is available but an incentive maybe required encouraging growers to use it.

   A postharvest handling article could be written to be placed on the websites used by strawberry growers and this article could also appear in key industry magazines. Such an article will remind growers of the importance of correct postharvest handling.

5. Label strawberries to encourage product identity and customer loyalty to a good cultivar and good grower which should be matched with a guaranteed premium price.

1. Introduction

"Ideally, strawberries should have:
bright red colour but not too dark or light;
consistent heart shape with few dents and a leafy, green calyx;
medium size;
strong strawberry aroma;
strong, sweet and ripe strawberry flavour;
firmness but not 'woodiness'; and
moist/juicy mouth feel.
If consumers felt they could rely on strawberries to deliver on these qualities, the market (demand) for strawberries could double."

FR00039 National berryfruit consumer survey (2001)

This is the challenge for the strawberry industry, delivering consistent quality to the consumer. This report aims to understand and quantify the reasons for the inconsistency of strawberry quality in Australia.

1.1 Project Description

This project aims to review the relative impact of genetic quality characteristics and the supply chain on consumer satisfaction of strawberries.

Breeders have a difficult job selecting varieties that are high yielding, disease resistant, full of flavour and which are also robust enough to travel through the supply chain. This project will review two projects funded by HAL that address these issues and that are aimed at producing "Better Berries" for the Australian consumer. The projects to be reviewed are

1. BS01002 "Better berries program phase 2 - towards a sustainable strawberries system" finishes 2004, and
2. BS01006 "Commercialising Australian bred strawberry varieties in WA - better berries WA" finishes 2004

Current scientific literature will also be reviewed in order to determine the relative impacts of environment influences on fruit quality as well as the potential for using genetics to improve the eating quality of strawberries. In addition, supply chain and postharvest issues will be evaluated in consultation with key industry personnel in an effort to develop a strategy for ensuring consumers always receive flavourful, quality strawberries.

2. Background

2.1 Industry Snapshot

The industry has approximately 600 growers, with production spread across Queensland (50% of total production), Victoria (about 30% of total production), Western Australia (11% of total production), South Australia, Tasmania, and New South Wales. (http://www.horticulture.com.au/industry/strawberries.asp).

In Australia strawberries are available locally year-round. Northern growers predominately, Queensland growers plant in March and pick from May to September and the Southern growers, Victoria and other states growers plant in April and pick from October until April. This provides a year round supply of strawberries.

2.2 Strawberry Physiology

The strawberry plant is an herbaceous perennial. Strawberry growth and development is regulated by a complex set of environmental and physiological cues. The timing of the growth stages is influenced by genotype (cultivar) as well as environmental factors such as temperature, light intensity and light quality (Hancock, 1999). There are two main classes of strawberry cultivars;

1. Short-day cultivars – where the inflorescences are generated when days are short and temperatures are cool. These are grown mainly in Queensland and some plantings in the southern states.

2. Day-neutral cultivars – where flowers are produced in a cyclical pattern regardless of day length as long as temperatures remain relatively cool. These are grown in Victoria and the other Southern states.

The classification of varieties is not black and white. For example the variety Camarosa grows well in Queensland but is too vegetative if grown in Victoria. In Victoria the variety Selva is the day-neutral cultivar that is planted to ensure consistent cropping throughout the season. Another option for Victoria is to grow several short-day varieties such as Diamante and Aromas which will have alternate crops creating an even supply.

The variety Camarosa has markedly improved the eating experience of consumers. However the comments regarding poor quality often result from the shoulder periods of both the Queensland and Victorian seasons when the selected varieties are not performing at their best.

Strawberry production is very dependent on temperature, day length and solar radiation. For example a rest period is induced in strawberries by short days and low temperatures. Cultivars vary widely in their chilling requirements but most need at least some chilling to be fully productive (Hancock, 1999).

Strawberry fruit are very strong photosynthetic sinks and the photosynthetic temperature optima vary widely among cultivars (Hancock, 1999). This photosynthetic activity relates to the accumulation of sugar in the fruit which is related to fruit quality. Sunny days and cool nights produce better flavoured strawberries than cloudy, humid days and warm nights (Sistrunk and Morris, 1985; Morgan. 2004). Inadequate light intensity can also reduce the level of ascorbic acid (Vitamin C), pH, colour and soluble solids in the fruit.

Strawberries are a non-climacteric fruit. This means that the main quality changes associated with ripening and fruit flavour and texture occur when the fruit is still attached to the mother plant (Cordenunsi *et al*., 2003). Ripening from flowering to harvest averages about 30 days depending on the environmental conditions (Hancock, 1999). Elevated temperatures have a negative effect on fruit size and quality, as strawberries have a high respiration rate, high surface to volume ratio and a thin cuticle (Hancock, 1999).

Ripe strawberries are approximately 90% water and 10% soluble solids and contain numerous amounts of important vitamins and minerals (Hancock, 1999). The main soluble sugars in strawberries are glucose and fructose and the major organic acid is citric acid. The strawberry also contains significant levels of ellagic acid, which is thought to be an anticarcinogen (Hancock, 1999).

Strawberry Flavour

The level of soluble solids of strawberries is an important flavour attribute. The level continually increases during strawberry development, from 5% in small green fruit to 6 – 9% in red berries. Green and red fruit vary little in their pH, but titratable acidity gradually declines during ripening. Soluble solids and titratable acidity are dependant on both the cultivar and the environmental conditions during ripening (Kader, 1991).

Another important quality parameter for strawberries is the aroma. Hundreds of volatile esters have been identified with furaneol and furanone thought to be particularly important (Hancock, 1999). Concentrations of these volatiles vary widely among cultivars (Hancock, 1999). Strawberry softening is also highly correlated with cultivar and the pre-harvest environment (Kader, 1991).

The nutrient status of the plant in the field can influence final fruit quality. Too much nitrogen can result in smaller fruit, more fruit decay, higher fruit respiration and decreased soluble sugar concentrations as well as reduced flavour and firmness (Hancock, 1999).

Fruit must be picked when they are at least three-quarters ripe with most standards being based on the area of fruit coloured, ideally three quarters or more of the fruit must be coloured pink or red at harvest. At this stage the reminder of the fruit should colour during transport and marketing (Kader, 1991). If the fruit is picked too early with more of the surface area not coloured then the levels of sugars, acid and volatiles will be below the optimum for that variety. The quality of non-climacteric fruit such as strawberries does not improve after harvest.

Strawberries have a short shelf life after harvest. They are at their best for only a week to 10 days after harvest if stored in air at 0 - 5^{o}C. Pelayo *et al* (2003) reported the storage life (visual quality) at 5^{o}C of the cultivars Aromas, Diamante and Selva was 7, 9 and 9 days respectively. Importantly the visual shelf life was longer than the "flavour life". The "flavour life" being the maximum period of storage during which the fruit maintain the same flavour profile as was present when they were freshly harvested. It was found that the cultivar Aromas exhibited a shorter flavour life 5 days versus 7 days while Diamante and Selva fruit had the same shelf life and flavour life of 9 days. This indicates that there are varietal differences in shelf life and flavour life of strawberries. Strawberry breeders should measure both the flavour life and shelf life of new cultivars.

Strawberry Quality

Strawberry quality is also determined by the appearance of the fruit and this can be reduced as a result of bruising or physical damage and mould growth. Physical damage and bruising can occur throughout the supply chain which results in softening, weight loss, an unacceptable appearance and mould infection (Kader, 1991). The major postharvest pathogen of strawberries is Grey mould (*Botrytis cinerea*). Low temperature storage close to 0^{o}C and CO_2 enriched atmospheres can reduce the rate of growth of grey mould (Kader, 1991). These techniques are recommended for strawberry growers around the world.

There is a considerable amount of information on the proper ways to harvest and handle strawberries but despite this there are still considerable losses throughout the supply chain (Kader, 1991). Estimated losses of strawberries through a supply chain in the USA showed that losses at the wholesale, retail and consumer levels were 5.9%, 4.9% and 18.0% respectively (Kader, 1991). The major cause of the loss was the result of grey mould and this was commonly associated with bruise damage and or soft leaky fruit. The story is very similar in Australia.

2.2 The Current Strawberry Supply Chain

There are several supply chains for strawberries depending on the growing location, distance from markets and whether it is sold via the central markets, directly to supermarkets or as farm gate sales or pick-your-own.

In Australia, production involves annual planting of bare-rooted runners into plastic covered raised beds at a rate of about 40,000 plants/ha (Herrington, 2004). Fruit are bulk harvested in the field, then pre-cooled, graded and packed into 250 – 550g containers in a packing shed.

Fruit are then shipped to market using refrigerated transport and arrive at the central market or distribution centre within 1 – 4 days of harvest (Herrington, 2004). In California (Driscolls http://www.driscolls.com/) berries are picked directly into punnets on trays and transported to the depot for inspection and cooling within an hour and may be trucked out shortly after, in modified atmosphere liners (see p15)

The fruit are packaged in either "over wrapped" or "clam shell" punnets. Neither packaging option is ideal for strawberries as both encourage bruising. Fruit in the over wrapped punnets can be squashed from the top whereas fruit in the clam shell punnets get vibration damage as the fruit do not fit firmly into the punnet. Bruising damage breaks the skin of the fruit and this encourages the growth of grey mould. The best control for grey mould is a continuous cold chain at 0 – 4^{o}C. Any warming due to breaks in the supply chain will hasten the growth of grey mould.

Some recent research aimed to quantify the loss of quality resulting from a poor supply chain (Nunes *et al*, 2003). They compared fruit of the cultivar Sweet Charlie that were intact, bruised or bruised and inoculated with Botrytis (Grey mould). They were stored under two temperature regimes, semi-constant and fluctuating. These conditions simulated temperatures that had been previously measured throughout 2 strawberry supply chains. Fruit from all treatments stored under semi constant conditions maintained their quality better than those in a fluctuating temperature environment.

The research also found that greater losses in quality occurred during the simulated airport handling, in-flight and retail display than during the warehouse storage on farm, truck transport or during backroom storage at the supermarket (Nunes *et al*., 2003). The results showed that fluctuating or high temperatures during transport and handling, even if the duration is short can cause a considerable loss of quality of strawberries.

3. The Relative Impact of Variety versus Supply Chain Management on Strawberry Quality

3.1 Strawberry Flavour

The flavour of strawberries is a combination of sugars, acids and aroma compounds. The soluble sugars and acids contribute directly to the perceived sweetness of the fruit whereas volatile compounds produce the aroma that creates the "strawberry" flavour. Strawberry aroma is mainly determined by a complex mixture of esters, alcohols, aldehydes and sulphur compounds. The composition of strawberry aroma is influenced by cultivar, maturity and growing conditions (Wang and Bunce, 2004; Sturm *et al*., 2003).

There are large genotypic variations in strawberry composition (Table 1). It is therefore possible to develop new cultivars which have good eating quality and which maintain their firmness when fully ripe so they can withstand the postharvest supply chain (Kader, 1991).

Table 1. Composition of strawberry fruit (taken from Kader, 1991 and Hancock, 1999)

Constituent (unit)	Range
Total solids (%)	7.0 – 12.7
Total soluble solids (%)	4.6 – 11.9
Total sugars (%)	4.1 – 6.6
Reducing sugars (%)	3.7 – 5.2
Sucrose (%)	0.2 – 2.5
Fructose (%)	1.0 – 3.5
Glucose (%)	1.4 – 3.4
pH	3.18 – 4.10
Titratable acidity	0.5 – 1.87
Citric acid (%)	0.29 – 1.24
Malic acid (%)	0.09 – 0.68
Total ascorbic acid (mg/ 100g)	26 - 120
Total phenolics (mg/ 100g)	58 - 210
Total anthocyanins (mg/ 100g)	55 - 145

Impact of Growing Conditions on Strawberry Quality

Some very early work by Frits Went in the 1950's found that strawberries required very specific growing conditions to produce the ideal flavour (Patterson, 1998). Went showed that to produce the ideal balance between sugar, acid and aroma levels a strawberry required at least 2 hours per day lower than 15^{o}C to produce the aroma profile and then temperatures above 17^{o}C during the day to produce the maximum sugar. Since this research, there has been considerable effort in breeding new varieties, particularly ones that perform in conditions with warmer growing conditions such as in Queensland Australia. The quality of the short-day winter harvested varieties is superior to the day-neutral varieties harvested in the summer. This is a function of both genetic variation and seasonal conditions (Morrison, pers. Comm.). Fruit quality can only be assured if the best variety for a given set of environmental conditions is grown.

Strawberries need sunlight to produce sugar and cloudy days close to harvest can severely affect final sugar content (Hancock, 1999). Strawberry fruit rely on sugars imported from photosynthesis in the leaves to increase sweetness. There is little storage of carbohydrates in the form of starch in strawberries. This means that harvested fruit use sugars, acids and lipids for respiration and other metabolic processes after they have been removed from the mother plant. As a result the levels of these compounds slowly decrease after harvest (Wang and Bunce, 2004). The sugar, acid and aroma levels in strawberries at harvest are the major factors determining consumer acceptability (Cordenunsi *et al*.2003; Chandler *et al*., 2003). This means that maturity at harvest is critical. Sturm *et al*. (2003) showed that the "chemical composition of strawberry fruit significantly varied among genotypes as well as the stage of maturity of the fruit". The concentration of individual sugars and acids changes significantly during the last period of maturity (Table 2).

Influence of Harvest Time

The average increase in the total sugar content from commercial harvest (Maturity stage 1) to fully ripe fruit (Maturity stage 2) was 48.2 to 54.7 g/kg (13.7% increase) and the average total acid level was reduced from 9 to 8.7 g/Kg (3% reduction)(Table 2). These changes altered the sugar acid ratio from 5.5 for maturity 1 to 6.5 for maturity 2. Sweet strawberries have a

sugar/acid ratio of 7 and fruit defined as acid had a ratio of 6 (Sturm *et al*., 2003). This indicates that the fruit harvested at the commercial maturity would have been regarded as acid by consumers. It is important to note that there was a significant difference between cultivars with Mohawk being the sweetest in terms of sugar to acid ratios and Elsanta was the least sweet (Table 2). The relative difference in sugar to acid ratio was greater between varieties (3.8 to 8.7) than it was between average maturities (5.5 to 6.5) indicating that genotype is a very significant factor in determining strawberry flavour.

Another factor to consider is that growers who have a supply chain that requires several days of transport must compromise some of the flavour of the fruit by harvesting at Stage 1 to ensure adequate shelf life on arrival at the market.

The Better Berries Program (Greer, 2001) compares several varieties throughout the growing season. The trials in 2000 compared the varieties Camarosa, Flame. Joy, Kabala, Selva and Sweet Charlie. They found that the variety with the highest level of %TSS was Flame (8.7%) and the variety with the lowest level was Selva (7.1%). Flame also had the highest level of titratable acidity and Sweet Charlie had the lowest level. These trials have continued in recent years in an effort to select the most consistent variety over the growing season. This work again highlights the variability between cultivars and the importance of selecting the best variety for the growing conditions.

Table 2. Changes in the sugar and acid level of different strawberry varieties during maturity. (from Sturm *et al.* (2003)). Maturity 1 is commercial harvest when the shoulders are white or green and Maturity 2 is when the fruit are fully ripe.

Varitiety	Maturity	Total sugar (g/Kg)	Change (%)	Total acid (g/Kg)	Change (%)	Sugar/acid ratio	Change (%)
Marmolada	1	37.2	4.3	7.4	-1.4	5.0	5.7
	2	38.8		7.3		5.3	
Miss	1	32.8	27.4	5	0.0	6.6	27.4
	2	41.8		5		8.4	
Elsanta	1	44	-3.0	10.9	2.8	4.0	-5.6
	2	42.7		11.2		3.8	
Pegasus	1	47.7	-0.2	9.6	-12.5	5.0	14.0
	2	47.6		8.4		5.7	
Simphony	1	41.4	17.1	9.5	-8.4	4.4	27.9
	2	48.5		8.7		5.6	
Cortina	1	46.8	10.3	9.3	-9.7	5.0	22.1
	2	51.6		8.4		6.1	
Selena	1	46.5	17.6	10	-1.0	4.7	18.8
	2	54.7		9.9		5.5	
Eros	1	49.4	16.6	7	-2.9	7.1	20.0
	2	57.6		6.8		8.5	
Kent	1	44.6	29.8	8.3	-7.2	5.4	39.9
	2	57.9		7.7		7.5	
Northaester	1	58.6	7.2	7.9	30.4	7.4	-17.8
	2	62.8		10.3		6.1	
Evita	1	55.6	15.5	10.4	-3.8	5.3	20.1
	2	64.2		10		6.4	
Fern	1	53.4	28.5	11.2	-8.0	4.8	39.7
	2	68.6		10.3		6.7	
Mohawk	1	69.2	7.1	10.7	-20.6	6.5	34.8
	2	74.1		8.5		8.7	
	1	**48.2**		**9.0**		**5.5**	
Average	2	**54.7**	**13.7**	**8.7**	**-3.3**	**6.5**	**19.0**

Growing under Conditions of Elevated CO_2

Another example of how growing conditions affect strawberry flavour is where strawberries are grown in greenhouses with elevated CO_2. Wang and Bunce (2004) found that strawberries grown under conditions with elevated CO_2 increased the concentration of glucose, fructose and sucrose. The relative increases in these sugars are important as fructose is perceived to be 1.8 times sweeter than sucrose and sucrose is 1.7 times sweeter than glucose. This flavour characteristic is not taken into account when "sweetness" is measured as the percentage of soluble solids. The %TSS is often an inadequate indicator of sweetness.

Growing strawberries under conditions of elevated CO_2 also resulted in enhanced aroma production. The study by Wang and Bunce (2004) showed that growing strawberries under conditions of elevated CO_2 improved fruit quality by increasing fruit dry weight, sugar and aroma concentrations and decreasing acid content. This study is another example of how growing conditions can affect fruit quality. It is not recommended that all strawberries be grown under conditions of elevated CO_2 particularly as most Australian strawberries are field grown but it is important to determine the quality of new cultivars under conditions where they will be produced.

Varieties and Breeding

Many of the major common commercial varieties grown in Australia such as Camarosa and Selva come from the Californian breeding programmes. The difficulty with using these varieties is that they don't always perform as well in Australia as they do in California. The Californian climate is milder and has clear skies during the growing season. In Australia, particularly in the summer in the Southern States the weather can be much hotter and the days are often overcast. These 2 factors can limit the rate of photosynthesis of the plant which in turn limits the accumulation of sugar (Atwell *et al*., 1999). Less sugar correlates with poor flavour. The productivity of the Californian varieties also compares very poorly under Australian production conditions. The Californian breeding programme is large and has been going for many years and so using varieties from this programme makes sense however it is important for growers to know how well the Californian varieties perform under Australian conditions.

An alternative approach is to breed varieties in Australia to suit Australian conditions. There are currently two major breeding programmes in Australia, the LAWS (Long Autumn, Winter, Spring) combined with the Better Berries Program in Queensland, co-ordinated by the Queensland Department of Primary Industry and the Victorian breeding program run by the Institute of Horticultural Development at Knoxfield.

The Queensland program focuses on producing varieties that suit sub-tropical production in autumn and winter and the Victorian program produces varieties for a more temperate climate using "short day" and "day-neutral" types for spring and summer production (Phillips *et al*., 2004).

The quality of short day varieties is far superior to the quality of day-neutral varieties (Morrison, pers.comm, 2005). One reason for this is that many more years of breeding effort has been made into the short-day varieties compared to the day-neutral varieties. The first commercial release of a day-neutral variety was in the 1970's. The relative breeding time invested in Australian day-neutral varieties is even less. As a result the improvements in quality and

adaptability to Australian conditions are not as advanced as in the short-day varieties (Bruce Morrison, pers. Comm.2005).

The aim for the Victorian breeding programme is to breed the flavour quality characteristics of short-day varieties into day-neutral varieties. This will provide growers in the Southern states with a variety that has a long season and good flavour quality. Unfortunately this breeding strategy can be slow. However, a number of varieties have been released to date (ref p18)

The commercial life of an outstanding variety is 10+ years for a moderately good variety 2 – 3+ years and others never go ahead. In the future strawberries could be labelled with the variety name so that consumers have a more active choice, as they currently do with labelled apple varieties.

3.2 Consumer Acceptability

Neil Greer recounted the study carried out by the University of Queensland. The anecdotal evidence suggests that 70% of consumers want sweet fruit, with a typical strawberry flavour, soft inside with a firm outside to prevent bruising and scuff damage. The variability in response of consumers for the quality of fresh horticultural products is very large as the response depends on a consumer's age, past experience, socio-economic level, race and education (Heintz and Kader, 1983; Patterson, 1998).

In the University of Queensland study there was a comparison between three varieties throughout the growing season. The varieties trialled were;

1. *Kabala* – early fruiting variety bred by Qld breeding program and released in 1993.
2. *Redlands Joy* – a high sugar variety (up to 14% total soluble solids) with low acid and less aromatic than some other varieties. This variety was bred by Qld breeding program and was released in 1993.
3. *Sweet Charlie* – this is a Florida variety which was released in 1996/7 and released in Qld in1999. It has lower acid levels, is sweet and has a high aromatic profile.

A consumer panel was asked to rate the quality of the strawberries using a 1 – 9 hedonic scale (1 = poor quality, 9 = excellent quality). The results showed that Redlands Joy and Sweet Charlie had a similar average acceptability score of 7.5. The range of scores around the average value was small from 7 to 8. Kabala on the other hand had an average acceptability score of 6.5 but the range in scores was between 5 and 10 (a couple of panellists made an extra point because they thought it was so good). What this showed was that when Kabala "was good it was very good but when it was bad it was horrid". At some time during the growing season Kabala quality in terms of flavour was excellent (scores of 10) at other times the flavour was very poor (scores of 6.5). This is an example of the inconsistency in quality that consumers often comment on.

This shows that seasonality and agronomy can influence fruit flavour and the aim for breeders is to breed a variety where the quality is consistent over a wider range of climatic and seasonal conditions. The most notable change has been to select varieties with a lower level of acidity.

Research work done by Pelayo *et al*. (2003) also illustrates the importance of the genetic component of strawberry quality. This work compared the quality of 3 strawberry cultivars

(Aromas, Diamante and Selva) after storage at 5°C in air or in air with 20% CO_2 added to the storage atmosphere. The postharvest life varied between the cultivars with Aromas having a shelf life of 7 days compared to 9 days for the other two varieties. The addition of CO_2 extended the shelf life by 4 days for the variety Selva and 2 days for the other two varieties tested.

Another study done by Cordenunsi *et al*. (2003) compared the quality of five strawberry varieties during cool-storage at 5°C. They concluded that the initial values for the quality parameters measured were different for the different cultivars "indicating that the cultivar is the most important factor for determining postharvest quality and extended shelf-life".

Both these experiments show that the genetic characteristics of a variety have a major influence on the flavour potential of strawberries.

3.4 Postharvest Handling of Strawberries

The main causes of quality loss after harvest for strawberries results from physical damage causing bruising and fungal growth. To minimise fungal growth and ensure maximum shelf life the fruit should be cooled as quickly as possible after harvest to 0°C. Loss of quality, as a result of delaying cooling is very rapid. Nunes *et al* (1995) showed that if cooling was delayed by 6 hours after harvest undesirable changes in colour and texture were observed as well as a reduction of around 50% of water content in comparison to those that were immediately cooled after harvest.

Table 3 shows the relative loss of shelf life in terms of the level of total sugars, total acids and the sugar to acid ratio which makes up most of the strawberry flavour. The summary shows that for these cultivars the loss of quality during time in storage as measured by the decrease in the sugar to acid ratio is about 10%, although the variety Selva lost 30% of quality from day 11 to day 13. There was also a difference between the cultivars when they are compared after 9 days in storage Aromas and Diamante had a 10% decrease in the sugar to acid ratios whereas the sugar to acid ratio of Selva did not change. Seva is a high acid, high sugar variety and so when the growing conditions promote high sugar levels at harvest the flavour of this variety is maintained for longer than some other varieties. Under optimum conditions this variety will have excellent flavour but if the sugar levels are reduced due to the seasonal conditions and availability of sunlight then the fruit will have poor flavour as the sugar to acid ratio will be low.

Table 3. Comparison of the relative loss of shelf life of three strawberry cultivars stored at 5°C in air (from Pelayo *et al*., 2003 and Cordenunsi *et al*., 2003)

Varitiety	Storage (days)	Total sugar (g/Kg)	Total acid (g/Kg)	Sugar/acid ratio	Change (%)
Aromas	0	41.2	7.7	5.4	
	7	40.7	8.4	4.8	-9.4
	9	37.8	8	4.7	-11.7
Diamante	0	52.2	8.9	5.9	
	9	45.6	8.8	5.2	-11.7
	11	44.1	8.8	5.0	-3.3
Selva	0	51.3	10	5.1	
	9	49.9	9.7	5.1	0.3
	11	45.6	9.8	4.7	-9.3
	13	43.1	11	3.9	-30.9
Oso Grande	0	58.8		9.9	
	6	47.2		8.4	-15.2
Toyonoka	0	52.6		8.9	
	6	61.3		8.6	-3.4
Dover	0	37.3		5.5	
	6	41		5.8	5.5
Campineiro	0	38		5.4	
	6	38.7		5.8	7.4
Differences between varieties after 9 days in storage					
		Total sugar (g/Kg)	**Total acid (g/Kg)**	**Sugar/acid ratio**	**Change (%)**
Aromas		37.8	8	4.7	-9.4
Diamante		45.6	8.8	5.2	-11.7
Selva		49.9	9.7	5.1	0.3

3.4.1 Storage of Strawberries in Elevated CO_2 Atmospheres

Carbon dioxide levels above 10% are known to inhibit the growth of fungi in strawberries (Smith and Skog, 1992; Hancock, 1999). Postharvest fungicide use in strawberries is not recommended and so researchers have looked for alternative control measures, one of which is packaging the fruit in atmospheres of CO_2 at concentrations of 20$^+$%.

Work in the area of pre-cooling and CO_2 addition for strawberry shelf life extension began in the 1950's (Kader, 1991). In a study comparing the cultivars Aromas, Diamante and Selva in atmospheres of air and air plus 20% CO_2 at 5°C the shelf life was extended by 2, 2 and 4 days respectively in the CO_2 enriched atmosphere (Pelayo *et al*., 2003). An additional benefit of adding CO_2 was the increase in flesh firmness during storage. This affect has been reported by others. However the CO_2 effect and its magnitude are cultivar dependent (Pelayo *et al*., 2003; Smith and Skog, 1992; Watkins *et al*., 1999).

This use of CO_2 enrichment is used during transport by strawberry producers in the USA; most notably Driscolls, one of the largest strawberry growers in California, USA use elevated CO_2 when they ship strawberries from California on the west coast to cities on the east coast of the USA. The CO_2 enriched atmosphere is created by sealing a pallet bag over a pallet of packed strawberries and injecting the bag with 20$^+$% CO_2 (Hancock, 1999, picture 1). The CO_2 diffuses out of the bag slowly during the journey but the atmosphere is always higher than 10% CO_2 which is the lower limit of the CO_2 fungistatic (fungal growth inhibiting) effect. OzFresh will be

establishing a similar packaging system for their growers in Australia in the near future (Greer, 2004, pers. comm.).

There is a new technology being developed by Sydney Postharvest Laboratory in conjunction with Horticulture Australia Limited and the Australian Chestnut Growers Association which controls the CO_2 level in a pallet of produce. This system could very easily be used for pallets of strawberries under refrigeration. The system uses the respiration rate of the product to build up the CO_2 level inside the bag. At the same time it monitors and controls the oxygen level inside the sealed bag around the pallet. This control prevents anaerobic conditions developing in the bag and ruining the product. This system has been very successful in extending the storage life of chestnuts in the preliminary trials (HAL project CH02003) and has enormous potential for strawberries and other berry fruit susceptible to fungal infection.

The following pictures were taken at Driscolls Strawberry packing shed in California, USA.

Photo 1. Forced air cooling of Packed strawberries

Photo 2. Bagging pallets for CO_2 injection

3.5 Strawberry Breeding Overview

The first strawberry species were domesticated sometime in the last 2000 years with the first major commercial species *F x ananassa* being bred only 250 years ago (Hancock, 1999). The dessert strawberry was one of the first crops to be systematically bred. Over the last 2 centuries a constant stream of new cultivars has been generated. Breeding programmes have generated cultivars that are resistant to a range of pest and diseases, that have extended flowering and fruiting habits, increased yield and improved fruit quality (Hancock, 1999).

The improvements in strawberry cultivation and quality are the result of breeding and optimising cultural practises for that variety. The dominance of the Californian strawberry industry is due to the development of a total cultural system that maximises the potential of each individual cultivar (Hancock, 1999).

Objectives

One of the objectives of Strawberries Australia Inc. the national strawberry peak industry body is to match strawberry production and consumption and to grow domestic consumption of fresh fruit to from 1.0 to 2.0kg currently to 2.7kg per head by 2008 and to lay the foundations for further increases beyond that date (Strawberry Industry Annual Report 2004, http://www.horticulture.com.au/docs/industry/annualreports/strawberry.pdf).

There are two issues that need to be addressed in order to satisfy that goal;

1. Consumer acceptability and consistent fruit quality
2. Increasing yield and crop management; including finding an alternative to methyl bromide for soil fumigation.

Consumer acceptability

Consumer acceptability is one of the key objectives of strawberry breeders around the world. The ultimate aim for breeders is for early fruiting varieties, disease resistance and the optimum consumer experience. For a good consumer experience the balance between the sugar and acid levels must be right.

In recent years there has been a move away from high acid varieties to low acid and high sugar to reduce the risk of a bad experience. If the seasonal conditions are not ideal then the sugar level in the fruit may be low. Under these conditions a high sugar, high acid variety becomes too acidic. If a variety has a low acid level to start with then the relative reduction in quality as a result of poor sugar accumulation is less than for a high acid variety (Greer, 2004, pers. comm.). Selection for these varieties increases the consistency of the quality of the fruit produced.

Methyl Bromide

The international industry is struggling to find alternatives to methyl bromide for soil fumigation. It is likely that alternatives will be found however there is also the potential to identify sources of genetic resistance in strawberries and to add those qualities into breeding programmes (Hancock, 1999). This is an important issue for the strawberry industry for the future.

3.6 Breeding Strawberries in Australia

3.6.1. The Victorian Program (Main breeder Bruce Morrison)

The Victorian strawberry breeding program (Institute for Horticultural Development) serves growers throughout temperate Australia and is part of a national strawberry breeding program funded by the Horticulture Australia Ltd, Strawberries Australia, fruit growers associations, and runner growers across Australia.

"The Victorian program aims to produce strawberry varieties that are suited to a range of climates, with excellent flavour, improved disease resistance, and which will allow growers to extend the fruit season with high quality fruit." (http://www.nre.vic.gov.au/agvic/ihd/r&d/doc-146a.htm, Dec 2004).

Commercial cultivars from this program include Lowanna, Tallara and Alinta which were licensed in 1999, and produced their first commercial crops during spring 2000 and the cultivar Kiewa (95-041-19) was released for large-scale commercial trials in 2001 (HAL Project BS01006 Commercialising Australian bred strawberry varieties in Western Australia, http://www.nre.vic.gov.au/agvic/ihd/r&d/doc-146a.htm, Dec 2004). There is another promising variety 98-049-119 which will be named and released in the next couple of years (Morrison, pers comm. 2005).

In Victoria, Toolangi is the major centre for strawberry runner production in Victoria and only a very small number of runners (less than 10,000) would be purchased from interstate sources. The predominant varieties in Victorian remain the California varieties Selva and Pajaro these varieties are licensed from the University of California. (http://www.vicstrawberry.com.au/Industry%20Profile.htm)

3.6.2. The Queensland Program (Main breeder Mark Herrington)

The Qld runner program produced 25 million runners last year and this is slightly over half of the Australian total. For 2004 five million of those runners were Ruby Gem which is a promising new variety from the Qld breeding program and it includes another 500,000 of other varieties from the Qld program.

The breeding program in Qld is supported by the Better Berries Program which is a joint project between the Queensland Government, Horticulture Australia and industry. This program selects and develops strawberry varieties for national and international markets. Through targeted research and development (R&D), the program has played a major role in building the Queensland strawberry industry (http://www.dpi.qld.gov.au/horticulture/15667.html, Dec 2004).

The program's research activities are helping the industry by:

- Developing agronomic information to support new varieties bred in Queensland
- improving yields through irrigation and nutrition management
- reducing chemical requirements

The varieties from the LAWS breeding program are evaluated using a "value index" that rates each new variety relative to its favourable production, harvesting and marketing, appearance and flavour as well as shelf life (Herrington *et al*., 2002)

3.7 Successes and Limitations of the Current Breeding Programs

Breeding new varieties of any horticultural product takes considerable time and investment. One of the criticisms of the current breeding programs in Australia has been that the commercial spin-offs relative to the investment by stakeholders is small (Phillips *et al*., 2004).

The Queensland program has achieved a higher level of adoption for its varieties into commercial cultivation than the Victorian program (Phillips *et a*l., 2004). One of the reasons for this is the difficulty in breeding high quality day-neutral varieties that suit the climate of the Southern states. The selection of day-neutral varieties which have a longer season than short-day varieties was relatively recent with the first commercial release being in the 1970's (Morrison, pers.comm, 2005). To be commercially successful growers aim to avoid a trough and glut cycle of marketing. A longer production season as a result of using a day-neutral variety helps prevent that cycle. Unfortunately the consumer suffers as the quality of those strawberries is much lower. The main day-neutral variety planted is Selva and this is the variety that consumers are often dissatisfied with (Good Fruit and Vegetable, Dec, 2004). The Victorian breeding programme is working towards developing varieties that have the flavour quality of the short-day varieties and the growing season of the long-day varieties.

3.8 Quantifying the Impact of Variety and the Supply Chain on Quality

The following table summarises the research data from Table 2 and Table 3 which addressed the issues of cultivar and storage life elative to the sugar to acid ratio.

Table 4. The relative impact of cultivar versus supply chain management on strawberry fruit quality.

Quality variation	Variation in sugar to acid ratio	% Quality change
Between cultivars	3.8 to 8.7	+ 56
With maturity at harvest	5.5 to 6.5	+ 14
After 9 days storage at 5^{o}C	5.5 to 5.0	- 10
Loss at the consumer level		- 18
Loss at wholesale markets		- 6
Loss at retail markets		- 5
Summary	Quality Component	Percentage of quality lost in the supply chain (%)
Total loss for supply chain	Flavour loss	-10
	Volume loss	-29
	Combined loss	-39

The data shows that the relative effect of cultivar is significantly greater than the variation due to harvest maturity, storage conditions and the supply chain. Many references supported this outcome (Cordenunsi *et al*., 2003; Pelayo *et al*., 2003; Sturm *et al*., 2003;Kader , 1991; Herrington pers comm.; Morrison pers. comm). The varietal difference in flavour quality as measured by the sugar to acid ratio is very large and it is up to plant breeders to make use of that potential by breeding varieties that suit local conditions. At the same time postharvest handling and supply chain management must also be managed correctly so that bruising and grey mould does not cause significant losses.

Strawberry quality cannot be improved during supply chain handling and so the level of flavour and fruit quality at harvest must be high in order for it to be maintained through the supply chain there is a potential for a 10% loss in flavour during marketing and a 29% loss in volume. Managing the supply chain is critical for a successful industry. However starting with the best possible variety increases the potential for success of any supply chain.

4. Methodology

This report was compiled from information from a range of sources. To follow is a summary of those sources;

The two HAL funded projects, BS01002 "Better berries program phase 2 - towards a sustainable strawberries system" finishes 2004, and BS01006 "Commercialising Australian bred strawberry varieties in WA - better berries WA" were used. The final report of the Better Berries program phase 2 was not available but I did receive several milestone reports and research papers from Mark Herrington, Qld DPI who is a principle researcher on that project.

I visited Neil Greer and Mark Herrington Qld DPI Ph: 07 5444 9605 for the day on the 14th December 2004. Neil Greer had recently resigned from Qld DPI and will take up a position with Driscoll's. I spoke to Bruce Morrison from IHD Knoxfield on the telephone to get his perspective on the Australian strawberry industry. I also spoke to John Oakeshott the Program Manager for these programs at Horticulture Australia Ltd.

I reviewed the abstracts from the ISHS International Strawberry symposium in Brisbane September 2004 and I also did a scientific literature search for related material. The references cited are listed in Section 5 of this report.

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