# Agronomic and postharvest improvement in iceberg and cos lettuce to extend shelf life for fresh cuts salads

Gordon Rogers
The University of Sydney

Project Number: VG03092

**VG03092**

This report is published by Horticulture Australia Ltd to pass on information concerning horticultural research and development undertaken for the vegetable industry.

The research contained in this report was funded by Horticulture Australia Ltd with the financial support of Harvest FreshCuts Pty Ltd.



ISBN 0 7341 1463 X

Published and distributed by:

Horticultural Australia Ltd

Level 1
50 Carrington Street
Sydney NSW 2000
Telephone: (02) 8295 2300
Fax: (02) 8295 2399

E-Mail: horticulture@horticulture.com.au



Know-how for Horticulture™

# POST HARVEST IMPROVEMENT IN ICEBERG AND COS LETTUCE TO EXTEND SHELF LIFE FOR FRESH CUT SALADS

## Horticulture Australia
## Project Number: VG03092


**Project Leader**

Dr. Gordon S. Rogers
Applied Horticultural Research
Po Box 3114
BUNDEENA NSW 2230

**Key Personnel**

Gordon Rogers – AHR
Michael Titley – AHR
Brad Giggins – AHR
Bartley Bauer – AHR

Robin Poynton – OneHarvest
Adam Kocks – OneHarvest
Tom McAuliffe – OneHarvest
James Le Budd – OneHarvest



**Funding Sources**

This project is jointly funded by OneHarvest and Horticulture Australia Limited.

Funding by both the Industry and HAL is gratefully acknowledged by Applied Horticultural Research.


**Date**: December 2006

## Table of Contents

# Executive Summary

## 1. Crop Scheduling

- Preliminary Scheduling models have been prepared for Cos and Iceberg lettuce grown in several districts in Qld and Victoria. (Figures 5.1 to 5.4 and Appendix 2)
- For Iceberg lettuce planted in Gatton, Qld the time from transplanting to harvest varies from as little as 49 days for the May harvest extending out to 70 – 77 days for the mid-winter harvest and then decreasing back to 63 and 56 days for September/October harvesting. During this time yields can vary from 30t/ha (350g/head) in the May and October period, up to 45 – 50t/ha (1.5 kg) in the optimum harvest period in July through to August.
- For Cos lettuce grown in East Gippsland, Vic the time from transplanting to harvest varies from 95 –100 days for the early part of the season decreasing to 42 – 49 days in mid-summer and then extending out to 70 – 75 days for the late autumn harvest period. The yield per hectare during this time varies from a lower yield in mid-summer of 500 – 550g/head compared to 750 – 800g/head produced in the autumn and spring period.

Bolting is a major consideration for crop scheduling. The potential causes for bolting could include:

- Day length (especially long days)
- High diurnal temperature range e.g. maximum daily temperatures equal to or greater than 27°C and minimum temperatures dropping to 5°C.
- A combination of long days, high temperatures and transplanting into dry soil.
- Soil temperatures, both waterlogged and drought conditions.
- Number of leaves when transplanted (especially if the leaf number is greater than 7).
- Length of time Cos seedlings held in soil-less media once the optimum root ball has been developed.
- Stress, especially moisture, soil compaction and salt.
- Genetics, with some varieties exhibiting slow bolting tendencies

## 2. Harvest maturity

- The trials in Gatton in 2005 demonstrated how yields can be increased in this region and time of year without significant detriment to lettuce processing quality.
- This change in production practice is best suited to cooler periods in the season when growing conditions are optimal to avoid the issue of bolting.
- The results showed that yield increases as high as 60% could be obtained for Iceberg lettuce (cv. Titanic transplanted 26-04-05) and a 35% increase in Cos lettuce (cv. Cyclone transplanted 27-4-05).

- There was no impact on shelf-life when iceberg or Cos lettuce was grown for an extra seven days and the average core length in the plants from the later harvest, was well within the specification for lettuce processed as fresh-cut salads.
- These findings are specific to the conditions experienced during these trials and research encompassing a range of regions, seasonal timing and varieties is required to verify a broader application.

**3. Postharvest handling**

<u>Storing and Trimming</u>

- The results showed that storing the unprocessed heads for 5 days prior to processing resulted in a reduction in the quality by 22-31% (Fig. 109).
- The harder trimmed lettuce (55%) was able to maintain close to initial quality until day 8 whereas the normal trimmed lettuce (70%) was declining in quality from day 4.
- Once the lettuce quality started to decline, it seemed to be programmed on that track, and this may mean that shelf life assessment protocols could be developed with less assessment points, but which were aimed to identify the beginning of the decline in quality and the rate of change.
- The effect of storing lettuce for 5 days prior to processing results in a reduction in overall score of about 28% (10 score units).
- Storing heads reduces the starting quality by about 28% compared to using fresh heads for processing.
- Storing heads for 5 days then trimming to only 70% of initial weight resulted in a shelf life on only 8.0.

<u>Reducing moisture in the bags</u>

- The results show that having an absorbent sachet in the bag increased the shelf life of the product by about 3 days (Figure 113). This is an important result as it demonstrates the fact that the current processing can be improved.

<u>Postharvest temperature Management</u>

- Lettuce must be vacuum cooled with in half an hour of harvest to ensure maximum shelf life.
- Vacuum cooling 6hours after harvest did not improve shelf life compared to the forced air cooled samples.
- Vacuum cooling improved shelf life compared to forced air cooling
- A break in the cool chain (2 hrs at 15$^{o}$C) negated the benefits of on farm cooling and reduced the overall shelf life of the product

The physical impact of processing lettuce

- Other research shows that more cuts and blunter equipment increase the response and increase the rate of deterioration (Cantwell and Suslow, 2002).
- The translicer used in this processing line was not having a significant impact on the shelf life of the product compared to manual cutting with a sharp knife (Figure 117).
- The results in relation to the degree of trimming support those from the previous section. Trimming lettuce to 55% prior to processing significantly improves the shelf life of the processed product.

**4. Variety Selection**

- Trials with lettuce varieties are relatively easy to design, establish and grow to harvest. They are very time consuming making observations, collecting data, analysing and interpreting before making a decision on adopting a new variety as shown over the three years of the project.
- Attributes other than marketable yield (Nasonovia resistance for iceberg & slow bolting for Cos) must be taken into account when adopting new varieties.

**5. Crop Nutrition**

- It is essential that nutrients are applied at the appropriate ratio with other nutrients rather than simply applying elements independently if optimal yield and quality is to be achieved.
- Excessive nitrogen application can reduce both yield and quality (shelf-life)
- Phosphorous management is important for sustaining the maximum, long-term performance of the crop
- Phosphorous supply can be an issue on soils new to horticultural production, where relatively high rates may need to be applied
- Calcium foliar sprays are ineffectual in tip burn alleviation and cultural practices that aim to prevent excessive growth rates are a better strategy for reducing the incidence of tip burn.

**6. Crop Establishment**

- If the potential value of Cyclone, or similar varieties, is to be fully explored for the fresh-cut salad industry, specific cultural practices which optimise yield must be considered
- Cyclone yield has been shown to increase significantly when planting density is raised to 80 000 – 100 000 plants per hectare and the appropriate, supporting nutrition is applied
- The ability of direct-seeded lettuce crops to produce yields comparable to that of transplanted crops has been demonstrated, presenting a means to reduce planting costs

**7. Soil Moisture Management**

- Trickle irrigation can be used successfully to grow lettuce with higher water use efficiency than using sprinkler irrigation.
- Lettuce plants should be maintained free of water stress right up to harvest for maximum yields.

## Standout results

- **Identification of the most productive times** and shelf life for each of the main lettuce production regions in Qld and Vic.
- **New Varieties** – The identification and agronomic work on important new lettuce varieties including Cyclone, Challenger and Nr varieties.
- **Effect that trimming** and time held before processing has on shelf life of Cos lettuce.
- **Later harvesting -** improvements in yield without adverse effect on shelf life or core length by later harvesting (main production season).
- **Development of crop scheduling** for predicting days to harvest and yield.
- **Trickle irrigation** can be used to produce high yielding and quality lettuce with significant water savings compared to overhead irrigation.
- **Rapidly cooling lettuce** as soon as possible after harvest significantly improves shelf life.

# Introduction

Fresh cut lettuce is an expanding category for supermarkets in Australia. In an effort to meet this market demand processors need a year round supply of good quality product. OneHarvest create a year round supply by sourcing Australian Iceberg and Cos lettuce from different regions throughout the year. They source product from Queensland (Lockyer valley and Toowoomba) and from Victoria (Bairnsdale and Robinvale). There is a summer and winter location in both Queensland and Victoria to ensure a year round supply of fresh product.

The lettuce is processed in the winter in Brisbane (Harvest Fresh Cuts) and in Bairnsdale (VEGCO) in the summer. The processed products are then sold Australia-wide, mainly through the supermarket chain stores. The key to growing this category is to supply customers with a consistent quality product. The difficulty comes in achieving this when environmental conditions change between districts and seasons. This project aims to identify management strategies that can help growers produce a quality product during sub-optimal seasonal periods.

The long-term prospects for the fresh-cut salad industry are excellent. The current Australian market share for fresh cut products is around 3% of the total fruit and vegetable sales. This is in comparison of other markets where the market share is much larger. For example in the US fresh cuts account for 12% of the total fresh market sales and in Europe it accounts for 18% of fresh sales (OneHarvest, pers. comm). This data shows that there is enormous potential to expand the fresh-cut market segment if products meet consumers' needs.

A key issue for the success of the fresh-cut industry is the consistency and length of shelf-life of the product. Currently in Australia washed and processed products have a shelf life of 10 days. In the US they achieve a 14 day shelf life which greatly increases the opportunity cost for this product.

This project will identify varieties, agronomic factors and processing and handling issues that influence shelf life with the aim of identifying a "best practice" approach to ensure a quality product with a longer shelf life.

The overall objective of the project is to develop specifications for irrigation and nutrient management, harvesting and postharvest techniques and specification which will consistently extend postharvest life of fresh-cut lettuce from the current 8-10 days to 14 days for lettuce grown in the Lockyer Valley, Toowoomba, Bairnsdale and Robinvale.

## General Agronomy

A review of lettuce production and processing was presented to the Lettuce Industry conference in June 2000 (Titley 2000). The key issues raised in that review are summarised below.

**Crop Establishment**: A consistent germination rate ensures a consistent growth and maturity rate of the crop which is a key quality parameter. Some varieties in some districts and seasons have erratic germination which is caused by high temperature induced dormancy. This issue can be overcome by using transplant seedlings and efficient mechanical transplant methods which minimise transplant shock (Titley 2000).

Minimising transplant 'shock' is important as it has a major impact on the incidence of bolting and long cores during mid summer and early autumn. Both factors reduce final harvest quality. The critical stage is the 10 – 14 leaf stage where heat stress during this period potentially results in long core and bolting (Kim et al. 2000). It is important to note that transplanting cool stored seedlings and/or old seedlings also increases the percentage bolting. Professional nurserymen should provide actual seeding dates on delivery batches to minimise the risk of supplying 'old' seedlings to growers.

The root structure of direct seeded crops is different to transplants. Cell grown seedlings and transplants have a much shallower but extensive root system in the upper 30cm of the profile compared to a deep 1.2 – 1.5 m tap root on direct seeded crops (Jackson 1998). This major change presents crop management challenges to producers in the 21st Century particularly in relation to water management.

**Crop Nutrition**: Crop nutrition also influences product quality. The classic nutritional work was done by Zink & Yamaguchi (1962) for direct seeded lettuce in California. This work provides the benchmark for nutrient removal of a 50 tonne/hectare crop. Lettuce crop nutrient removal/ hectare is estimated to be;

| | | |
|---|---|---|
| 100 | kg | Nitrogen |
| 18 | kg | Phosphorus |
| 180 | kg | Potassium |
| 33 | kg | Calcium |
| 15 | kg | Magnesium |

and small amounts of Sulphur and micronutrients.

Sanchez et al. (1989) tested a wide range of N, P and K rates over many seasons. This work showed that there was a response to N at rates up to 250 kg/ha, especially during periods of cool temperatures or heavy and frequent rainfall. There were responses to phosphorus at rates up to 500 kg P/ha when there were low soil P levels and there was a response to potassium applied at rates up to 625 kg K/ha when the soil K content was low.

The work showed that the leaf N concentration was not closely related to yield. They also showed that the critical concentrations of P and K in 6- to 8-week-old leaves were 0.44 and 5.6%, respectively. Shelf life was not affected by N, P and K application levels although the trimming losses of stored lettuces increased with increasing N application rate. Other work linking nutrition to shelf life has shown some affects. Yano and Hayami (1978) found that high rates of phosphorus fertilizer prolonged lettuce shelf life and Steenhuizen and Boon (1985) found a link between growing lettuce using a high N regime and poor shelf-life. More research is needed in this area to optimise crop nutrition for optimum yield, quality and shelf life.

**Organic Supplements**: There has been increasing interest in added nutrients to crop by using organic supplements. Zodape (2001) found that fertilizing plants with seaweed extracts was able to extend shelf life and a similar study by Yano and Hayami (1978) also found that organic fertilizers produced longer-lasting heads than lettuce grown using inorganic fertilizers. This research suggests the need for a better understanding of the link between crop nutrition and the product shelf life.

**Tipburn**: An important physiological disorder of lettuce is tipburn. Traditionally this disorder has been associated with low calcium levels in the developing heart tissues. A recent study investigating tipburn control in lettuce by Murdoch et al. (2000) found that the application of calcium was actually ineffective in controlling the disorders.. This research found that the most effective control strategy was to slow the growth rate of the lettuce, and reduce the nitrogen supply to the plants.

There is recent evidence that some disorders which have been traditionally attributed to calcium deficiency such as bitter pit in apples, may in fact be caused by high Gibberellic acid levels which slows calcium transport and encourages rapid cell expansion (Saure, 2001). The low calcium may be a response to the disorder rather than the cause. It may be possible that tipburn in lettuce is similar to bitter pit in apples where the low calcium in the tissues is a symptom rather than a cause. This would explain why lowering growth rate was effective and calcium sprays were not.

**Salinity**: Another issue for Australian growers is soil salinity. Lettuce is classified as a moderately salt sensitive crop, therefore producers should account for any salinity effects from soil or irrigation water. This is important for some Southern growing regions which have experienced below average rainfall over the past 3 – 4 years and have seen 'salt burn' on lettuce during mid summer which has impacted on iceberg lettuce quality and quantity (Titley 2000).

**Moisture sensitive stages**: To ensure a good quality crop of lettuce it is important to avoid water stress at critical times. For lettuce the most critical stages are during germination, seedling establishment and from the cupping stage until harvest. Research has shown that 70 % of the fresh weight is accumulated from the cup stage until harvest (Salter and Goode 1967).

**Pest Control**: Pest management is always an important part of crop agronomy and the supply of insect-free lettuce for processing is crucial. Strategies for pest control in lettuce in the future will include initiatives such as, routine crop scouting, introduction of 'new' chemistry, strategies to build up native predators, crop rotation, adequate spray coverage and trap crops.

**Bolting:** Bolting can be a problem for lettuce growers although new varieties are bred to be bolting resistant. Bolting is the undesirable formation of flowers and seeds. Bolting destroys the flavour of the leaves by making them bitter and tough. Bolting is induced by high temperatures, long periods of high light intensities, and drought. Research has shown that lettuce has an internal counter that keeps track of the number of daylight hours the plant receives. Once a critical number of hours have been received then the plant sends up its flower stalk. The exact number of hours varies from cultivar to cultivar. The plant can handle environmental stresses when vegetative. However, once the lettuce reaches the intermediate growth stage, environmental stresses, such as high temperatures or drought, will cause the plant to bolt. Growers must schedule their planting to ensure that harvesting is finished before hot temperatures occur. This is the reason that processors in Australia often have Northern and Southern states supplying product for processing.

**Harvesting**: In the US, a practice has been developed where iceberg and Cos lettuce are being de-cored in the field. This results in less waste material being transported back to the processing factory.

Immediately after coring, a protein-based solution is sprayed into the cut surfaces of the lettuce, and this solution has the effect of protecting the cut surfaces from enzymic (PAL) browning. Once the lettuce reaches the factory, the protectant solution is washed off in the normal washing process and the lettuce is processed normally.

Kraker et al. (1996) found that if lettuce is harvested in the early morning, when the head is fully turgid, that it is highly susceptible to internal cracking. The research showed that delaying harvest until the outer leaves were dry, significantly reduced internal cracking.

## Storage and Postharvest Techniques

**General Storage Conditions**: Reyes (1996) has written a review of the general storage conditions for minimally processed vegetables. The review outlines recent improvements in packaging, preservation systems, refrigeration and antioxidants. Some of the recent improvements are summarised below.

**Controlled Atmosphere storage (CA):** Research has shown that gas concentrations of 2% $O_2$ and 5 % $CO^2$ will extend the post harvest life of lettuce. This concentration of gasses is suitable for lettuce, even though the temperature through the cold chain may vary from $0^oC$ which is optimum (O'Hare et al. (2000).

The effects of ultra low oxygen (ULO) concentrations in combination with high and low levels of $CO_2$ on the storage and quality of butterhead lettuce (cv. Krolowa Majowych), was studied. Butterhead lettuce stored in a controlled atmosphere (CA) containing 1% $O_2$ + 3% $CO_2$ retained green colour of leaves and a high content of vitamin C during 21 days at 1 $^oC$ (Adamicki 1997).

CA storage could be an option for processors in the future for holding over product. At the moment the infrastructure Costs are too high for it to be a commercial reality. A commercial option may be the same atmospheres using modified atmosphere packaging.

**Modified Atmosphere Packaging**: For lettuce equilibrium modified atmosphere (EMA) should be 2-3% $O_2$, 2-3% $CO_2$ and 94-96% $N_2$ (Jacxsens et al. 1999). The critical success factor for the use of MA packaging is a good cold chain where temperatures can be maintained at between 0 to $4^oC$.

Control over the atmosphere can also be achieved using Modified Atmosphere packaging (MAP) (Beaudry 2000). Martinez and Artes (1999) found that 5% $O_2$ and 0 % $CO_2$ , applied using 30 mm active perforated polypropylene were best for overall visual quality of lettuce.

The use high $CO_2$ to control enzymic browning can be used, however the $CO_2$ should be kept below 5% when $O_2$ levels are low. Potassium leakage from the cells was a good indicator of damage caused by high $CO_2$ (Varoquax et al. 1996).

When packing shredded lettuce in low density polyethylene, a flush of 5% $O_2$, 5% $CO_2$ and 90% $N_2$ resulted in a shelf life of 14 days.

**Effects of MAP on Microbial Growth**: Research has shown that modified atmospheres do not inhibit microbial growth. The main effects of MA's are on the sensory quality of the lettuce (Jacxsens et al. 1999).

**Vacuum Cooling**: Temperature management is the best tool for extending the postharvest shelf life of lettuce. Vacuum-cooling has been shown to reduce the incidence of both pink rib and heart leaf injury during storage (Martinez and Artes 1999).

**Nitrogen Flushing**: Koseki and Itoh (2002) report that Nitrogen flushing of bags is effective in extending the shelf life of fresh-cut lettuce. 100% $N_2$ at packing should stabilize to about 1.2-5% $O_2$ and 0.5-3.5% $CO_2$ after 5 days at 5 °C.

**Use Of Heat Shock Proteins To Control Post Harvest Enzymic Browning**: Browning of the cut surfaces of lettuce is a major quality defect for consumers. The browning results from wounding and the breaking of cells. The wounding leads to the rapid accumulation of phenolic compounds which cause tissue browning via an increase in the activity of enzymes of phenolic metabolism such as phenylalanine ammonia-lyase (PAL). This enzymatic browning has been controlled through the application of antioxidant compounds such as ascorbate.

Research has shown that exposure of cut lettuce to 45 °C for 90 seconds prevents an increase in phenolic compounds and hence browning, if administered either 4 h before or 2 h after wounding. This diversion of wound-induced protein synthesis by heat shock might be used to prevent browning in other crops that normally have low phenolic content, such as celery and lettuce. The effects of heat treatment last for 15 days in lettuce held at 5 °C.

This heat treatment offers a new way to control browning in lightly processed fruits and vegetables. The design of processing lines using a heat shock to extend the shelf-life of fresh-cut lettuce will need to be modified from existing designs to take full advantage of the effect of the heat treatment.

## Summary of the Experimental Approach

Four regions with significant production value to the Australian lettuce industry were chosen as trial locations for the three year duration of the project. There were 2 districts in and two areas in Victoria. The locations chosen included:

1. ***Queensland*** - Gatton (27° 33' S, 152° 17' E) and Toowoomba (27° 33' S, 151° 58' E). Gatton, 82km west of Brisbane, provided a site for winter production in this state. Toowoomba, although only 35km west of Gatton, experiences significantly different temperatures due to it's elevated position on the Great Dividing Range. Toowoomba's altitude is 700m above sea level (cf: 89m at Gatton) and is used for summer production of lettuce during the shoulder period.

2. ***Victoria*** - Bairnsdale (37° 55' S, 147° 43' E) and Robinvale (34° 34' S, 142° 44' E). Bairnsdale, 306km east of Melbourne, is a major location for the summer production of lettuce in southern Australia and Robinvale, 438km north-north-west of Melbourne, was used for winter production in Victoria.

All trials were conducted on commercial properties that supply fresh cut processors. Two growers in the Gatton area and one grower in Toowoomba provided field sites in Queensland. The postharvest research for these trials was done at the OneHarvest facility in Brisbane.

In Victoria, one grower's property was used in Robinvale and two grower's properties were used in the Bairnsdale area. There were field sites in the surrounding production districts of Lindenow and Boisdale. The OneHarvest facility in Bairnsdale provided the resources for the postharvest evaluation of the Victorian field trials.

**Field Trial Design**: The field trials were set up as completely, randomised block designs with the blocks running down a bed. The nutrition trials and early variety screening trials were designed with each treatment having two to four replicate plots per block. Each block was on a separate bed. Each treatment plot comprised of 7m lengths of bed, including a buffer of unused plants at each end.

Once the initial screening trials were completed the field trials were scaled up in size. The trials had fewer treatments but larger plot areas. . This was valuable as a means of assessment after initial screening trials had selected the best performing varieties. This was also an efficient way of providing large samples (for both field and postharvest assessment) throughout a growing season, this design was integrated with commercial production and therefore allowed variety performance to be measured within the context of typical grower practices.

For the large field trials small plantings of the test varieties were transplanted within a block of the grower's standard varieties. The size of each planting varied but the number of plants always exceeded 100 plants. This provided sufficient plants for sampling to assess yield, quality and shelf-life.

In all trials the commercially recommended plant spacing was used. The planting configurations were three rows of lettuce on beds with 1.5m centres or four rows on beds with 2m centres. Intra-row spacing varied but plant density was always in the order of 60 000 plants per hectare.

**Assessment of Yield and Quality**: The measurement of yield and quality at the time of harvest was consistently executed using a standard protocol.

The standard unit sample was twelve plants, which was taken from each replicate of each treatment. The samples were taken twice from the plots of commercial-scale trials, resulting in two replicates. Samples were always taken using plants representative of the entire plot. Plants from the edges of the plot were never taken.

The following measurements were made from the twelve plants in a sample:

1. The trimmed weight was recorded for all plants (the weight of a head of lettuce trimmed as it would be in a commercial harvesting operation, for processing)
2. For two of the plants an untrimmed weight was also recorded (the biomass of the above ground parts of the plant)
3. The core length and dimensions of the heart were also measured for all plants and
4. Any incidence of disease or disorders was also documented along with any other observations of note.

**Shelf Life assessment**: For the assessment of shelf-life, a sufficient amount of lettuce was harvested per treatment, for processing at either of the two plants. Six standard cartons per treatment (a total of 72 heads per treatment) provided ample material for processing in the factory. The harvested treatments were vacuum cooled before being sent to the processing plant. The commercial temperature management ( approx. 4$^{o}$C) was used during periods of storage before processing.

The field treatments were processed as per the routine operation of each processing facility. The final product was a fresh-cut salad, packaged with only one type of lettuce. Iceberg lettuce was processed as shredded lettuce and Cos lettuce was processed as a Caesar salad. These bags, commercially sold at retail level, were stored in their treatments at 7$^{o}$C, to simulate the conditions experienced in a chain store. A 7$^{o}$C storage regime is the protocol OneHarvest use for their in house quality and shelf life evaluation for their products.

<u>Quality Rating</u> – During the postharvest evaluation each treatment was rated for seven aspects of quality: visual, crispiness, odour, taste, damage, consistency and overall freshness. Each score comprised a number between 1 and 5, with 5 indicating excellent quality and 1 being unacceptable quality with respect to purchase. This is the protocol OneHarvest use for their in house quality and shelf life evaluation.

For the work presented in this report the scores for each category were totalled for each day of assessment, to give a total quality score out of 35. The total quality scores were averaged for replicates and when this average score reached 12.5 or less, the treatment was said to be unsaleable. The end of shelf-life of a treatment was defined as the number of days until it became unsaleable or reached a quality score of 12.5.

<u>Statistical Analysis</u>
In most field experiments the data was analysed as a completely randomised designs with the plots being the treatment replicate. In some locations it was possible to design the field trials as

completely randomised blocks when more resources were available. The shelf life trials were analysed as completely randomised designs with appropriate replicates. The analysis of variance was computed using Genstat ver 8.0 (VSN International Ltd, Lawes Agricultural Trust 2005). Multiple mean comparisons were performed using LSD generated in Genstat ($p = 0.05$).

# Experimental Results

## 1. Crop Scheduling

### *Introduction*

Crop scheduling in processing lettuce has become a problem as both the wholesale processing lettuce and retail processing lettuce categories grow throughout Australia. Correct crop scheduling assures a consistent supply of quality raw product which is essential for successful product development. However, there are often problems in supply during the Christmas/New Year period; for the period in early March and also in the transition from summer production in southern Australia to winter production in the northern parts of southeast Queensland. This part of the project aimed to develop better scheduling models for Cos and Iceberg lettuce grown in different regions around Australia.

The shelf life of processed lettuce varies from 10 –14 days. As a result there is a need for continuity of production of harvested head lettuce year round. As distinct from processing vegetables such as peas, beans and sweet corn that can be harvested at optimum harvest time and then stored as frozen or canned product, the need for scheduling is more critical in the fresh cut industry. The other factor that growers have to consider is that days from transplanting the seedling to maturity of the head of lettuce varies throughout the year. Scheduling is not simply a matter of planting at weekly intervals. The days to maturity can vary from as short as 42 – 49 days in mid summer to 90 –100 days for mid-winter production in inland areas of Victoria. Not only do the days from planting to harvest vary but also the yield varies from as little as 350g/head in mid summer to as much as 1.5kg in mid-winter.

There are two main examples of lettuce scheduling highlighted in this report; one for summer (a case study of Cos grown in East Gippsland) and one for winter (a case study of Iceberg grown in Gatton, Qld). Other examples of scheduling and predicted yield are presented in Appendix 2 for Cos grown in Gatton, Iceberg grown in East Gippsland and Iceberg grown in Toowoomba.

### *Method*

The crop scheduling models were developed and validated using data collected from Victoria and Queensland over 2004 and 2005.

In Victoria 4 plantings were used in 2004 and in 2005 weekly plantings which were harvested from December to May were used. In Queensland, data was collected from 4 plantings in 2004 and 5 plantings in 2005. In 2005, data was also collected from commercial plantings from January to April in Toowoomba.

Table 1.1. Planting details for the Crop Scheduling Trials 2004 and 2005.

| | GATTON (Trickle) | LOWOOD (Sprinkler) | LINDENOW (Sprinkler) | BOISDALE (Lateral move) | WEMEN (Fixed sprinkler) | TOOWOOMBA (Movable sprinkler) |
|---|---|---|---|---|---|---|
| Tractor Wheel Centres (Mm) | 2000 | 1500 | 1500 | 1500 | 1500 | |
| Rows/Bed | 4 | 3 | 3 | 3 | 3 | 4 |
| Plant Spacing (Mm) | 400-300 | 375mm | 350 | 375 | 400 | |
| Plants Hectare | 50,000 - 55,600 | 53,400 | 57,143 | 53,400 | | |

## Experimental Design

The trials were all transplanted, and the varieties were grown in a tray by themselves, not as mixed seedlings. The trays ranged from 144 cells per tray up to 198 cells per tray. The configurations of the plots in the fields were sown at a rate of 60 – 80 plants per plot depending on whether there were 3 or 4 rows. The experimental harvests were taken from the middle 1 or 2 rows leaving a buffer at either end. All varieties were sown in two completely randomised blocks per sowing date per district. Measurements were made on 12 individual heads per treatment per block. The measurements taken are described below.

The scheduling model presented was based on planting the right type of lettuce at each time slot for each district. The type planted is recorded in the scheduling Tables 1.1 and 1.2.

## Measurements

The following measurements were taken from the 12 heads harvested for each treatment in each block:

1. Untrimmed weight of 2 heads
2. Head weights (trimmed to OneHarvest specification) for all heads
3. Butt diameter in millimetres of all heads
4. Heart size in millimeters (taken across the head, putting the measurements right on top of the core) of all heads
5. Core size in millimetres(the length of the core from the butt to the tip of the core) of all heads
6. Density ratio (trimmed head weight divided by the heart size) of all heads

A quality assessment of the variety was also done which included head size, vigour, shape, colour, variety type, external tipburn, internal tipburn, diseases (if any), disorders (if any) and an overall comment of the suitability of the variety. For Cos types all of the above was assessed as well as an addition measurement called 'heart length' (the total length of the trimmed heart from the butt to the tip of the closed in heart). During the second and third years of the project where we did semi-commercial plantings of 'best bet' varieties; sample harvests of 2 lots of 12 plants were taken using the same criteria for consistency.

# Results and Discussion

## 1.1 Variation in Crop Growth Period and Yield in Gatton – Iceberg Lettuce

The first example for modelling crop scheduling is the winter production of Iceberg lettuce in the Lockyer Valley located in southeast Queensland. This is a 22 – 24 week harvest period commencing in early to mid May and continuing through until early October. In order to maintain yields growers must synchronise appropriate lettuce variety types with the growing season. The challenge in this environment is to transplant summer Vanguard types in mid-March that will cope with extremely high temperatures and decreasing day lengths that will be ready for harvest in May, then transition to Salinas x Vanguard types (cv. Seagreen) in June, move to winter Vanguard types for July/August harvest and then return to summer Vanguard types for late September/early October. This involves a coordinated approach involving selection of the correct variety and growing of an optimum sized seedling to ensure that there is a minimum amount of bolting.

Figure 1.1 shows that for Iceberg lettuce planted in Gatton, Qld the time from transplanting to harvest varies from as little as 49 days for the May harvest extending out to 70 – 77 days for the mid-winter harvest and then decreasing back to 63 and 56 days for September/October harvesting.

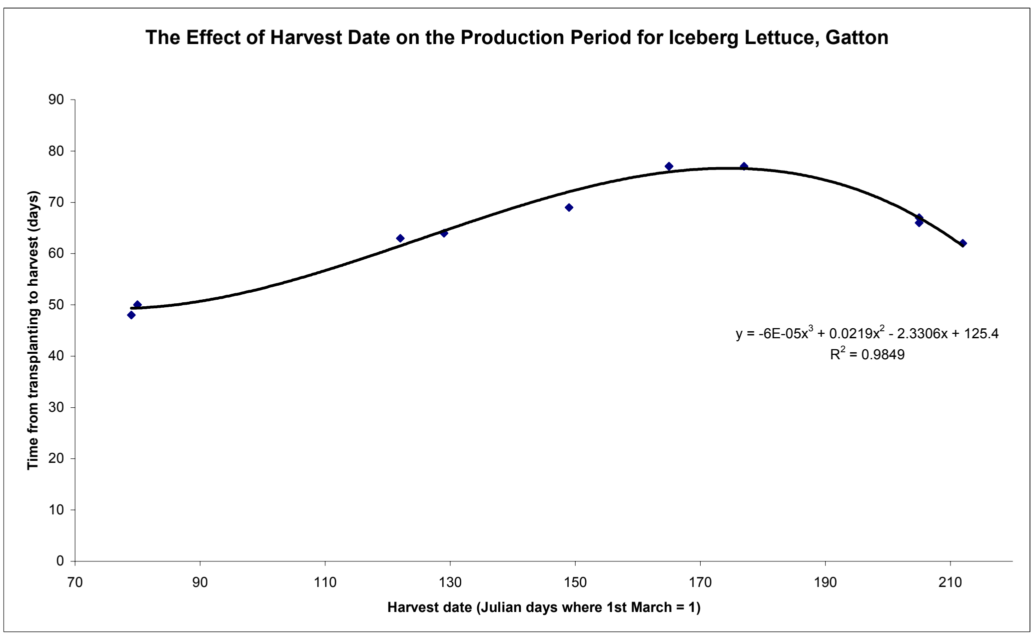



Figure 1.1: The effect of harvest date on the production period for Iceberg lettuce grown in Gatton, Qld.

The other factor to consider is that during this time yields can vary from 30t/ha (350g/head) in the May and October period, up to 45 – 50t/ha (1.5 kg) in the optimum harvest period in July through to August. Growers must vary the area planted in an effort to maintain a constant volume as specified in processing contracts.

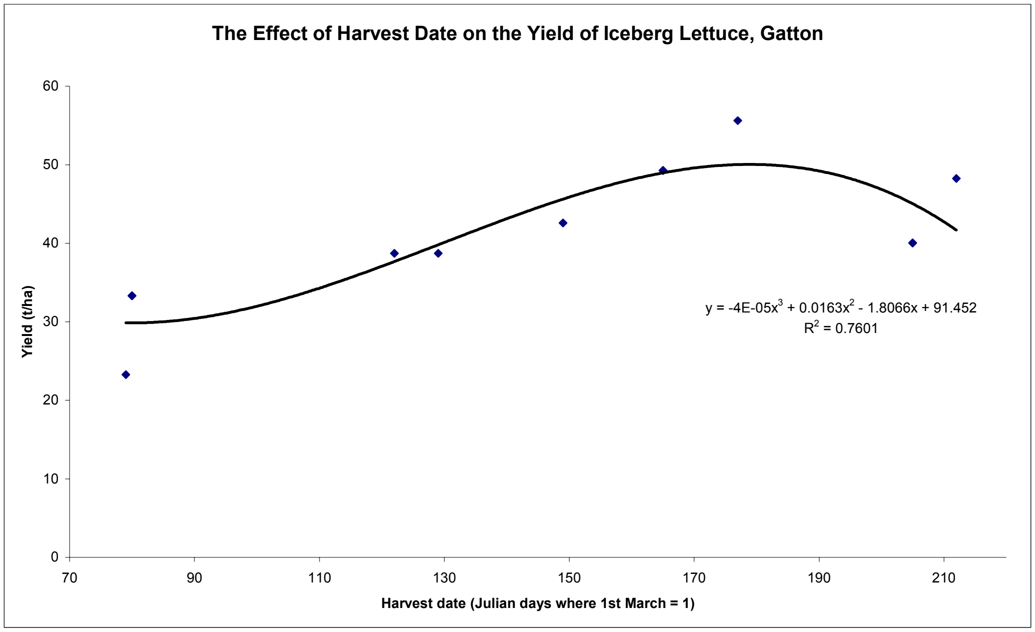



Figure 1.2: The effect of harvest date on the yield of Iceberg lettuce grown in Gatton, Qld.

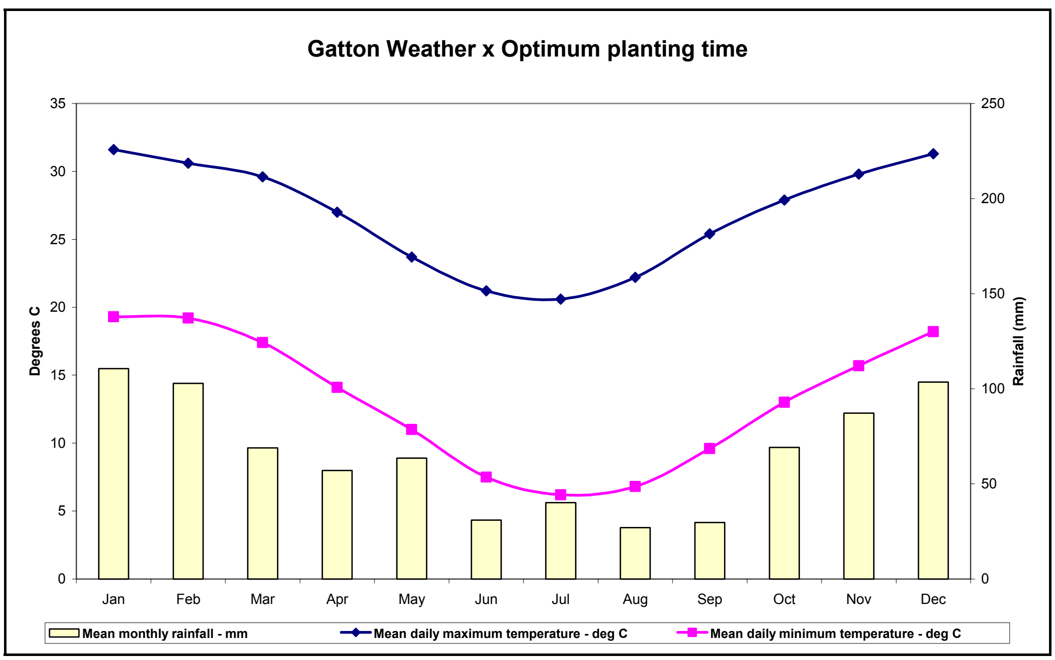



Figure 1.3. Lockyer Valley weather data

Another issue is that certain physiological disorders that affect quality at harvest can occur in winter grown lettuce. These problems include tipburn (a problem for lettuce harvested in May and September), long-core/bolting (a problem in May and early June) and leaf breakdown referred to as 'slime' which occurs in September. Slime can be induced in Winter Vanguard types because they do not handle the hot spring conditions which often prevail in south east Queensland.

The above examples are for Iceberg lettuce. The same issues are also present for Cos (Romaine) lettuce but the maturity is generally 4 – 6 days earlier and the physiological disorders are more severe in Cos than in Iceberg.

Table 1.2 Gatton Iceberg Schedule – Gatton 2004 and 2005.

| Harvest Date | Type of Lettuce to Plant | Number of Days to Harvest | Planting Date | Yield (t/ha) | Plants Required per Tonne |
|---|---|---|---|---|---|
| 15-May | Summer Vanguard | 49 | 27-Mar | 33 | 1818 |
| 22-May | Summer Vanguard | 50 | 2-Apr | 33 | 1818 |
| 29-May | Summer Vanguard | 52 | 7-Apr | 33 | 1818 |
| 5-Jun | Summer Vanguard | 53 | 13-Apr | 34 | 1765 |
| 12-Jun | Salinas x Vanguard | 56 | 17-Apr | 34 | 1765 |
| 19-Jun | Salinas x Vanguard | 59 | 21-Apr | 36 | 1667 |
| 26-Jun | Salinas x Vanguard | 62 | 25-Apr | 38 | 1579 |
| 3-Jul | Salinas x Vanguard | 65 | 29-Apr | 40 | 1500 |
| 10-Jul | Salinas x Vanguard | 67 | 4-May | 42 | 1429 |
| 17-Jul | Winter Vanguard | 70 | 8-May | 44 | 1364 |
| 24-Jul | Winter Vanguard | 72 | 13-May | 46 | 1304 |
| 31-Jul | Winter Vanguard | 74 | 18-May | 47 | 1277 |
| 7-Aug | Winter Vanguard | 75 | 24-May | 49 | 1224 |
| 14-Aug | Winter Vanguard | 76 | 30-May | 50 | 1200 |
| 21-Aug | Winter Vanguard | 77 | 5-Jun | 50 | 1200 |
| 28-Aug | Winter Vanguard | 76 | 13-Jun | 49 | 1224 |
| 4-Sep | Summer Vanguard | 74 | 22-Jun | 48 | 1250 |
| 11-Sep | Summer Vanguard | 72 | 1-Jul | 46 | 1304 |
| 18-Sep | Summer Vanguard | 68 | 12-Jul | 43 | 1395 |
| 25-Sep | Summer Vanguard | 64 | 23-Jul | 38 | 1579 |

***Disclaimer**: This scheduling model is presented as a guide for growers only as it is based on two season's data for the Gatton district. Days to harvest and yield will vary with season, growing district and crop production methods.*

## 1.2 Variation in Crop Growth Period and Yield in East Gippsland – Cos Lettuce

The second example of crop scheduling is the supply of spring, summer and autumn lettuce from the East Gippsland and southern Victoria region, 36 – 37° south. The harvest period in southern Victoria varies from 28 – 32 weeks depending on the transition from southeast Queensland and then subsequently back to southeast Queensland. Generally the aim is to commence harvesting in early to mid-October and then continue until the second week of May.

The three main variety groups were used during this period. Firstly winter Vanguard types (cv. Greenway-Marksman) which are planted in mid-winter and harvested in October and November; secondly summer Salinas and Salinas x Vanguard types that are harvest in December, January, February and early March and finally the third group are autumn Vanguard types which are harvested in the cooler period in March, April and early May as day length decrease and temperatures decrease including quite cool nights.

During this timeframe the maturity from transplanting to harvest varies from 95 –100 days for the early part of the season decreasing to 42 – 49 days in mid-summer and then extending out to 70 – 75 days for the late autumn harvest period (Figure 1.4). Interacted with this 'Days to harvest' by 'Time of year' graph is the yield per hectare which is high in the autumn and spring and is the lowest in the mid-summer period (Figure 1.5). Growers have to adjust the number of plants that are sown to account for the lower yield in mid-summer compare of 500 – 550g/head to the 750 – 800g/head that are produced in the autumn and spring period.

Several physiological disorders affect summer lettuce with the major problem being associated with tipburn. Tipburn has been found to be caused by many factors which have been outlined a previous study by Craig Murdock, however temperature spikes, water management, inappropriate variety selection and the wrong calcium/magnesium ratio have been the major influences of tipburn. The second problem during this period is bolting or longcore which is worse during a combination of long days and high temperatures especially with older transplants and under water stress. The worse period for bolting in the south is on plants that are transplanted in the field in December/early January and then show this longcore in late February/early March. The problem with longcore in processing lettuce is that the percentage recovery is reduced dramatically as the core has to be taken out and often the extended growing point has to be hand removed in the factory. The third physiological problem that has been show to be a problem is slime and this is associated with periods of high humidity and high temperature which can often occur along the east coast especially when a low pressure system develops in the Tasman sea.

The same principles apply to the scheduling of Cos lettuce with the difference in maturity being 4 – 7 days earlier than iceberg and the incidence of tipburn being far greater than in iceberg. Parris Island Cos types have been the main industry benchmark for years where the variety Verdi dominated however, there is now an emergence of three quarter closing Cos which have the tendency to be slower growing and hence slower bolting and are also a little bit tolerant of tipburn.

Growers obtain maturity information from seed company representatives and will often schedule 2 – 3 different varieties at any one transplanting time to give them some flexibility in their harvest schedule for their various fresh market clients.

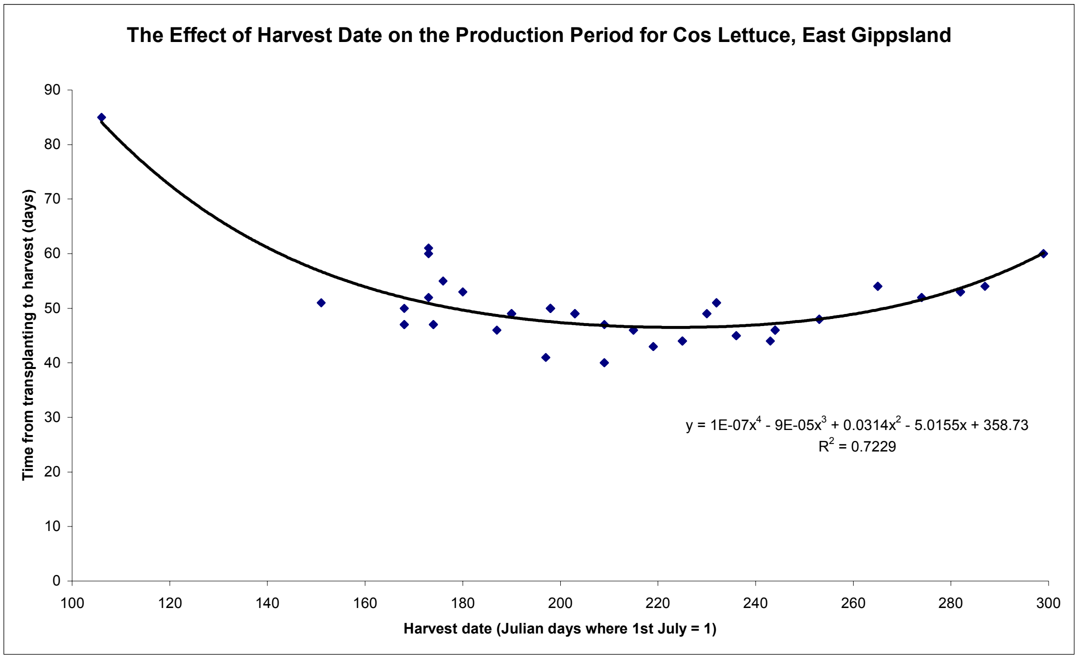



Figure 1.4: The effect of harvest date on the production period for Cos lettuce grown in East Gippsland.

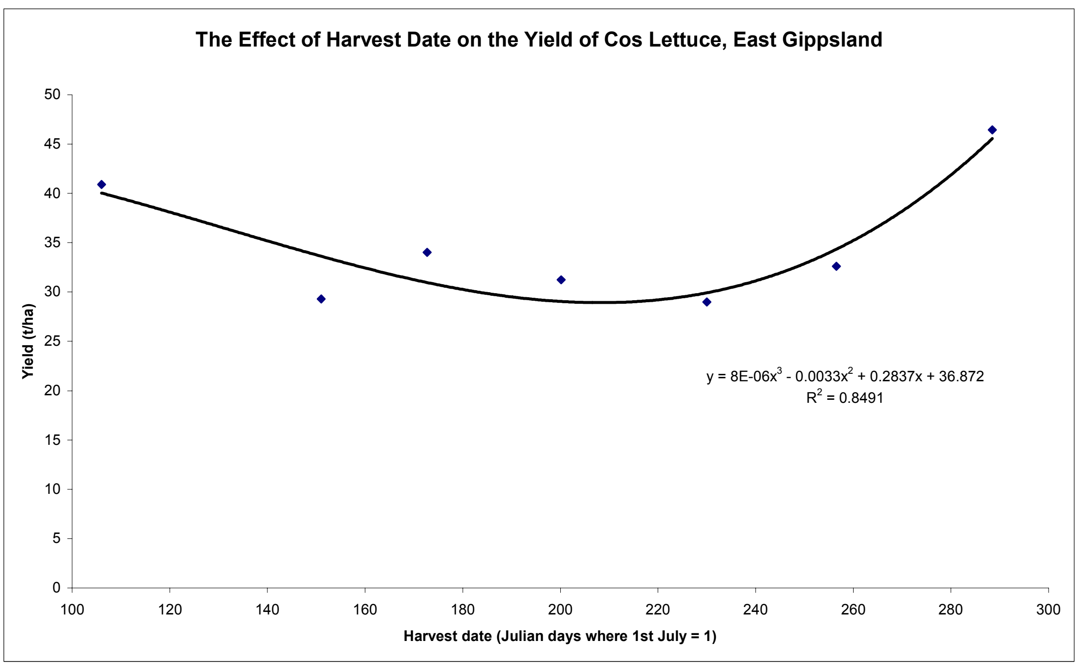



Figure 1.5: The effect of harvest date on the yield of Cos lettuce grown in East Gippsland.

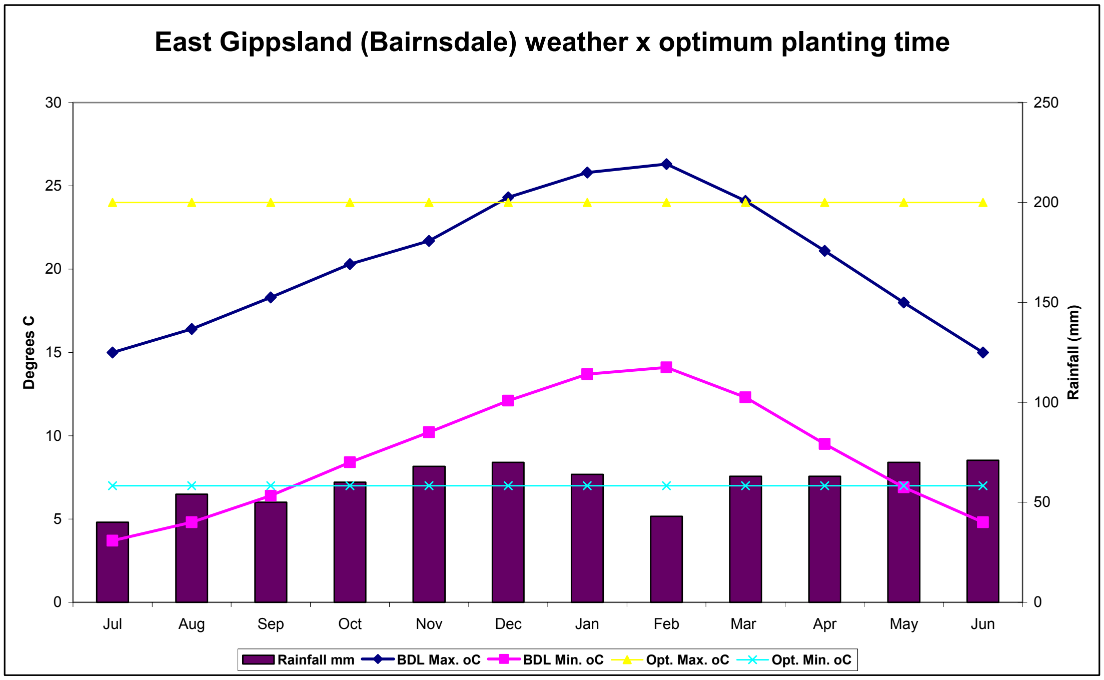



Figure 1.6. East Gippsland (Bairnsdale) weather data

Table 1.3 East Gippsland Cos Schedule – East Gippsland 2004 and 2005.

| Harvest Date | Type of Lettuce to Plant | Number of Days to Harvest | Planting Date | Yield (t/ha) | Plants Required per Tonne |
|---|---|---|---|---|---|
| 14-Oct | Winter Vanguard x El Toro | 84 | 22-Jul | 84 | 714 |
| 21-Oct | Winter Vanguard x El Toro | 78 | 4-Aug | 82 | 732 |
| 28-Oct | Winter Vanguard x El Toro | 73 | 16-Aug | 76 | 789 |
| 4-Nov | Winter Vanguard x El Toro | 68 | 28-Aug | 70 | 857 |
| 11-Nov | Winter Vanguard x El Toro | 64 | 8-Sep | 65 | 923 |
| 18-Nov | Winter Vanguard x El Toro | 61 | 18-Sep | 60 | 1000 |
| 25-Nov | Winter Vanguard x El Toro | 58 | 28-Sep | 55 | 1091 |
| 2-Dec | Summer Salinas | 56 | 7-Oct | 51 | 1176 |
| 9-Dec | Summer Salinas | 54 | 16-Oct | 47 | 1277 |
| 16-Dec | Summer Salinas | 52 | 25-Oct | 44 | 1364 |
| 23-Dec | Summer Salinas | 50 | 3-Nov | 40 | 1500 |
| 30-Dec | Summer Salinas | 49 | 11-Nov | 38 | 1579 |
| 6-Jan | Summer Salinas | 48 | 19-Nov | 35 | 1714 |
| 13-Jan | Summer Salinas | 48 | 26-Nov | 33 | 1818 |
| 20-Jan | Summer Salinas | 47 | 4-Dec | 31 | 1935 |
| 27-Jan | Summer Salinas | 47 | 11-Dec | 30 | 2000 |
| 3-Feb | Summer Salinas | 46 | 19-Dec | 28 | 2143 |
| 10-Feb | Summer Salinas | 46 | 26-Dec | 28 | 2143 |
| 17-Feb | Summer Salinas | 46 | 2-Jan | 27 | 2222 |
| 24-Feb | Summer Salinas | 47 | 8-Jan | 27 | 2222 |
| 3-Mar | Summer Salinas | 47 | 15-Jan | 27 | 2222 |
| 10-Mar | Summer Salinas | 48 | 21-Jan | 28 | 2143 |
| 17-Mar | Summer Salinas | 49 | 27-Jan | 28 | 2143 |
| 24-Mar | Summer Salinas | 50 | 2-Feb | 30 | 2000 |
| 31-Mar | Summer Salinas | 52 | 7-Feb | 31 | 1935 |
| 7-Apr | Salinas x Vanguard | 53 | 13-Feb | 33 | 1818 |
| 14-Apr | Salinas x Vanguard | 55 | 18-Feb | 35 | 1714 |
| 21-Apr | Salinas x Vanguard | 58 | 22-Feb | 38 | 1579 |

***Disclaimer**: This scheduling model is presented as a guide for growers only as it is based on two season's data for the East Gippsland district. Days to harvest and yield will vary with season, growing district and crop production methods.*

## *Conclusions*

When looking at scheduling either from a theoretical point of view or from a more practical one, there are several critical points that must be remembered.

First is the quality of the data. The reliability of any harvest timing or yield prediction will only be as accurate as the information used in the scheduling model. It is of vital importance to ensure that the best possible data is used when constructing schedules for transplanting and harvests. Clear and complete historical days-to-harvest (DTH) data is a very good point to start. The data is of greater value if it is variety or at least type specific.

Another important factor when looking at DTH data is to ensure that the accompanying weather data from the specific season in question is available. DTH data should never be looked at in isolation from weather data or any other relevant crop records that may help explain the time from transplant to harvest for each specific crop. Sources of DTH data can include; grower crop records, records from seedling producer, seed companies' records, on-farm weather records or the bureau of meteorology data if it is suitable.

It is possible to develop models that will accurately predict days-to-harvest when a combination of data is used to develop the model. However this is only part of the information required in many cases. The volume of lettuce that will be harvested at any point is also of great importance.

For fresh market producers the number of cartons produced per hectare is quite simple to calculate. It is simply the number of plants transplanted per hectare multiplied by the expected harvest percentage divided by the numbers of lettuce in the carton, usually twelve.

For producers of processed lettuce sold on a per kg basis, the same principle cab be used. Rather than dividing the number of harvestable plants by twelve to get the number of cartons produced per hectare, the number of harvestable heads per hectare is multiped by the average weight of each head to arrive at the number of kilograms produced per hectare.

It is this estimation of the final weight of each individual head that can cause much variation in the estimation of yield per hectare. As can be seen in figures 3& 6 the time of year will dramatically influence the total tonnes of material produced per hectare.

It is in areas such as these that grower knowledge is extremely valuable. Past seasons' harvest records from the grower or harvesting contractor can provide a good insight into the likely final head weights as well as seed company estimations.

### *Factors affecting Bolting in Lettuce*

One of the major considerations for optimum conditions for planting lettuce relates to the amount of bolting that occurs in Cos lettuce during late autumn and early winter in different regions of eastern Australia.

The two major growing regions during the May-September harvesting period are Robinvale in the Sunraysia area of Victoria and the Lockyer Valley in southeastern Queensland. During many recent seasons there have been severe problems with bolting during the mid May/end of June time period. This occurred when growers transplanted the industry standard Paris Island Cos types in mid-autumn using cell grown seedlings. In addition, the seedlings grew into decreasing day lengths and decreasing temperatures.

It is likely that bolting is caused by a combination of the condition of the seedlings at the time of transplanting and the weather conditions of the period immediately after transplanting.

Potential causes for bolting include:

- Day length (especially long days)
- High diurnal temperature range e.g. maximum daily temperatures equal to or greater than 27°C and minimum temperatures dropping to 5°C.
- A combination of long days, high temperatures and transplanting into dry soil.
- Soil temperatures, both waterlogged and drought conditions.
- Number of leaves when transplanted (especially if the leaf number is greater than 7).
- Length of time Cos seedlings held in soil-less media once the optimum root ball has been developed.
- Stress, especially moisture, soil compaction and salt.
- Genetics, with some varieties exhibiting slow bolting tendencies

## 2. Lettuce Harvest Maturity

### *Introduction*

In order to meet processing specifications growers must focus on both the yield and processing-quality of a crop at the point of harvest. Timing of harvest can be a compromise in terms of optimum crop maturity. Harvest may have to be earlier or later if scheduling has failed to provide appropriate processing volumes throughout the season. During warm, dry weather, there is also a greater risk of bolting or the development of tipburn as the crop nears maturity and these factors can mean that lettuce is harvested before the optimum head weight has been achieved.

It has been shown that lettuce can accumulate more than 70% of the final fresh weight during the 21 days prior to harvest (Zink and Yamaguchi, 1962). This means that there is potential for substantial yield increase for Cos and Iceberg lettuce if they are harvested later in the growing period. It is possible that relatively small delays in harvest, up to 7 days could significantly increase yield. This research aimed to determine if the theoretical yield potential was a commercial reality for Cos and Iceberg lettuce grown in Gatton, Qld.

## *Methodology*

Field Trial – Iceberg Lettuce

During the final season of the project, in Gatton the effect of harvest date on yield, core length and shelf-life was investigated for Iceberg and Cos lettuce. Three varieties of iceberg lettuce were planted on the 26th of April 2005 at Patrick Estate, approximately 25km north east of Gatton. Seedlings of varieties Titanic (the industry standard for this time and region), Patagonia and Cartagenas were transplanted into plots of approximately 100 heads each in three rows on beds with 1.5m centres. Plots were located within a commercial block of lettuce and subjected to standard grower cultural practices. The trial was irrigated using portable spray lines with overhead sprinklers.

All varieties were harvested at 56 days after transplant (considered the optimal time for commercial harvesting in this season) and then again at 62 days after transplant. At each harvest, two replicates of 12 plants each were sampled from each of the three plots. Outer leaves were removed to duplicate the trimming in a commercial harvesting operation and each head was then weighed. Plants were cut in half to expose a longitudinal section of the stem, so that core length could be measured.

The experiment was repeated for varieties Titanic and Patagonia, transplanted on the 18th of May 2005 with harvests occurring at 68 and then 75 days after transplanting.

Shelf Life Assessment – Iceberg Lettuce

For both Iceberg trials the shelf life of the processed product was assessed. Six cartons of twelve heads each were taken for each variety and for each harvest date, for processing as fresh-cut salad products.

Trial material was transported to a vacuum cooler directly after harvest and brought to a temperature of 3˚C before being placed into refrigerated storage at 4$^{o}$C. It was taken to the OneHarvest processing facility in Brisbane via refrigerated transport that evening. On receival at the processing facility the heads were processed according to standard commercial procedure the day after harvest. Overnight storage was at 4$^{o}$C.

This processing of iceberg lettuce involves trimming, shredding, washing / sanitisation and drying with centrifugal force before sealing into non-permeable, plastic bags which were flushed with nitrogen gas to reduce the oxygen content to less than 10%. Bags were kept at 6$^{o}$C for four days to replicate the conditions experienced in the type of refrigeration used in retail stores. After this period daily sampling took place, with three bags from each variety being assessed every day to determine changes in quality over time.

For each bag, carbon dioxide and oxygen levels were recorded and then seven aspects of quality were rated: visual appearance, crispiness, odour, taste, damage, consistency and overall freshness. For each category a number between 1 and 5 were assigned where 5 indicates excellent quality and 1 signifies an unacceptable level of quality. The scores for the seven attributes were summed to give an overall quality rating out of 35 and this was then averaged for the three bags. The product's shelf-life was determined as the time taken for the average rating to reach 12.5 or less.

Field Trial – Cos Lettuce

Field trials were also carried out for Cos lettuce, using the Cyclone variety, transplanted on the 27th of April 2005 at a site in Gatton. The trial design was the same as that used for iceberg lettuce except that trickle irrigation was used and plants were grown in four rows on beds with 2m centres. As with the Iceberg trial at each harvest, two replicates of 12 plants each were sampled from each of the three plots. Outer leaves were removed to duplicate the trimming in a commercial harvesting operation and each head was then weighed.

For this particular season for Iceberg, 54 days after transplant was found to be the optimal time for commercial harvesting of this planting. Trimmed weight, core length and shelf-life was measured at this time (as per the iceberg lettuce trial protocol) as well as at harvests conducted 5 days earlier and then at 6 and 14 days after commercial harvesting.

Shelf Life Assessment – Cos Lettuce

Processing of Cos lettuce as a fresh-cut salad requires the same methodology as described for iceberg lettuce with the exception of the type of cut. Cos lettuce is subjected to random slicing rather than shredding, resulting in varying rectangular shapes, in the order of 30-50mm in width. This leaf material is packaged with various condiment sachets and sold as a Caesar salad mix.

Bags were kept at 6$^{o}$C for four days to replicate the conditions experienced in the type of refrigeration used in retail stores. After this period daily sampling took place, with three bags from each variety being assessed every day to determine changes in quality over time. The quality assessment scale was the same as that which was described earlier for Iceberg lettuce.

## *Results and Conclusions*

## *2.1 Results for Iceberg Lettuce*

The first iceberg lettuce trial (transplanted on the 26th April 2005) showed a significant yield increase in all varieties, for plants harvested at 62 days after transplant, rather than 56 days after transplant (Figure 2.1). There was a significant difference between varieties with the greatest yield increase seen in the varieties Titanic and Patagonia compared to Cartagenas. Patagonia and Titanic are winter vanguard types and they are most suited to a July/Aug harvest date as reported here. Cartagenas in comparison is summer Salenus/Vanguard type and is more suited to a May/Jun harvest. For Caratgenas 56 days may have been the harvest optimum as the core length did not increase with the later harvest date.  Caratgenus is also bolting resistant which could have helped reduce the rate of core growth. The results show that Patagonia had the greatest yield increase with the smallest increase in core length. Titanic was the industry standard however data from this work has shown the benefits of Patagonia as the variety to plant at this time.

Figure 2.2 shows the comparative increase in core length. The processing specification for core length is less than 75mm. If the core length is greater than 75 mm then the shipment is rejected. Increases in core length can be associated with bolting and the emphasis has been on breeding bolting resistant varieties to reduce the problem.

The shelf life data showed no significant differences in the quality of the different varieties or harvest dates (data not shown).

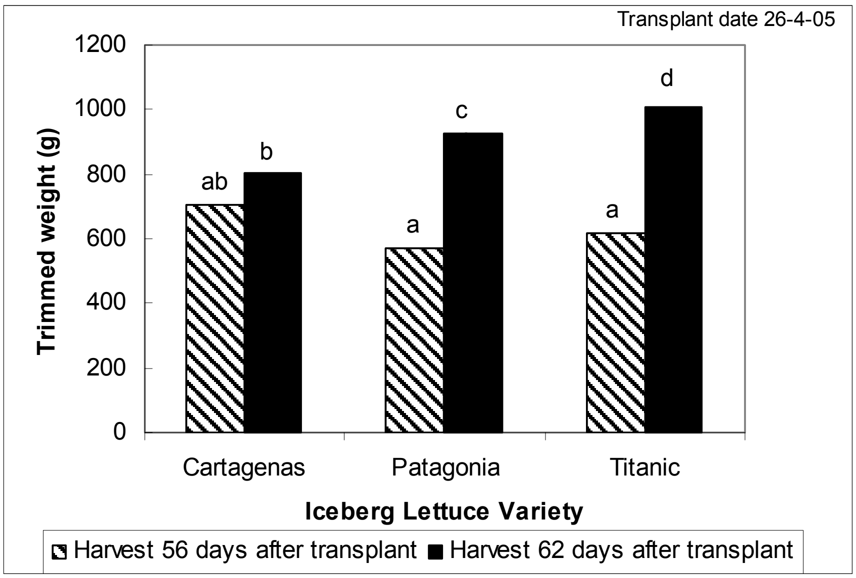



Figure 2.1. The effect of delaying the harvest date of lettuce by one week on the trimmed head weight of three varieties of Iceberg lettuce planted on the 26-4-05.

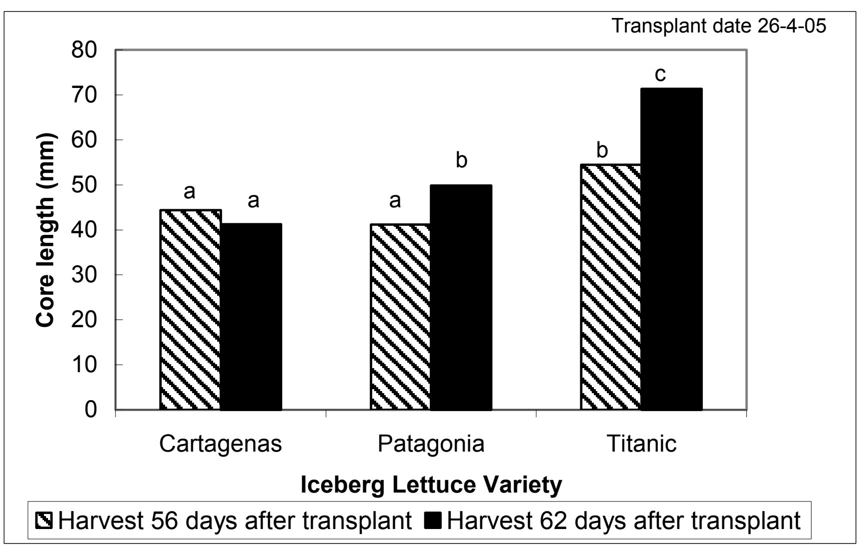



Figure 2.2. The effect of delaying the harvest date of lettuce by one week on the core length of three varieties of Iceberg lettuce planted on the 26-4-05.

The results from the second iceberg lettuce trial (transplanted on the 18th May 2005) also showed that the head weight of Patagonia and Titanic lettuce could be significantly increased by delaying the harvest for 7 days (Figure 2.3), and the core length for both varieties at the later harvest was within the processing specification (Figure 2.4). Again in this trial there was no effect on shelf-life (data not shown). The shelf-life remained constant at 11 days for both varieties, whether harvested at 68 or 75 days after transplant.

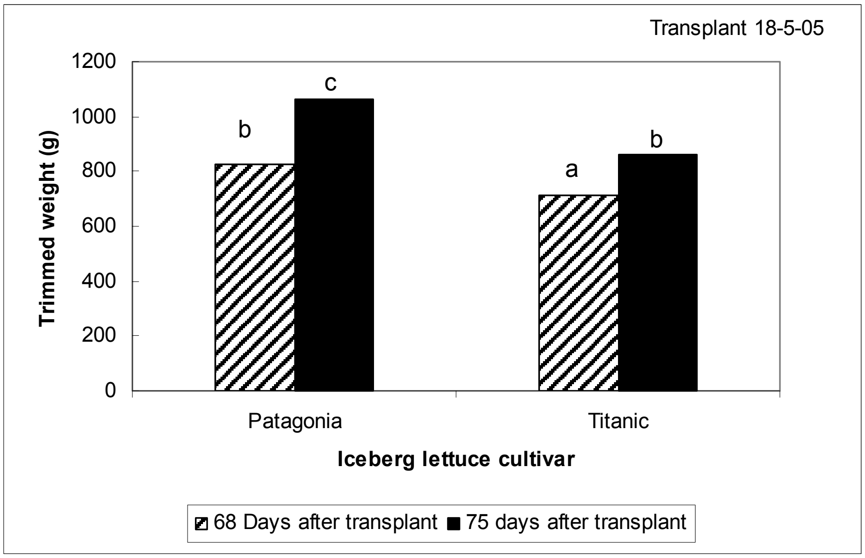



Figure 2.3. The effect of delaying the harvest date of lettuce by one week on the trimmed head weight of two varieties of Iceberg lettuce planted on the 18-5-2005.

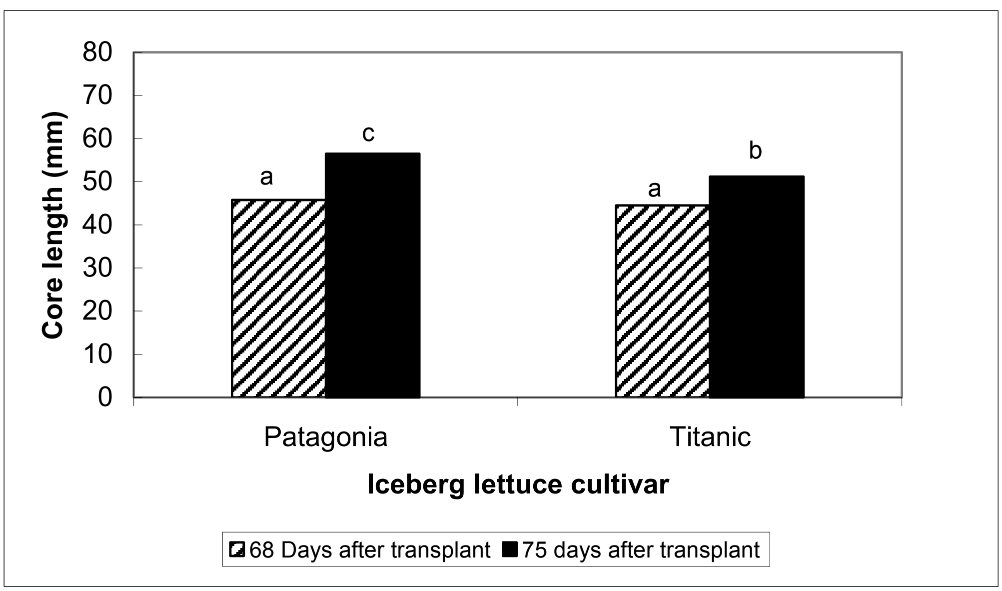



Figure 2.4. The effect of delaying the harvest date of lettuce by one week on the core length of two varieties of Iceberg lettuce planted on the 18-5-2005..

## 2.2 Results for Cos Lettuce

The results showed that Cos lettuce (cv. Cyclone) also benefited from an extended growing period, as the yield was seen to progressively increase with each harvest (Figure 2.5). The core length also increased with later harvest dates with the harvest at 69 days after transplanting being 90 mm and well above the processing specification. The average core length of 65mm, found in the previous harvest (61 days after transplanting) is acceptable. Therefore, it is the third harvest which has generated the maximum yield possible within specified quality for fresh-cut lettuce.

There were no significant differences between the shelf life of the four harvest times. Although the first and last harvests fall below the point of product failure (below dotted line Fig 2.6) earlier than the other two harvests. The quality rating for material harvested at 54 days after transplanting (typical of commercial practice) was the last to become unsaleable (Figure 2.7).

The shelf-life data confirms that the third harvest produced the best compromise of yield and quality. The first and last harvests had the shortest shelf-life. There was only a 0.6 day difference between the shelf-life periods for the second and third harvests (Figure 2.6). The shelf-life period of 11 days for fresh-cut salad manufactured from raw material from the third harvest, is greater than the shelf-life assigned to commercial products of this type which is currently 9 days.

The shelf life experiments produced very variable data and so this trend would have to be confirmed with further work.

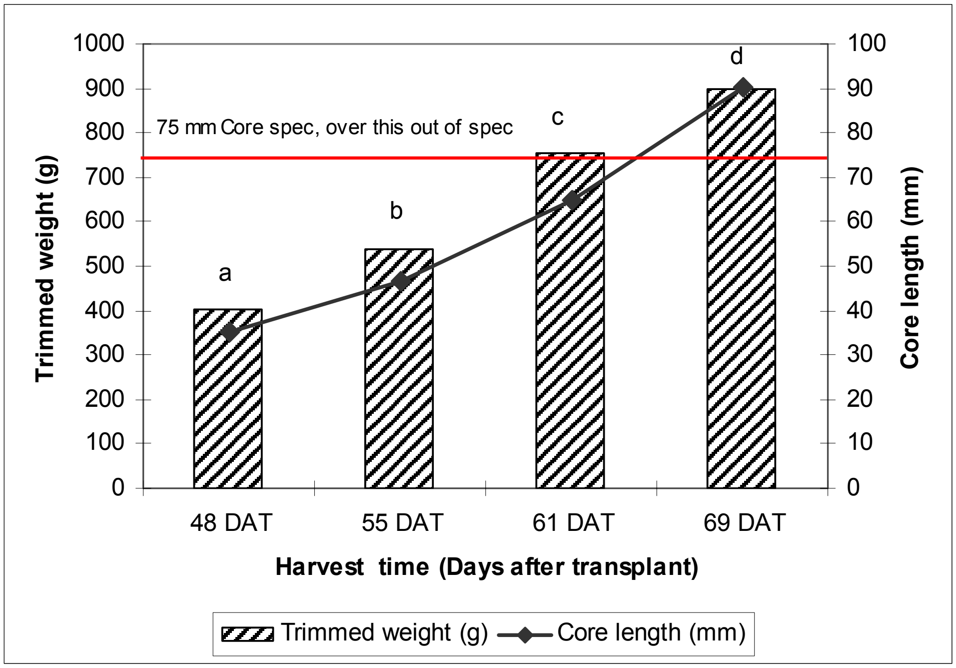



Figure 2.5. The effect of delaying the harvest date of Cos lettuce (cv Cyclone) transplanted on the 27-4-05 on the trimmed head weight and the comparative core length.

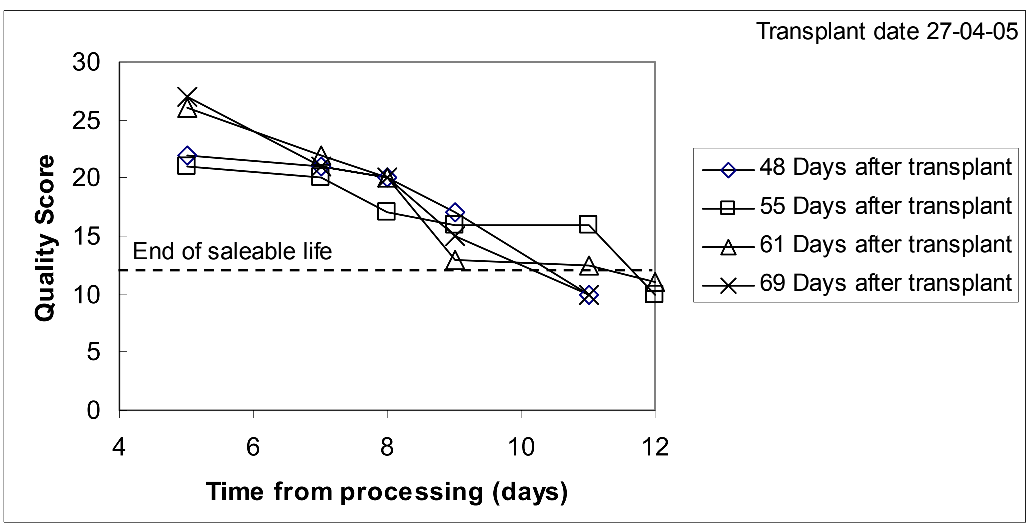



Figure 2.6. The effect of delaying the harvest date of Cos lettuce (cv Cyclone) transplanted on the 27-4-05 on the shelf life of the processed product.

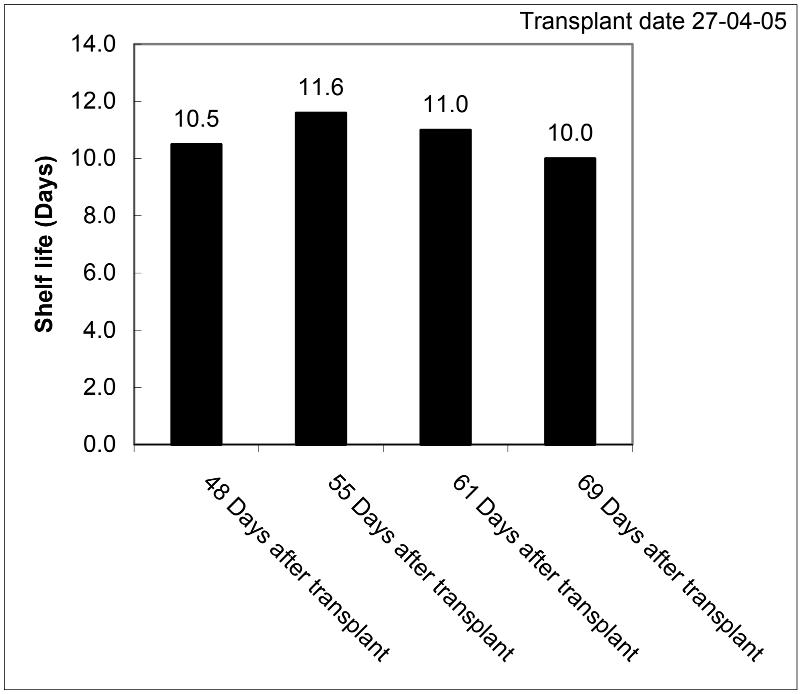



Figure 2.7. The effect of delaying the harvest date of Cos lettuce (cv Cyclone) transplanted on the 27-4-05 on the days to failure (unsaleable product).

## *2.3 Conclusions*

This work has shown that considerable yield gains are possible in both Iceberg and Cos lettuce, through extension of the growing by harvesting later than the current commercial practice. The trials in Gatton in 2005 demonstrated how yields can be increased in this region and time of year without significant detriment to lettuce processing quality. This change in production practice is best suited to cooler periods in the season when growing conditions are optimal to avoid the issue of bolting. The results showed that yield increases as high as 60% could be obtained for Iceberg lettuce (cv. Titanic transplanted 26-04-05) and a 35% increase in Cos lettuce (cv Cyclone transplanted 27-4-05).

There was no impact on shelf-life when iceberg lettuce was grown for an extra seven days and the average core length in the plants from the later harvest, was well within the specification for lettuce processed as fresh-cut salads.

This research showed that commercial yield could be significantly increased without compromising, for iceberg and Cos lettuce if the harvest time was delayed by 6-7 days relative to the current commercial practice. These findings are specific to the conditions experienced during these trials and research encompassing a range of regions, seasonal timing and varieties is required to verify a broader application.

# 3. Postharvest Management

Maximising shelf life of fresh cut lettuce is important because it can improve eating quality and increase flexibility in the production process by allowing for storage of product in response to peaks and troughs in demand (Titley 2000). Key factors for postharvest shelf life include rapid cooling after harvest and the delivery of a cool product to the factory, a processing line that minimises the physical injury to the product during processing, good packaging and a consistent cold chain from the factory to the consumer.

For processed lettuce it is common practice to store lettuce heads at 4 $^{o}$C for up to 5 days prior to processing to handle supply interruptions. Pre-processing storage of intact iceberg or romaine lettuce heads at 5 $^{o}$C for 7 or 14 days has been found to negatively affected overall visual quality and leaf edge browning in Cos lettuce (Lopez-Galvez, Saltveit et al. 1996). Any temperature abuse through the supply chain will have a detrimental affect on product quality.

It is also common practice to trim lettuce prior to shredding. The normal trimming in Cos is to remove about 30% of the weight of the heads prior to processing. This level of trimming leaves some dark green leaf materials and possible some damaged leaf material which breaks down more quickly than the lighter coloured leaves further in toward the heart (Kim, Luo et al. 2005). Removing more of these outer leaves may increase shelf life because the tissue will be physiologically younger (Nobile, Baiano et al. 2006).

Another important factor is the type of packaging used for the product. For fresh cut lettuce a sealed plastic bag is used which is flushed with nitrogen to reduce the rate of browning. In some situations the presence of condensation in the bag can have a negative effect on quality. Condensation causes solutes from the cut surface to leak out and this provides an ideal environment for bacteria growth. Bacteria contribute the soft breakdown of the tissue in the package. Ideally excess moisture should be removed during drying to minimise this problem.

In these experiments, two levels of trimming, two storage regimes, two packaging types, two processing methods and a temperature abuse scenario are evaluated. The experiments were done separately as factorial experiment was impossible to score for shelf life.

**Preparation of minimally processed lettuce**
(from Cantwell and Suslow, 2002)

1. High quality raw product. For example, lettuce from first harvest results in better quality, over mature lettuce browns more after cutting
2. Cool raw product before transport to factory particularly if field heat is high and transport distances or delays are long. Vacuum cooling is best for leafy vegetables.
3. Use strict sanitation procedures
4. Minimise mechanical damage using sharp knives
5. Rinse and sanitise cut surfaces
6. Dry to remove excess water. Forced-air tunnels over the conveyor line are better for delicate products.
7. Package with an appropriate atmosphere

8. Scrupulous control of product temperature at 0° to 5° C during storage, transportation and handling

## *Methodology*

Cos (Romaine) lettuce Lactuca sativa L (cv. Cosmic or Cyclone) were harvested from commercial farms in the Toowoomba, 80km from Brisbane, Australia, cooled to 2.5°C using vacuum cooling and transported in a refrigerated truck as whole heads to the processing plant in Brisbane.

Trimming and Storage Trial

The lettuce was stored in the coolroom in 30L commercial plastic crates at 4°C until next morning, or for 5 d. Immediately prior to processing, the lettuce heads were trimmed to either 55% or 70% (normal trim) of initial fresh weight. The heads were then processed commercially. This involved shredding, 3 washes, drying using a commercial spin dryer and packing into MAP bags and flushing with nitrogen gas.

Moisture reduction in the bags

The lettuce was processed as described earlier. For these experiments the contents of each bag was weighed after manual drying with absorbent paper towel. The comparison of the initial weights allowed an estimate of leaf-surface moisture to be calculated. The average value was found to be 11g of moisture per bag after normal commercial processing.

Sachets containing silica gel were placed into bags to absorb some of the moisture during storage. Each sachet could absorb approximately 11g of moisture and was similar in weight and dimensions as one of the condiment sachets that are normally included in the bag. Product shelf-life was evaluated and compared to that of control bags, containing material that was processed and packaged during the same production run.

Temperature abuse trial

The effect of temperature experienced between harvesting and processing was examined over two trials using Cos lettuce harvested in Toowoomba. The first of these trials was performed during the 2004-2005 season. Harvested lettuce was subject to one of four temperature treatments: Immediate vacuum-cooling, immediate forced-air cooling, exposure to ambient temperature for two hours before vacuum-cooling or exposure to ambient temperature for four hours before vacuum-cooling. All vacuum-cooled treatments were placed into a forced-air cold room directly after vacuum-cooling.

All material was then transported to the factory in a refrigerated truck and processed under commercial conditions. The shelf-life was determined for each treatment as described below. The experiment was repeated during the 2005-2006 season with an additional treatment: exposure to ambient temperature for six hours before vacuum-cooling.

Effect of the Translicer on Shelf life

As a means of assessing the impact of automated slicing on lettuce leaf quality, a number of fresh-cut salad bags were produced using manual slicing of lettuce material. This material by-passed the automated process used for slicing lettuce leaves in normal, commercial production. A number of control bags were taken from this same production run, containing material that had been sliced using the typical method.

Level of trimming was investigated again in this experiment within both slicing treatments. Retail bags of salad were produced using trim levels which yielded either 55% or 76% of the initial consignment. Shelf-life was determined for all four treatments as described below.

<u>Shelf life and Quality Evaluation for all Trials</u>

All bags were stored at 7$^{o}$C after processing as this was the commercial practice for quality evaluation.

The bags from all experiments were assessed for quality 4, 6, 7, 8, 10, 11, 12 and 13 d after processing by  turning out the contents of the bag and rating for the following characteristics on a 1-5 scale where 1=worst and 5=best: visual; crispiness; odour; taste; damage; consistency; and, freshness. These rating were then summed for each assessment to give a total score out of 35. Shelf life was defined as the number of days taken for the total score to fall below 13. Gas composition ($O_2$ and $CO_2$ of the bags were also measured at each assessment. ANOVAs were carried out in the summed score data, and each treatment was replicated 3 times (n=3).

## *Results*

### 3.1 The Effect of Trimming and Postharvest Storage of Raw Material

The results showed that storing the unprocessed heads for 5 days prior to processing resulted in a reduction in the quality score by 22-31% at the first assessment (day 4) compared to processing heads within 24 hours of harvest (Fig. 3.1). The harder trimmed lettuce (55%) was able to maintain close to initial quality until day 8 whereas the normal trimmed lettuce (70%) was declining in quality from day 4 in the fresh processed lettuce and earlier in the stored lettuce (Fig. 3.1).

Once the lettuce quality started to decline, it seemed to be programmed on that track, and this may mean that shelf life assessment protocols could be developed with less assessment points, but which were aimed to identify the beginning of the decline in quality and the rate of change.  It may be possible to model this pattern of decline.

When the two components of the experiment, trimming and pre-processing storage are considered separately, the harder trimming results in processed lettuce maintaining close to maximum score until 8 days after processing, whereas the current commercial trim to 70% of pre-trimmed weight starts do decline in quality after 4 days (Fig. 3.2). This is significant because most processed product would have been consumed by day 8, but not by day 4, meaning that consumers are likely to experience a better quality product if the lettuce is trimmed to 55% compared to 70% of initial weight.

The effect of storing lettuce for 5 days prior to processing results in a reduction in overall score of about 28% (10 score units). Quality then declines over time from there at the same rate irrespective of storage time (Fig. 3.3). This means that storing heads reduces the starting quality by about 28% compared to using fresh heads for processing.

The combined effects of pre-processing storage and the level of trimming resulted in a shelf life of 13 days for freshly processed heads trimmed to 55% of initial weight. Shelf life was reduced to 10.3 days be either storing unprocessed heads for 5 days or trimming to only 70% of initial weight. Storing heads for 5 days then trimming to only 70% of initial weight resulted in a shelf life on only 8.0 days, a reduction in life of 5 days compared to harder trimming of fresh heads (Figure 3.4).

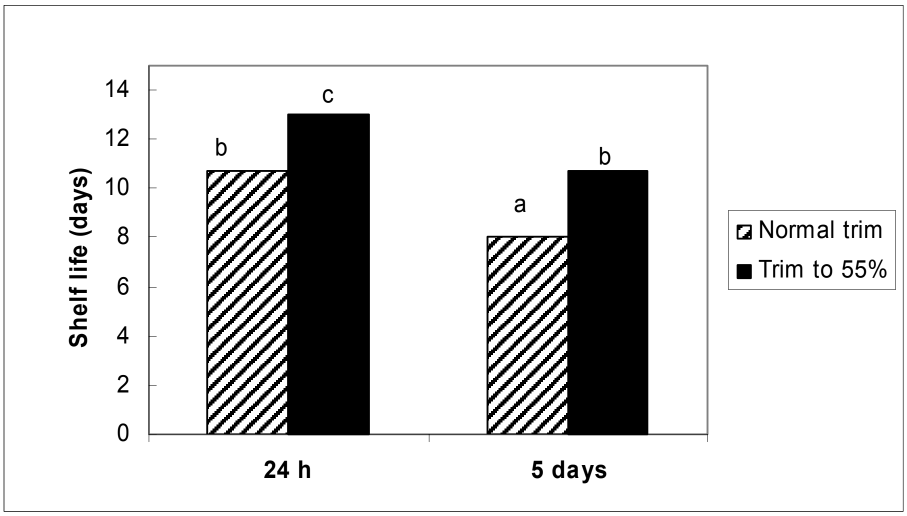



Figure 3.1. The Effect of Trimming and Postharvest Storage Period on Cos Shelf Life. Lettuce was processed within 24 h of harvest or after 5 d and trimmed to either 55% or 70% of initial weight. Means with the same letter are not significantly different (P<0.05).

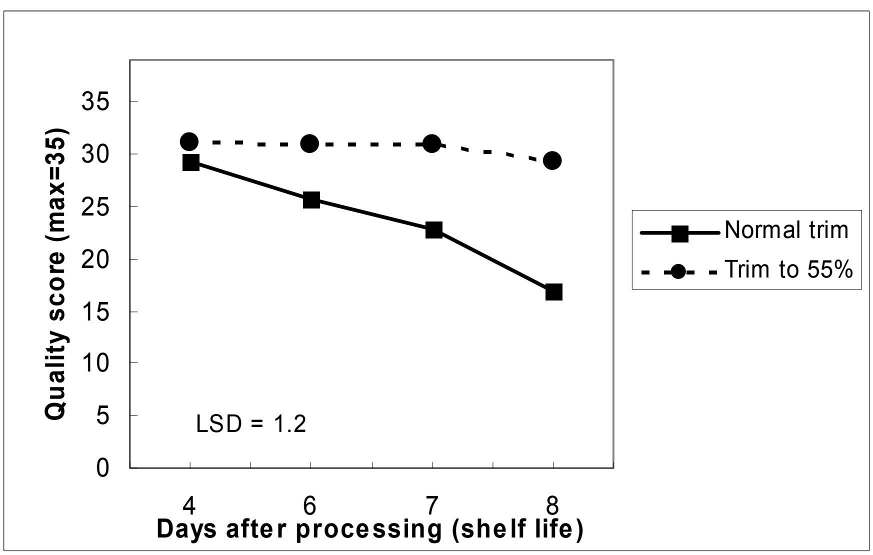



Figure 3.2. The Effect of Trimming Magnitude on the Declining Postharvest Quality of Cos Lettuce. Lettuce was trimmed to either 55% or 70% of initial weight.

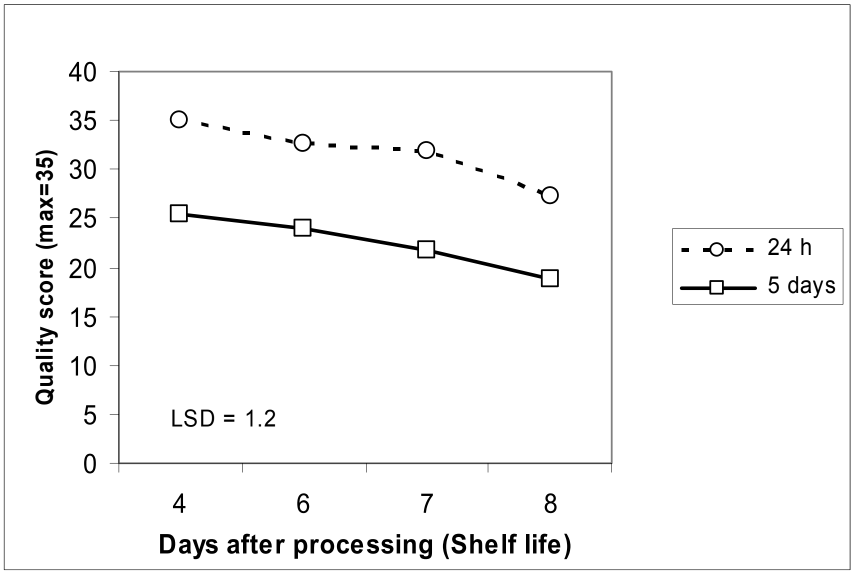



Figure 3.3. The Effect of Raw Material Storage Period on the Declining Postharvest Quality of Cos Lettuce. Lettuce was processed within 24 h of harvest or after 5 d.

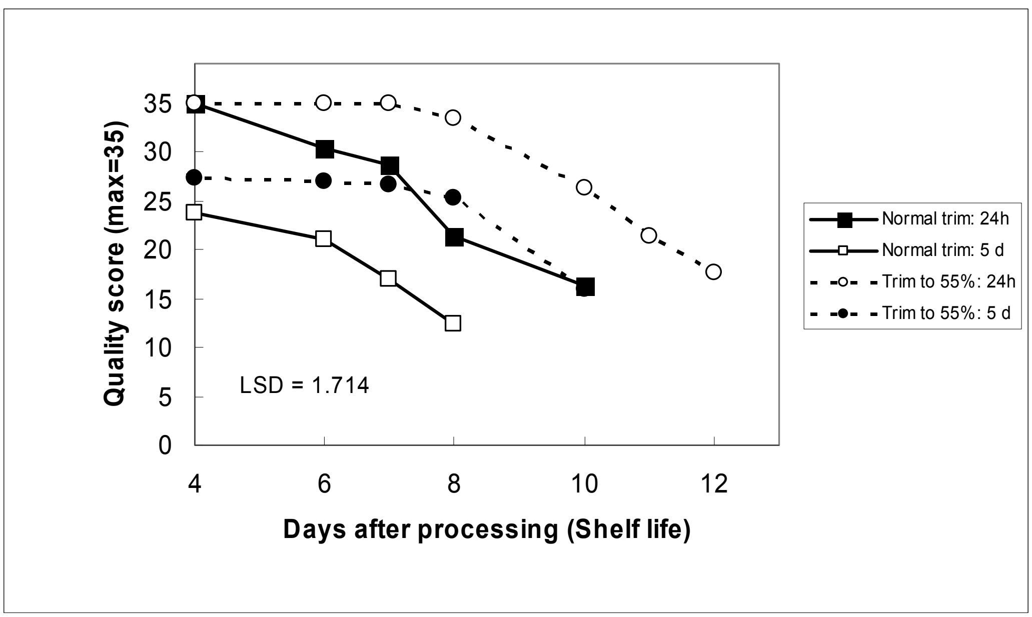



Figure 3.4. The Effect of Trimming and Postharvest Storage of Raw Material. Lettuce was processed within 24 h of harvest or after 5 d and trimmed to either 55% or 70% of initial weight

Conclusion

- The results showed that storing the unprocessed heads for 5 days prior to processing resulted in a reduction in the quality by 22-31% Fig 3.1.
- The harder trimmed lettuce (55%) was able to maintain close to initial quality until day 8 whereas the normal trimmed lettuce (70%) was declining in quality from day 4.
- Once the lettuce quality started to decline, it seemed to be programmed on that track, and this may mean that shelf life assessment protocols could be developed with less assessment points, but which were aimed to identify the beginning of the decline in quality and the rate of change.
- The effect of storing lettuce for 5 days prior to processing results in a reduction in overall score of about 28% (10 score units).
- Storing heads reduces the starting quality by about 28% compared to using fresh heads for processing.
- Storing heads for 5 days then trimming to only 70% of initial weight resulted in a shelf life on only 8.0 days, a reduction in life of 5 days compared to harder trimming of fresh heads.

## 3.2 The Effect of Moisture Reduction on the Quality of Processed Cos Lettuce

The results show that having an absorbent sachet in the bag increased the shelf life of the product by about 3 days (Figure 3.5). This is an important result as it demonstrates the fact that the current processing can be improved.

Excess moisture in the bag reduces the shelf life of the product by encouraging the leakage of solutes from the cut surfaces into the water droplets on the surface. These water droplets, rich in nutrients become ideal sites for bacterial growth. The bacteria cause the soft breakdown of the tissue which makes the product unsaleable.

Conclusion

The best solution to this problem would be to have a more effective drying system to minimise the water in the bag at the time of packing. Adding sachets to the bags creates health and safety issues for processing.

If sachets were the only option available then more work is needed to optimise this system. The sachet used in this trial had a small surface area and ideally this would be increased and the absorbent could also be improved by using a different salt that dried the air to the equilibrium relative humidity of the processed product to prevent dehydration.

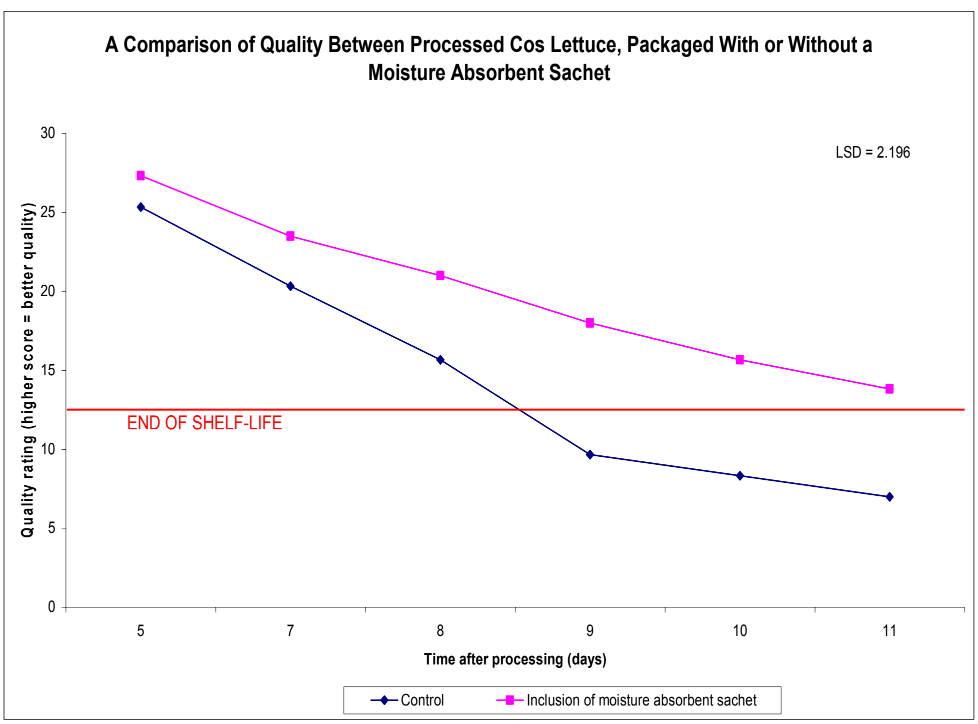



Figure 3.5. A comparison of the quality of processed Cos lettuce packaged with or without a moisture absorbent sachet.

## 3.3 The Effect of Temperature Abuse of Raw Material on the Quality of Processed Cos Lettuce

Fresh-cut products generally have a higher respiration rate than the corresponding intact products. Higher respiration rates indicate a more active metabolism and usually a faster deterioration rate. The most important aspect of postharvest handling of fresh cut products is refrigeration at as close to 0°C as possible.

Storage temperature affects the respiration rate and the rate of deterioration of the product with products stored at temperatures close to 0°C having the longest shelf life. Any period of temperature abuse will shorten the shelf life of the product (Cantwell and Suslow, 2002).

One option for cooling lettuce is vacuum cooling. Vacuum cooling works by evaporating water from the product at very low atmospheric pressures. Products that easily release water cool in 20 to 30 minutes.

Vegetables that have a high surface to mass ratio and that release water easily, such as leafy vegetables are best suited to this method of cooling. Vacuum cooling causes about 1% product weight loss for each 6°C of cooling. Some coolers can spray water on the surface of the product before or during cooling to reduce the level of weight loss. The water must be disinfected and in some cases the rapid release of the vacuum can cause some vegetables to have a water-soaked appearance.

Results and Discussion

Figure 3.6 and 3.7 show the effect of delays in cooling in the field on shelf life. In both experiments product that was vacuum cooled within half an hour of harvest had the best shelf life, although the benefit was most significant in the 2005 experiment. Product that was forced air cooled did not perform as well as product that was vacuum cooled.

Vacuum cooling 6 hours after harvest did not improve shelf life compared to the forced air cooled samples. The important result here is the demonstration of the benefits of best practice handling methods. Lettuce must be vacuum cooled with in half an hour of harvest to ensure maximum shelf life.

The shelf life results for the 2006 trial were not as clear as for the 2005 trial. The reason for this is shown in Figure 3.8. This figure shows the temperature changes during transit and there has been a temperature abuse event during transport to the factory. The temperature in the truck rose to a maximum of 15°C for 2 hours and it took another 4 hours for the product to be re-cooled to 5°C. This is not an uncommon event and these results show how detrimental breaks in the cool chain to product quality.

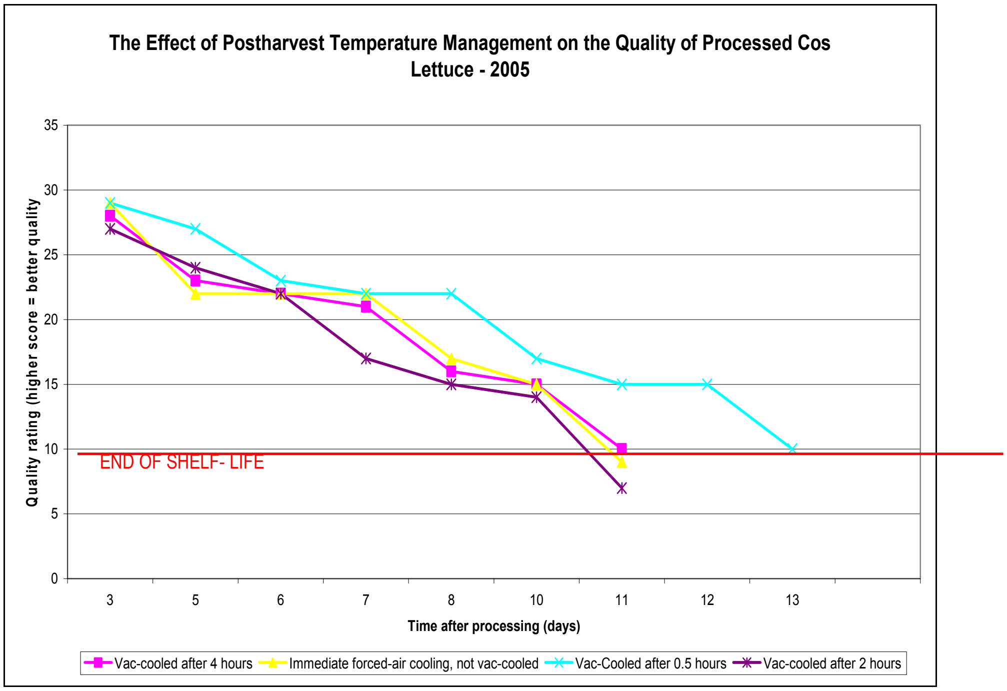



Figure 3.6. The effect of postharvest temperature management on the quality of processed Cos lettuce 2005.

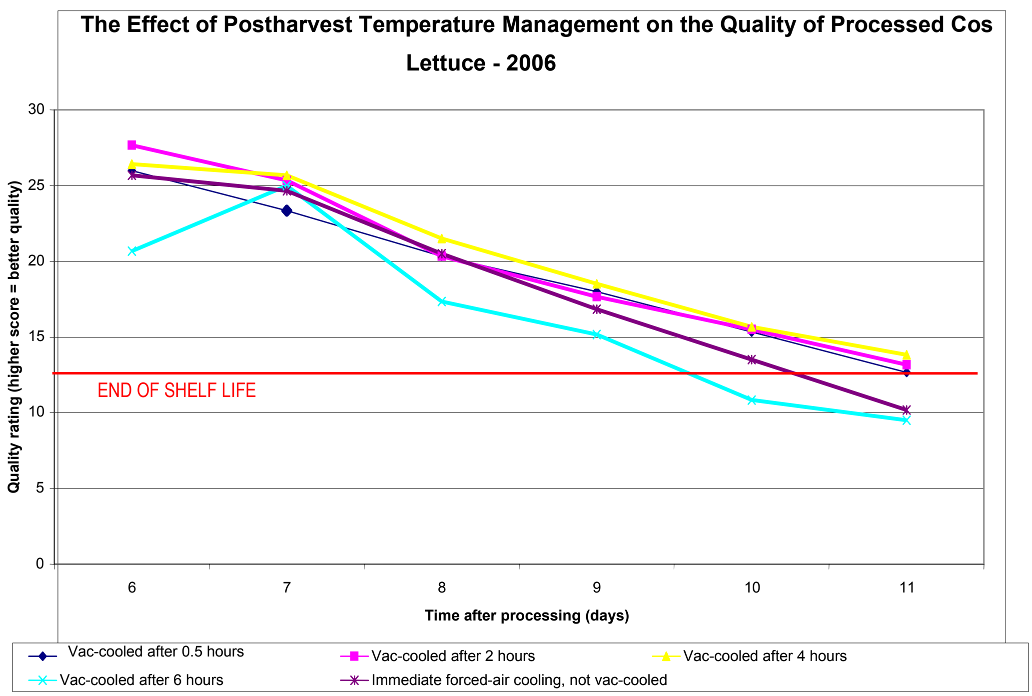



Figure 3.7. The effect of postharvest temperature management on the quality of processed Cos lettuce 2006.

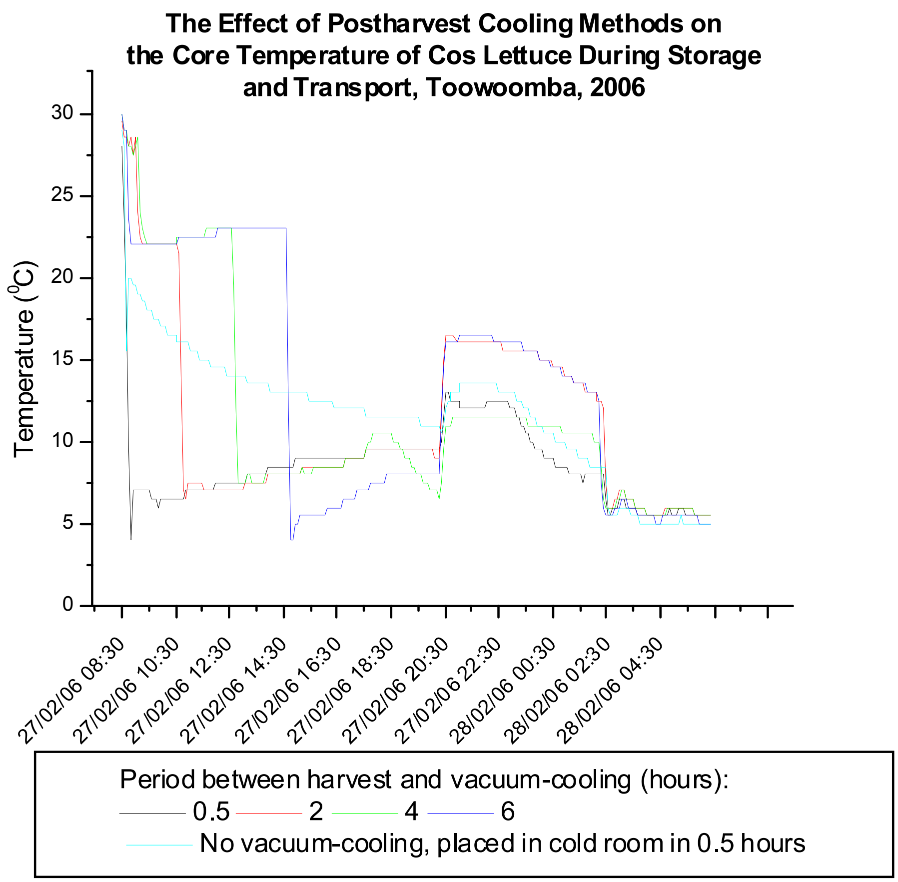



Figure 3.8: The effect of different methods of postharvest cooling on the core temperature of Cos lettuce during storage and transport, Toowoomba 2006.

## 3.4 The Effect of Physical Impact in Processing on Lettuce Quality

Physical damage or wounding has been shown to increase the respiration rate and ethylene production of fresh products within minutes. This causes an associated increase in the rate of reactions responsible for browning and changes in colour. These factors all combine to cause a reduction in the quality and shelf life of the product.

The degree of processing (number of cuts) and the quality of the equipment (sharpness of the blades) significantly affect the wound response. More cuts and blunter equipment increase the response and increase the rate of deterioration (Cantwell and Suslow, 2002).

This experiment aimed to determine if the translicer used in this processing line was causing too much wounding and therefore having an impact on reducing the shelf life of the product.

<u>Results and Discussion</u>

The results showed that the translicer was not having a significant impact on the shelf life of the product compared to manual cutting with a sharp knife (Figure 3.9). The results in relation to the degree of trimming support those from the previous section. Trimming lettuce to 55% prior to processing significantly improves the shelf life of the processed product.

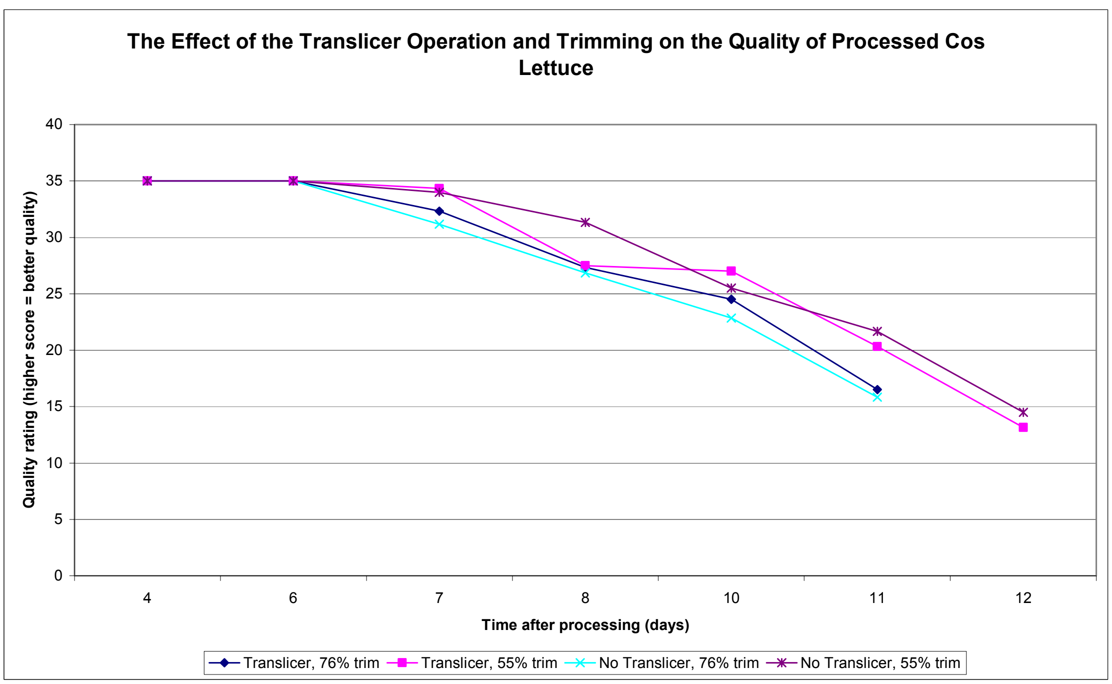



Figure 3.9. The effect of the Translicer operation and trimming on the quality of processed Cos lettuce.

# 4. Variety Selection

## *Introduction*

The tendency with Cos varieties is to go away from the Parris Island Cos types which have been the main industry benchmark for years where the variety Verdi dominated with now seeing the emergence of three quarter closing Cos which have the tendency to be slower growing and hence slower bolting and also a little bit tolerant of tip burn.

Prior to the turn of the century the Australian lettuce industry was dominated by varieties bred by Dan Trimboli of Yates (now part of Enze Zaden). However, as we've move into the new century two other seed companies have become very active in supplying material; those being Rijk Zwaan and Enze Zaden itself. This has meant that we now have a more diverse range of varieties that now cope with the fluctuating high and low temperatures which are characteristic of the east coast of Australia during the year round supply of lettuce. We do not have the luxury in Australia of having a Salinas type climate available at our disposal and we have to cope with daily maximums of 35 – 40$^{o}$ and greater and minimum temperatures in the summer as low as 7 – 10$^{o}$. This along with the day length at the time causes major stress on a developing lettuce plant.

With the arrival of the lettuce aphid on mainland Australia in May 2005 growers are now evaluated where Nasanovia resistant varieties fit into their schedule. Our experience to date is that Nas varieties are maturing 4 – 5 days earlier than their non-Nas equivalents which has to be accounted for in transplanting by variety schedule.

Selection of the most appropriate variety is one of the most important decisions commercial lettuce growers must make each season.

Some factors to be considered before adopting a new variety should include:

- Yield of trimmed heart/head at least equivalent or greater than current variety
- Disease and insect pest resistance (especially downy mildew and Nasanovia) is the most economic and effective means of disease and insect pest management.
- Adaptability of new varieties under Australian conditions up to 30$^{o}$C diurnal range especially during the transitional periods.
- Tolerance to physiological disorders such as tipburn, rib discolouration, bolting and russetting.
- Marketable hearts must exhibit acceptable horticultural traits.
- Maturity range you need to mange your season, supply your market, and reduce the risk of weather related crop failures.

## *General Methodology*

A comprehensive evaluation of all available iceberg and Cos lettuce varieties, with specific reference to their value to the fresh-cut salad industry, was a major undertaking of the project. For each of the regions, the project aimed to identify the most profitable variety to grow for early, mid-season and late plantings. Varietal performance was principally judged in terms of yield, shelf-life, heart quality and susceptibility to pests and disorders.

A large number of potential varieties were screened in small-plot trials in year one, based on yield and quality at harvest, with only the best performers evaluated further in the following years. The subsequent testing involved much fewer varieties, planted over larger plots, subject to the grower's standard, cultural practices. In this way, performance within a commercial production system could be rated. In this second stage of screening, shelf-life, as well as yield and heart dimensions, was measured for all varieties.

An emphasis was placed on resistance to lettuce aphid (*Nasonovia ribis-nigri*) in trial variety selection, as the Australian lettuce industry was concerned about the potential introduction of this pest in the early stages of the project. The lettuce aphid reached Australia during the second summer season of the project, with considerable impact on the industry.

A comprehensive evaluation of both iceberg and Cos lettuce varieties was undertaken in each of the four growing regions over the three year period. In the first year, replicated, small plot trials were used to assess a large number of varieties, enabling an initial screening of all varieties suitable for a given planting date, in a given region.

Two replicates were used in a complete, randomised block design, although an additional two replicates per variety were sometimes included with a higher level of basal fertiliser, to simultaneously investigate nutritional effects. Each block was allocated to a separate bed with plots consisting of 7m lengths of bed. All test varieties, plus one or two varieties considered as industry standards for the particular planting date, were transplanted as seedlings in 3 rows per bed at an intra-row spacing of 330mm and with 1.5m between bed centres. Some growers transplanted 4 rows of plants on beds with 2m between centres – both planting configurations result in the same planting density.

Trials were planted four or five times over the growing season to record variety performance relative to planting date. The trial area was always situated within a commercial planting and trial plants were grown to maturity subject to commercial, cultural practice. At maturity, a sample of 12 plants was taken from the centre of each plot so that a total of 24 heads were assessed for each variety. Each lettuce head was severed from its root system at ground level and two heads from each sample were weighed without trimming, to provide a measure of total, above-ground biomass.

All lettuce heads were then trimmed (as per commercial field practice) and weighed before being bisected longitudinally. Core length and butt diameter were measured, as well as heart diameter for iceberg lettuce and heart length and breadth for Cos lettuce. Any diseases or disorders were noted and rated for severity. At this stage, the evaluations were based on field performance and no shelf-life assessment was undertaken.

A second round of evaluation was conducted in East Gippsland (summer production) and Gatton (winter production) in the following season. This consisted of commercial-scale trials of two to three test varieties as well as one industry standard, incorporated into grower production, to reflect variety performance relative to grower practice. The varieties displaying the best yields and growth habit from the screening trials were selected for these larger scale trials. Trial varieties that had only been made available for testing after the first season were also considered, provided they possessed characteristics which gave them the potential to replace the standard variety in a given planting, in a given region.

The plots for the second year trials consisted of 100-150 seedlings, transplanted with the previously described plant spacing, without replication. Five plantings were assessed for both iceberg and Cos lettuce, through the winter season in Gatton. In East Gippsland, varieties were examined every one to two weeks. Field performance was assessed by sampling two replicates of 12 plants each from the centre of each plot and taking the same measurements used for screening trials.

Shelf-life was also assessed using 6 standard produce cartons (of 12 heads each) for each variety. Plants were cut, trimmed, packed into cartons and then vacuum-cooled to 2.5˚C within one hour of harvesting. Trial material was taken to a processing plant the same evening via refrigerated transport and kept at 4˚C until processing, which was typically within 24 hours.

The raw trial material was trimmed and sliced as per the usual manufacture of fresh-cut salads, with iceberg lettuce shredded and Cos lettuce subject to random slicing to produce leaf sections suitable for Caesar salad. After washing, sanitisation and spin-drying, leaf material was sealed in non-permeable plastic bags used for retail sale and flushed with nitrogen gas. Processed Cos lettuce was packaged with Caesar salad condiments. All treatments were stored at 6˚C to simulate the conditions experienced in the open-style refrigeration of supermarkets.

On the fifth day after production, three bags from each treatment were assessed for postharvest quality. Oxygen and carbon dioxide content was measured for each bag and seven quality aspects (visual appearance, crispiness, odour, taste, damage, consistency and overall freshness) were rated from 1 to 5, with a score of 5 denoting excellence and 1 indicating failure as a product suitable for sale. A total of the seven scores was used as an overall quality rating out of 35.

Assessments were also carried out on the seventh day after production and then every day until the end of a treatment's shelf-life, determined as the day on which the average overall score reached 12.5 or less.

## *Specific Crop Production Details*

The crop scheduling models were developed using data collected from at least 5 plantings per season per year in each district. Specifically in 2004 (year 1) in Queensland there were 4 plantings and in 2005 (year 2) there were 5 plantings. In Victoria in 2004 there were 5 plantings although one was washed out with rain. In 2005 data was collected from a commercial block and there were weekly harvests from December to May from commercial blocks. In Toowoomba in 2004 there were 4 plantings (although one was wiped out with a cyclone) and in

2005 a commercial block was used and there was a weekly data collection from January through to April. The planting details for each district are in Table 4.1.

Table 4.1. Planting details for the Crop Scheduling Trials 2004 and 2005.

| | GATTON (Trickle) | LOWOOD (Sprinkler) | LINDENOW (Sprinkler) | BOISDALE (Lateral move) | WEMEN (Fixed sprinkler) | TOOWOOMBA (Movable sprinkler) |
|---|---|---|---|---|---|---|
| Tractor Wheel Centres (Mm) | 2000 | 1500 | 1500 | 1500 | 1500 | |
| Rows/Bed | 4 | 3 | 3 | 3 | 3 | 4 |
| Plant Spacing (Mm) | 400-300 | 375mm | 350 | 375 | 400 | |
| Plants Hectare | 50,000 - 55,600 | 53,400 | 57,143 | 53,400 | | |

## Experimental Design

The trials were all transplanted, and the varieties were grown in a tray by themselves, not as mixed seedlings. The trays ranged from 144 cells per tray up to 198 cells per tray. The configuration of the plots in the fields were sown at a rate of 60 – 80 plants per plot irrespective of whether there were 3 or 4 rows. The experimental harvests were taken from the middle 1 or 2 rows leaving a buffer at either end. All varieties were sown in two completely randomised blocks per sowing date per district. Measurements were made on 12 individual heads per treatment per block. The measurements taken are described below.

## Measurements

The following measurements were taken from the 12 heads harvested for each treatment in each block:

- Untrimmed weight of 2 heads
- Head weights (trimmed to OneHarvest specification) for all heads
- Butt diameter in millimetres of all heads
- Heart size in millimeters (taken across the head, putting the measurements right on top of the core) of all heads
- Core size in millimetres(the length of the core from the butt to the tip of the core) of all heads
- Density ratio (trimmed head weight divided by the heart size) of all heads

A quality assessment of the variety was also done which head size, vigour, shape, colour, variety type, external tipburn, internal tipburn, diseases (if any), disorders (if any) and overall comment of the suitability of the variety. For Cos types all of the above was assessed as well as an addition measurement which was called heart length which was the total length of the trimmed heart from the butt to the tip of the closed in heart. During the second and third years of the project where we did semi-commercial plantings of 'best bet' varieties, sample harvests of 2 lots of 12 plants were taken using the same criteria for consistency.

## *Results*

This project illustrated that Iceberg lettuce varieties in Australia can be classified in into five major types (Table 4.2).

Table 4.2. Classification of Iceberg lettuce varieties.

| Type | Commercial Varieties 2006 |
|---|---|
| Summer Vanguard<br>(Heat) | Raider, 'Sahara Devil Sun, Aztec Sun, Invader |
| Salinas<br>(Main Season) | Casino, Target, Silverado, Foxtrot Nr,<br>Cartagenas Nr, Barcelona Nr |
| Salinas (2/3) x Vanguard (1/3)<br>(Intermediate) | Patagonia, Titanic, Lily Nr, Kong Nr |
| El Toro<br>(Cool Season) | Greenway, Marksman, Gatlin |
| Winter Vanguard | Winguard |

## 4.1 East Gippsland – Screening Trials – Iceberg

Figures 4.1 and 4.2 show a summary of yield and core length data, respectively, for selected varieties across all trials. In Figure 4.1, the yield differences seen between months, represents the typical trend of yield variation which can be observed in a growing season in this region. The early and late season harvests (October and April) produced the highest yields and the mid-season results in November were comparatively poor. For each harvest, trial varieties were found with yields that matched or exceeded the standard varieties.

Cartagenas proved to be a variety of note, for mid and late-season production. Comparatively high yields were displayed throughout January and February, while retaining cores lengths considered favourable for processing. In the April harvest, Cartagenas performance diminished to some degree, relative to standard varieties. Average core length, however, was found to be in the order of 15mm less than standard varieties at this time. It can also be seen in Figures 4.1 and 4.2 that, although LE258 yielded well in January and February, this variety also possessed core lengths that were significantly greater than all other varieties shown, in these months.

All the trial results for the early season (October) harvest of iceberg lettuce in East Gippsland screening trials are shown in Appendix 3. Varieties considered as standard for production in this region are indicated with black bars on these and the following graphs. Of these standard varieties, Frigo yielded significantly less than Patagonia and Marksman. Univert, Grenadier, Legend and Monument all produced yields that were equal to or greater than Patagonia and Marksman, allowing for standard error. Core lengths for these varieties were all within the acceptable specification for processing.

In the November harvest, only three varieties (LE254B, LE167 and LE052 Denver) produced yields comparable to that of standard variety Patagonia (Appendix 3). Of these, LE167 displayed the greatest performance, in terms of yield and core length. It produced the highest yield (although not significantly different to LE052 Denver) and the shortest core length (Appendix 3).

Silverado was used a standard variety to benchmark trial variety performance in the January harvest. The highest yields were obtained by 3SX 149 and 45-82, which has now been commercially named Cartagenas (Appendix 3). LE218 and LE258 yields were also relatively high and not significantly different to these yields. LE258, however, displayed one of the largest core lengths in this trial (Appendix 3) although still within processing specification. LE218 and 45-82 showed superior value in this trial, through a combination of relatively high yields and low core lengths. Silverado core length was significantly shorter than all four of these trial varieties.

3SX 149 performed well again in February, achieving the highest yield in this trial (Appendix 3). All other trial varieties displayed yields equal to or less than that of Silverado, used again as a commercial standard. Core lengths were greatest for LE258 and Liberty, although not considered excessive for processing quality (Appendix 3).

For the late season trial, harvested in April, commercial varieties Marksman, Patagonia and Frigo were used again as industry standard. None of the trial varieties achieved a higher yield than Marksman, which reached the highest yield of the three control varieties (Appendix 3). Only Barcelona, LE251 and TLE 4006 core lengths exceeded that of Marksman (Appendix 3). The cores in LE251 and TLE 4006 were significantly longer than in Barcelona and in a size range of potential rejection as a raw material for processing.

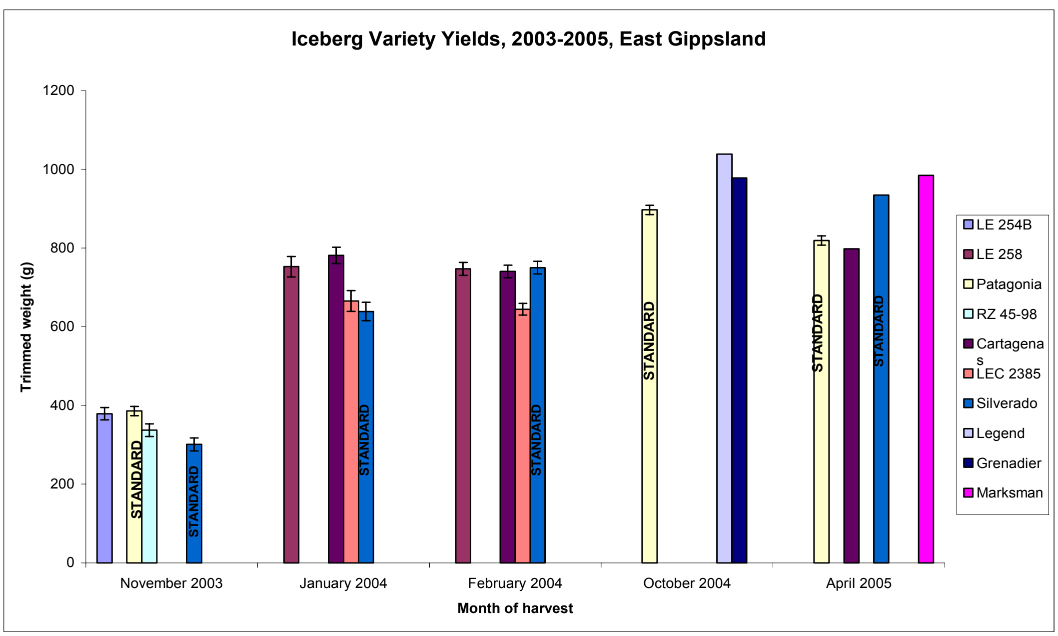



Figure 4.1. Iceberg variety trial yields East Gippsland 2003 – 2005.

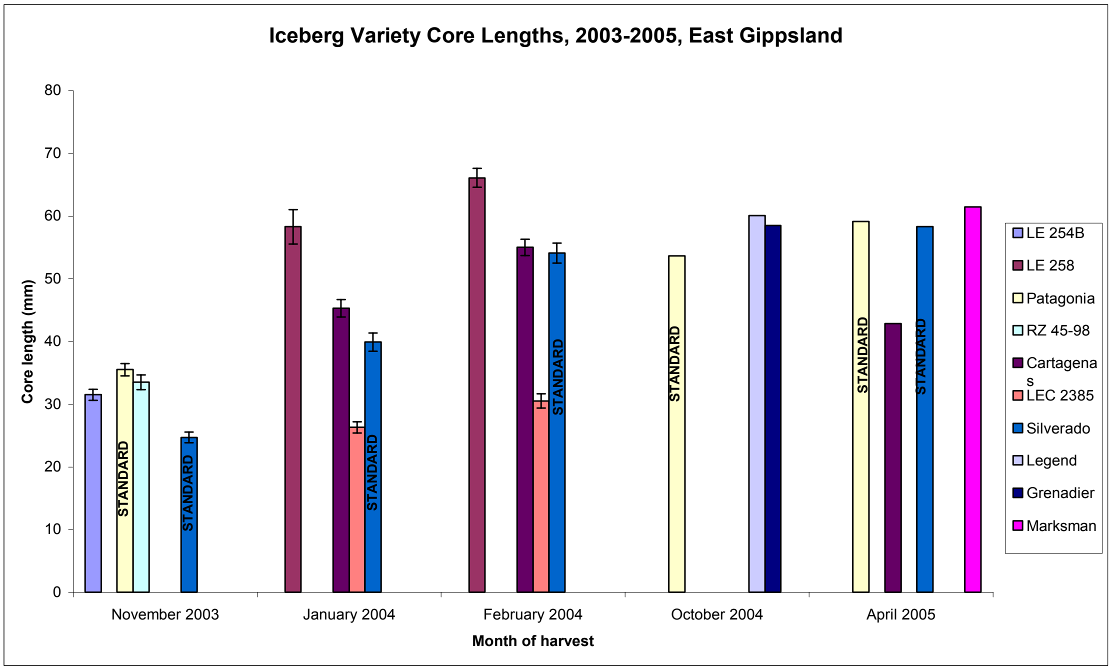


Figure 4.2. Iceberg Variety trail core length comparison East Gippsland, 2003 – 2005.

## 4.2 East Gippsland – Screening Trials – Cos

Figure 4.3 shows the overall yield performance of some key Cos lettuce varieties, across all trials. There is a general trend of decreasing yield as harvesting progresses from October into the warmer weather of November. Head weight then increases from mid-summer through to autumn. The relatively low core lengths measured during the warm weather of November through till January (Figure 4.4) corresponds with a shorter period of crop growth and lower yields.

The performance of Cyclone, relative to the full-size Verdi, as a standard reference, was greatest through spring and autumn. Cyclone yield remained between 83-86% of Verdi yield through spring and autumn but dropped to 63-64% through summer. Core length results for Cyclone display one of the advantages of this variety. In October, February and April, high yields are associated with core lengths above 70mm for all varieties except for Cyclone. Such core lengths are approaching (and in some cases exceeding) the acceptable limit for processing.

A comparison of Verdi yields with those of Challenger and LE250 reveals a stronger performance by the trial varieties in autumn. Verdi core length, however, remains equal to or less than those recorded for Challenger and LE250 throughout October, February and April, when these values are within the range of potential consignment rejection by a processor.

Cos lettuce small-plot trial results for an October harvest compared yield (Appendix 3) and core length (Appendix 3) for test varieties to the commercial standard variety Verdi (indicated by the shaded bar on the graphs).

The size difference between Paris Island Cos type varieties and Cyclone should be taken into account when reviewing the relative performance of Cyclone in this and all other Cos variety trials. A direct yield comparison cannot be made and the lower trimmed head weight measured for Cyclone, relative to Verdi, can be expected for a variety considered to have approximately 75% of the growth of a "full-size" variety. Cyclone displayed a short core which was significantly smaller than that of Verdi.

Saxon, another popular commercial selection for this time of year, produced a similar yield but with a significantly greater core length than Verdi. The highest yields were recorded for LE263, LE233 and LE236, however LE233 also developed an average core length which would typically result in consignment rejection by a fresh-cut salad manufacturer. Along with 41-41, LES3707 and LE196, core lengths in the order of 100mm were measured for this variety.

The trial harvested in November included both Verdi and Cosmic as commercial, standard varieties for this time. A number of varieties produced higher yields than both of these, including LE203, Cossack, Lucinda and SPS8348 (Appendix 3). Some of the varieties grown were not full-sized Cos varieties and, as expected, the trimmed head weights for these plants were the lowest recorded (Amadeus, Cosette). Cyclone, however, returned a yield that was similar to some full-sized Cos varieties and higher than that of Verdi, although less than the yield obtained by Cosmic.

The lowest observed core lengths were for the mini-Cos varieties (Amadeus and Cosette) and the control varieties Cosmic and Verdi, as well as third variety which is widely used for commercial production – Carinas (Appendix 3). The longest core, on average, was found in high-yielding variety Lucinda, although all varieties remained well within processing specification, as none of the average core lengths exceeded 60mm.

The January harvest of Cos lettuce showed less yield variation, relative to industry standard variety Verdi (Appendix 3). None of the trial varieties exceeded the yield of Verdi. Among the varieties that yielded significantly less than Verdi were commercially available Carinas and the smaller varieties Cyclone and Amadeus. Greater inter-variety differentiation was observed in the core length results (Appendix 3) although all averages indicated acceptable quality, at less than 70mm. Only Klamath and LE250 grew cores that were significantly greater than that of Verdi.

Yields obtained in February (Appendix 3) again showed relatively little variation, apart from those recorded for mid-size / mini Cos types. None of the test varieties were able to improve on the yield obtained by control variety Verdi, although trimmed head weights for LE200, LE250, 3SX411 and Cossack were not significantly different to this standard variety. Core length was considerably higher in this trial (Appendix 3) compared to the previous two harvests, with Verdi averaging 81mm. Only Klamath grew a longer core than Verdi.

The varieties with the lowest core lengths (Carinas, Apollo, Caesar, Cossack and LE236) were more acceptable for processing and therefore found to be very suitable for production at this time of year. Cossack, in particular, displayed the greatest yield (not significantly different to Verdi) as well as one of the lowest core lengths. The smaller Cos varieties that were tested achieved a predictably lower core length than Verdi, with the exception of Palace, which showed no significant difference.

The highest Cos lettuce yields of the 2003-2004 East Gippsland season were achieved in April. The highest yielding varieties (LE200, LE236, LE250, Lucinda, SVS6519619 and 3SX418) were all found to have average, trimmed head weights of more than 1kg (Appendix 3). Trimmed heads of all of these varieties weighed more, on average, than both Cosmic and Verdi (standard varieties) although relatively high variation within the LE250 sample resulted in the yield difference between this variety and Verdi being insignificant.

Of the high-yielding varieties, only LE250 and LE236 possessed an average core length of less than 80mm (Appendix 3). LE250 had the shortest core length of these, which was slightly greater than that of Cosmic but not significantly different to the core measurement for Verdi.

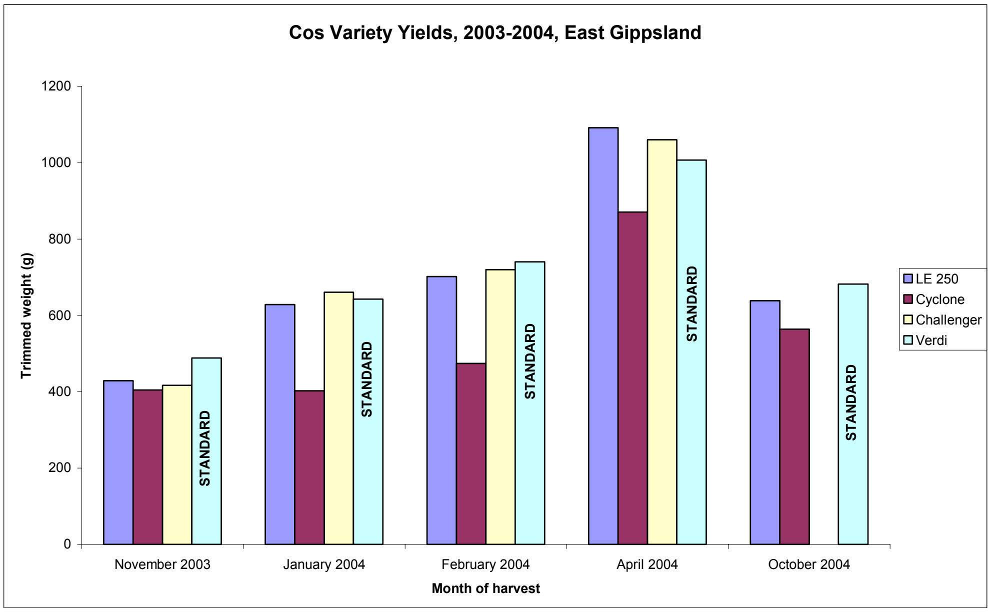



Figure 4.3. Cos lettuce variety trials East Gippsland 2003 – 2004.

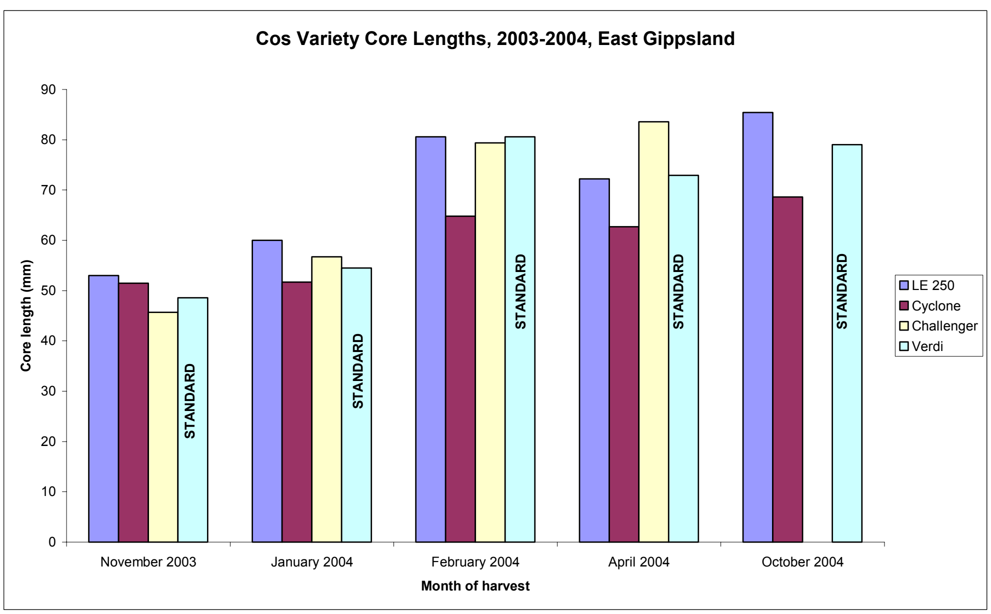



Figure 4.4. Comparison of the core length of the Cos Variety trial varieties East Gippsland2003 – 2004.

## 4.3 East Gippsland – Commercial Scale Trials – Iceberg

In Figure 4.5, a summarised yield comparison is presented for the iceberg lettuce varieties that showed potential industry value in the screening trials. In these larger scale trials, conducted within commercial production, Silverado and Marksman were used as standard varieties for comparison in December and Patagonia was referenced in April. In all other trials Silverado was considered the standard variety.

The most consistent yield performance, relative to control varieties, was seen in Cartagenas and Target. These varieties displayed yields that were equal to or greater than standards in the months of January, February and April and the December yield of Cartagenas was not significantly different to Silverado, although inferior to Marksman.

Rain events in January disrupted the activity of pre-emergent herbicides, resulting in patchy weed competition with lettuce harvested in March. These plants also experienced stress, brought about by dry, windy conditions. The highest yield obtained in March was for Barcelona, however these plants were bolting (as can be seen in the core lengths presented in Figure 26) and data generated in this month may not be indicative of long-term performance.

Average core length measurements (Figure 4.6) reveal a distinction between the leading varieties in yield performance – Cartagenas and Target. Target, on average, displayed a longer core than Cartagenas in March and had the greatest core length recorded in January. Core lengths for Cartagenas were equal to or less than those of standard varieties in all months and in December and March Cartagenas achieved the lowest average core length.

The head density calculated for Cartagenas was equal to that of a standard variety in all months except for March, when extrinsic factors may have influenced results, as explained previously (Figure 4.7). Target achieved the highest head density in January, however this was associated with an average core length of 95mm, which would result in rejection as raw material for fresh-cut salads. The importance of Cartagenas as a processing lettuce in this region is verified further with shelf-life data (Figure 4.8) which demonstrates shelf-life for Cartagenas, Eldorado and Ardinas exceeding that of standard varieties.

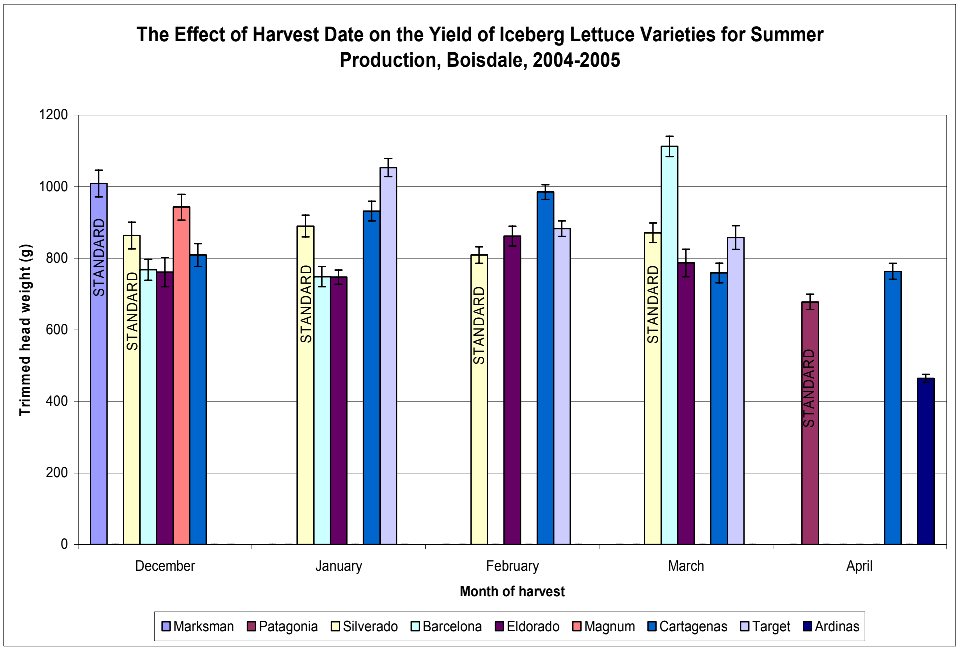



Figure 4.5. The effect of harvest date on the yield of Iceberg lettuce varieties summer production, Boisdale 2004 – 2005.

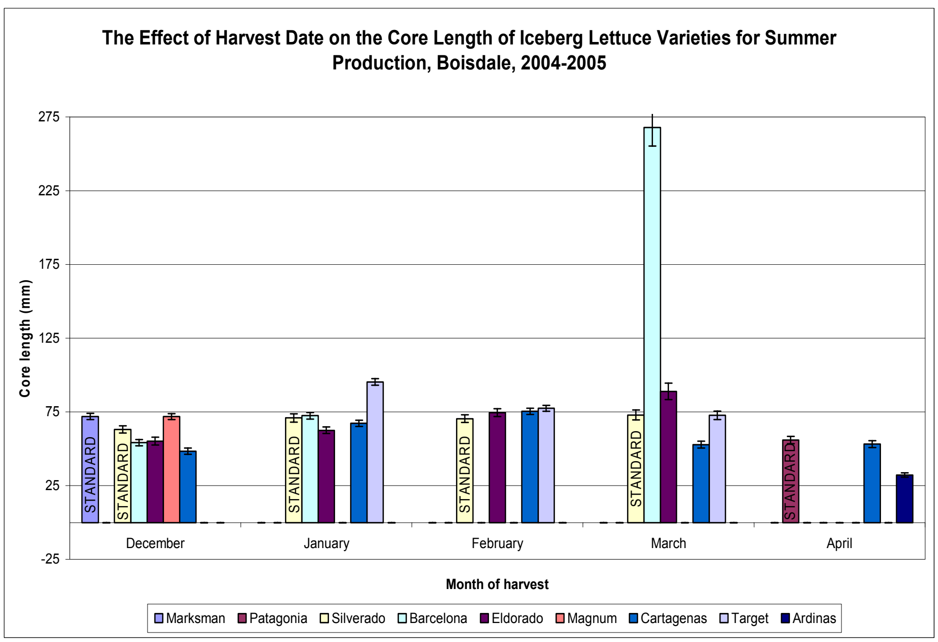



Figure 4.6. The effect of harvest date on yield of Iceberg lettuce varieties, summer production, Boisdale 2004 – 2005.

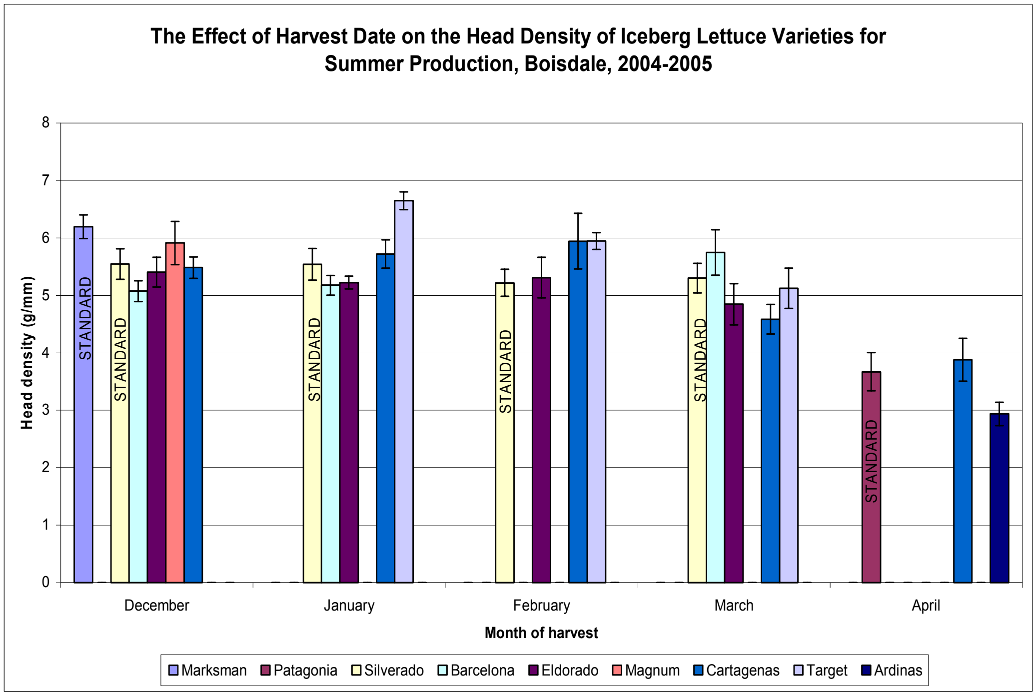



Figure 4.7. The effect of harvest date on the head density of Iceberg lettuce Varieties for summer production, Boisdale 2004 – 3005.

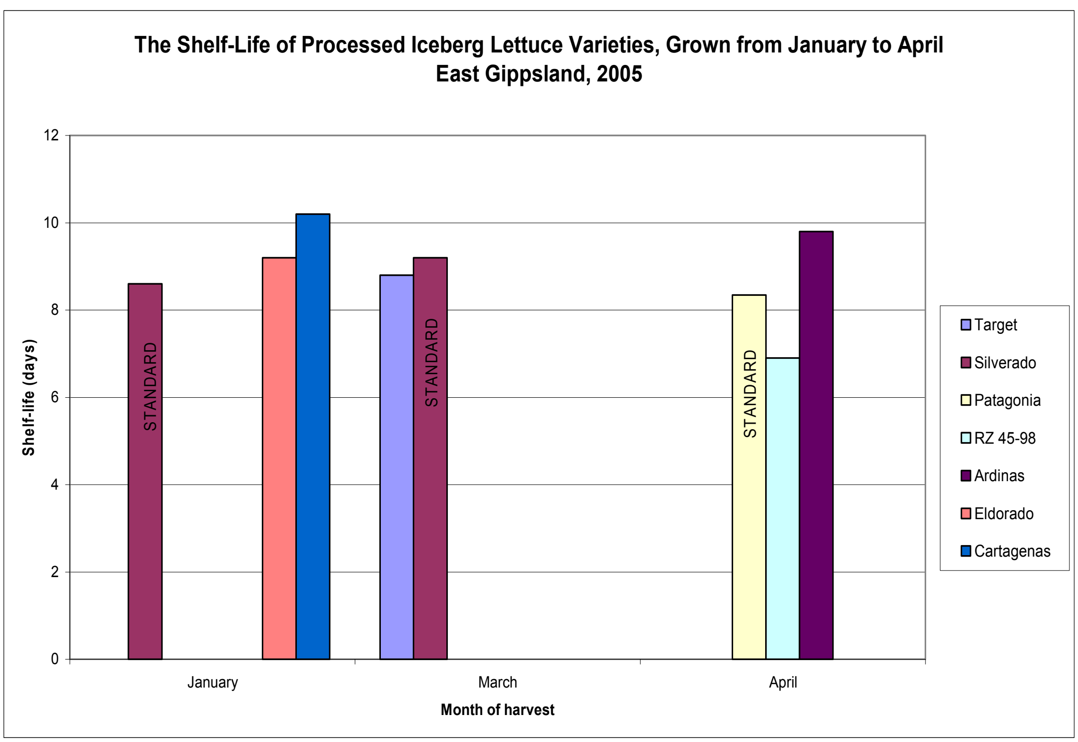



Figure 4.8. The shelf life of processed Iceberg lettuce varieties from January to April East Gippsland, 2005.

## 4.4 East Gippsland – Commercial Scale Trials – Cos

In Figure 4.9 the yields of commercially grown Cos lettuce are compared to standard varieties for East Gippsland. Cosmic is used by growers as a mid-season variety, Carinus is harvested in the autumn and Verdi is used in the transitional period between summer and autumn with some overlap with both Cosmic and Carinus.

The highest yield achieved each month belonged to one of the standard varieties, although these were not statistically different to the yields reached by Challenger in January or Shrek in March. Cyclone yields were consistent in following the trend generally observed in this region – declining to a minimum value in mid-summer and then climbing through to the end of the season. Although always significantly lower than the average yield of standard varieties, the smaller head size of Cyclone must be taken into account when interpreting yield results.

The use of Challenger through the summer months provided inconsistent core length results (Figure 4.10). In December, the average core length for Challenger was 80% of that obtained by Cosmic. In January and February however, Challenger core length was greater than that of Cosmic but not significantly different to that of Verdi. Cyclone cores were always significantly shorter than or not significantly different to those of standard varieties. Cyclone showed particular grower value in the February harvest. While the average Verdi core length was 78mm and verging on unacceptable processing quality, Cyclone cores measured only 61mm.

Shelf-life trials proved that Cyclone has postharvest quality that is comparable to the industry's standard varieties (Figure 4.11). In January, Cyclone displayed a similar shelf-life to that of Verdi and slightly less than that achieved by Cosmic (a difference of less than one day). Cyclone's shelf-life was greater than that of Verdi in March and equal to that of Carinus in April.

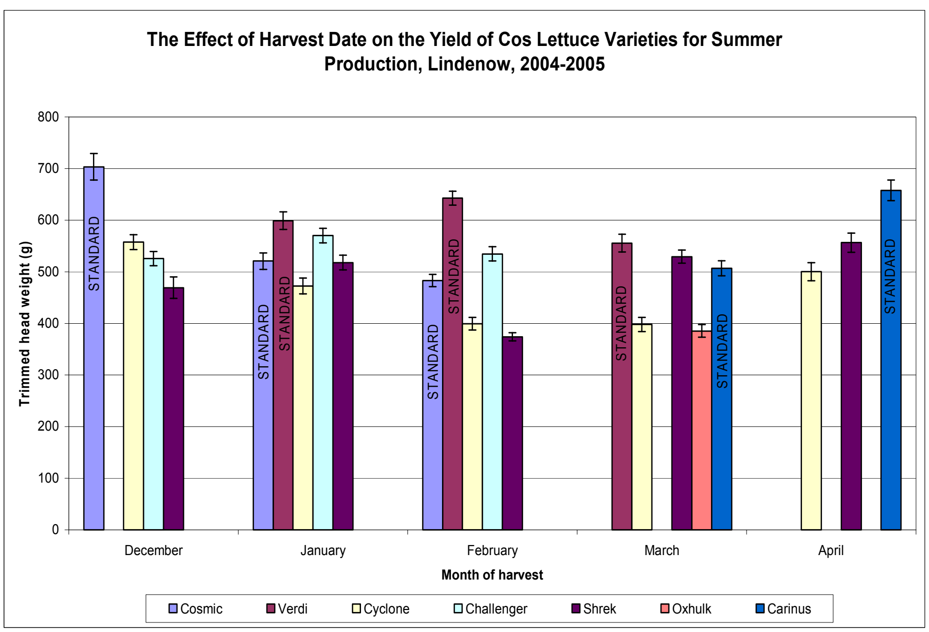



Figure 4.9. The effect of harvest date on the yield of Cos lettuce varieties for the summer production, Lindenow 2004 – 2005.

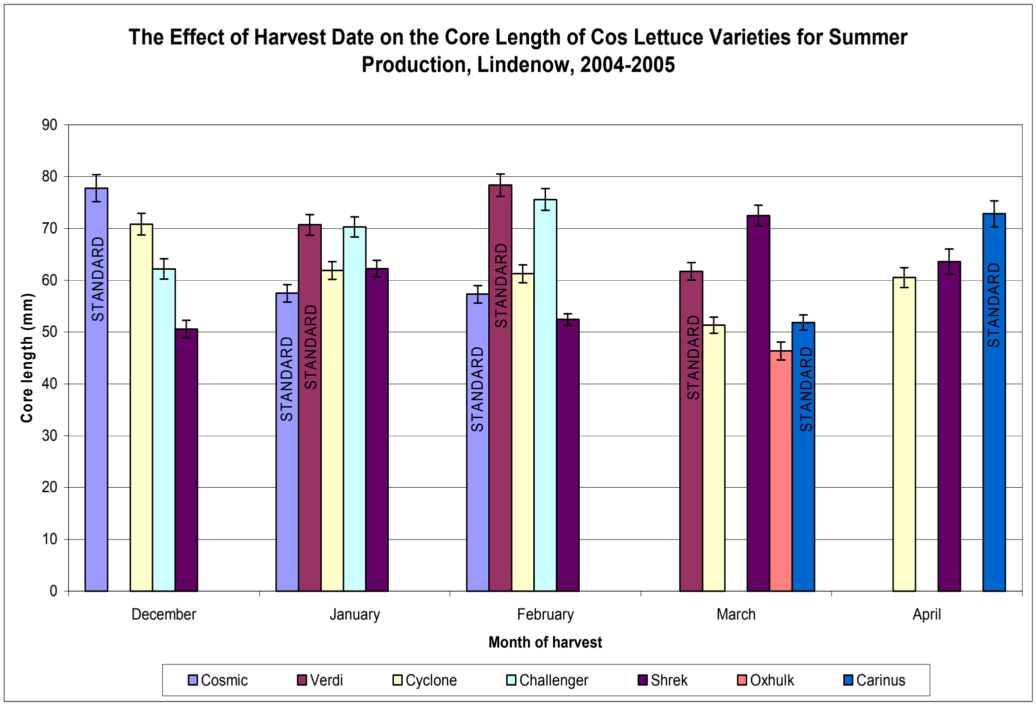



Figure 4.10. The effect of harvest date on the core length of Cos lettuce Varieties for the summer production Lindenow, 2004 - 2005

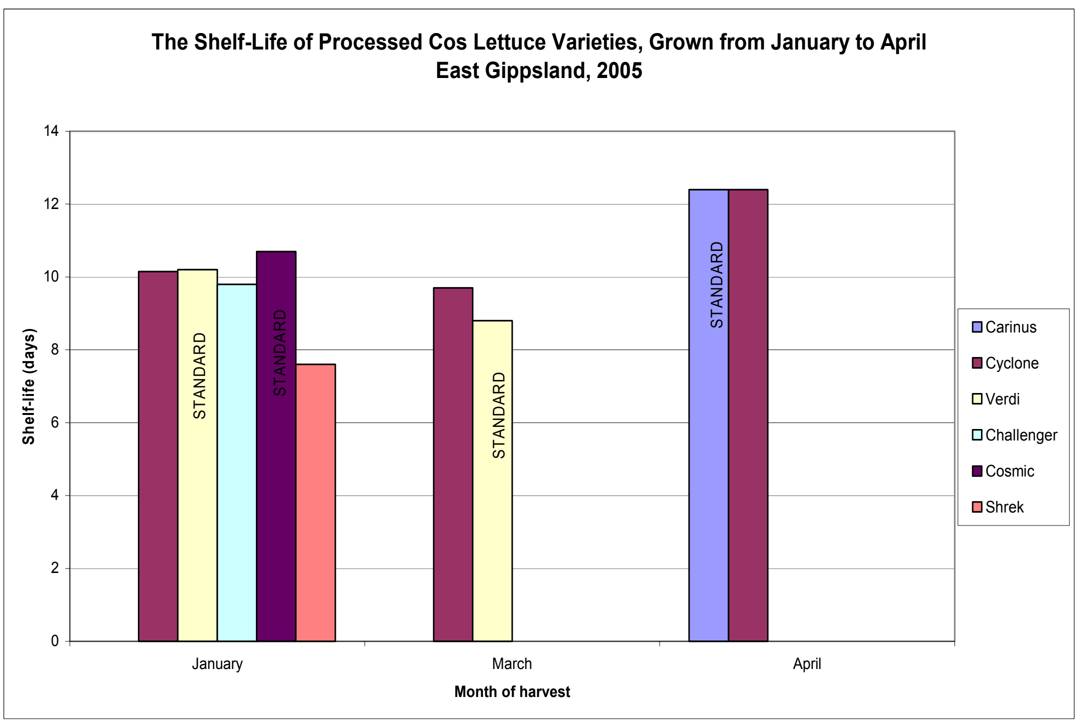



Figure 4.11. Shelf life of processed Cos lettuce varieties grown from January to April in East Gippsland, 2005

## 4.5 Toowoomba – Year One Screening Trials – Iceberg

Appendix 3 displays yield results for a large number of iceberg lettuce varieties screened for a November harvest in Toowoomba. In broad terms, three tiers of yield performance can be observed. A majority of tested varieties produced a yield within a range of approximately 400-550 g/trimmed head and fewer varieties reached an average trimmed head weight of approximately 550-700 g, including Raider and Seagreen (shown as standard varieties with black bars).

Only Patagonia displayed a yield that was significantly higher than the standard varieties, with an average head weight that was 27% greater than that of Seagreen and 42% greater than that of Raider. There was also some evidence to suggest that Patagonia's core length was similar to that of these standard varieties and in the order of 35-40mm (Appendix 3).

In this particular trial, core length measurement was not replicated and therefore the results displayed in Figure 4.13 are only an indication of varietal differences. The greatest core length recorded was for Lagunas, however none of these results exceeded 60mm and all observations therefore remained within specification for processing.

There was a substantial difference in the yields obtained by Seagreen and Raider in the second iceberg lettuce screening trial for Toowoomba, harvested in January (Appendix 3). For this time of year Raider displayed the highest yield, which was not significantly different to yields for EXP9145, Icon, Delta John and Liberty. Seagreen obtained one of the lowest yields in this trial, with only La Quinta and Gulf Stream producing significantly lower yields.

Icon, Delta John and Liberty all displayed relatively high core lengths (data not shown) were greater than both standard varieties and within a range of potential rejection as raw material for processing. Liberty was bolting at harvest with a core length of 104mm and only Badger's core was longer at 125mm. Patagonia, Brisbane and LE230 also developed cores which could be considered too long, at greater than 80mm.

EXP9145, however, exhibited a short core as well as a relatively high yield. At 38mm, this average core length was just 65% and 56% of the core lengths for Seagreen and Raider respectively. Only LEC2385's core was shorter.

The highest yield performance for iceberg lettuce harvested in March was by LEC2384, LE145, 3SX124 and Desert Queen, which all achieved greater yields than Seagreen (Appendix 3). LE145's yield result however, was marred by an excessive core length of 93mm (Appendix 3). The lowest yields recorded were for Gator and Gulf Stream, which were below that of Raider, the lower-yielding of the two standard varieties.

As well as LE145, a number of varieties in this trial produced unacceptable core lengths, including Gator, Mohawk and the commercial standard, Seagreen. A relatively low core length (59mm) was achieved by the second standard variety, Raider, with only LEC2385, 3SX122, Goblin, Sahara and Lucy Brown obtaining shorter cores.

## 4.6 Toowoomba – Year One Screening Trials – Cos

The earliest evaluation of Cos lettuce performance in the Toowoomba region involved the collection of observational data for 37 varieties harvested in November. Two replicates were used in the trial design, however only one head was sampled from each of the two plots grown for each variety.

Many of the varieties tested achieved a yield that was similar to that of standard variety Verdi (480 g/trimmed head) (Appendix 3). Cosmic, included as a second standard variety, attained a higher average trimmed head weight of 590 g. The highest yielding varieties, observed to produce yields that were similar to or higher than Cosmic, included Donatus, LE214, LE250, LE200, LE254, Lucinda and PRO1028. At 535 g/trimmed head, Cyclone produced a higher yield than a number of full-sized varieties, including Verdi.

Cosmic and Verdi core lengths were among the lowest recorded at 33mm (Appendix 3). Results indicate that none of the test varieties produced cores that were substantially shorter than these. None of the cores measured in this trial were greater than 60mm, suggesting that excessive core growth may not be an issue for the quality of these varieties at this time of the season.

Cyclone and Verdi shared the lowest yield for January (Appendix 3) however Cyclone displayed a core length that was 18% less than Verdi (Appendix 3). Cosmic trimmed heads were, on average, 35% heavier than those of Verdi or Cyclone, with an average core length of 71mm. Only Donatus obtained a yield that was significantly greater than that of Cosmic, although this was associated with a core length which was outside of the specification for fresh-cut salads (88mm). Lucinda, Dominator, LEO74, LE264, PRO1006, Klamath and 6519619 also produced core lengths that were greater than 80mm.

Lucinda and LE264 also revealed high core lengths in March (Appendix 3) along with LE203, LE239, Clemente, 3SX419 and 3SX420, which all exceeded 140mm. Crop stress resulting from local conditions caused the majority of trial varieties to grow cores that were longer than 100mm, including standards Cosmic and Verdi. Only the cores displayed by Quasar, LE236, Cyclone and Nero were less than 100mm.

Of these four varieties, Quasar obtained the highest yield (398g) which was not significantly different to the yield of either standard variety (Appendix 3). LE200, LEO74 and 6519619 were the three highest yielding varieties and were all significantly different to the control varieties4.7

## 4.7 Gatton – Year One Commercial Trials – Iceberg

Commercial-scale plots of iceberg lettuce test varieties were found to generate significantly higher yields than commercial standards throughout the Gatton season in 2004 (Figure 4.12). Cartagenas was the best performing early-season variety and Patagonia and Brisbane provided the highest yields for mid and late-season respectively.

Although the higher yields of the new varieties generally corresponded with higher core lengths (data not shown) this was not particularly relevant, as none of these varieties produced an average core length greater than 55mm. Patagonia shelf-life trials (data not shown) revealed that postharvest quality endurance was equal to that of the standard (Oxford) in July but approximately two days shorter than Titanic in August.

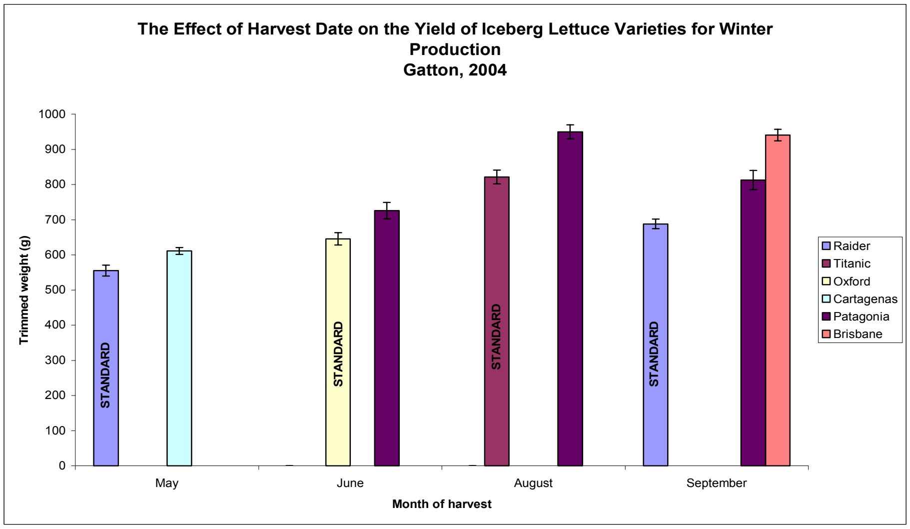



Figure 4.12 the effect of harvest date on the yield and production of iceberg lettuce varieties for winter production in Gatton, 2004.

## 4.8 Gatton – Year One Commercial Trials – Cos

In Figure 4.13 the yields of Cyclone are compared to standard Cos lettuce varieties during the first season in Gatton. Unfortunately, Cyclone was not available for harvest in the month of August. Cyclone, a smaller than standard variety, consistently displayed average head weights that were significantly lower than those of Outback or Regal. Advantageous characteristics can be seen in this variety, however, when relative core length measurements are considered (Figure 4.14).

Significant differences between average core lengths for Cyclone and standard varieties can be observed in May and July. Values shown for Cyclone (76mm and 67mm for these months respectively) can be considered much more acceptable for processing than the corresponding averages for standard varieties (87mm and 81mm). Such disparity may represent the difference between consignment acceptance and rejection in commercial reality.

Outback and Cyclone core lengths were not significantly different in September, however in this month, yields were also relatively similar. Figure 4.13 shows that yields increased progressively through the season with the difference between Cyclone and standard varieties diminishing from May to September. Cyclone head weight was 17% less than the standard variety for May in the first trial of the season and 11% less in the final trial in September.

The average shelf-life of Cyclone in June 2004 was found to be very similar to that of standard variety Regal with a difference of less than 12 hours (Data not shown).

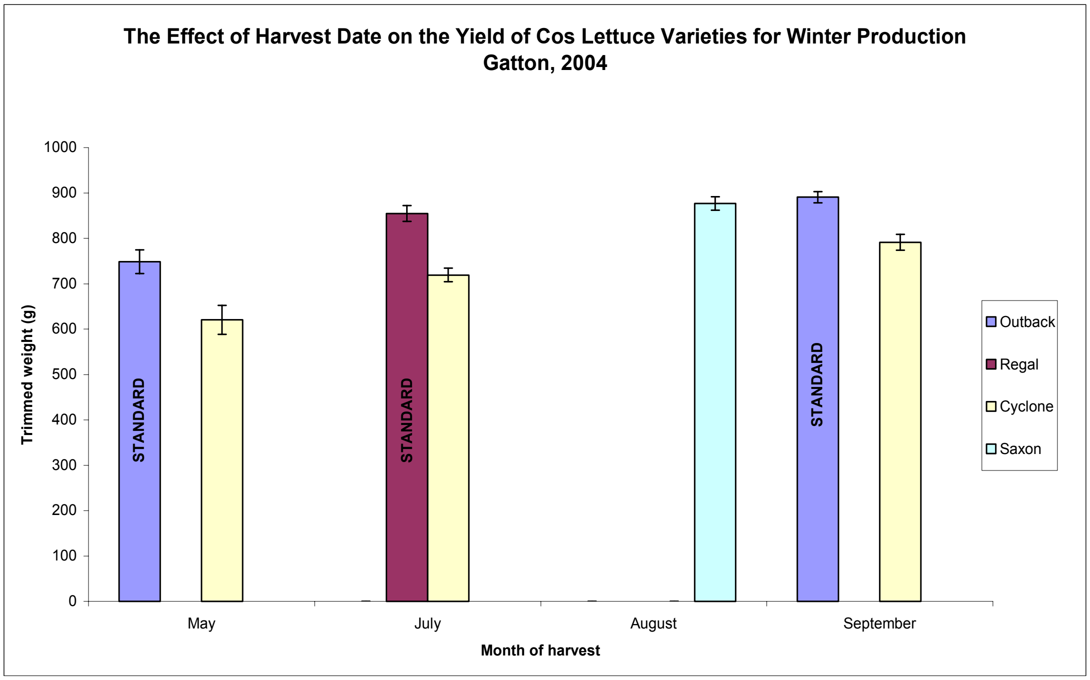



Figure 4.13. Effect of harvest date on the yield of cos lettuce varieties for winter production Gatton, 2004

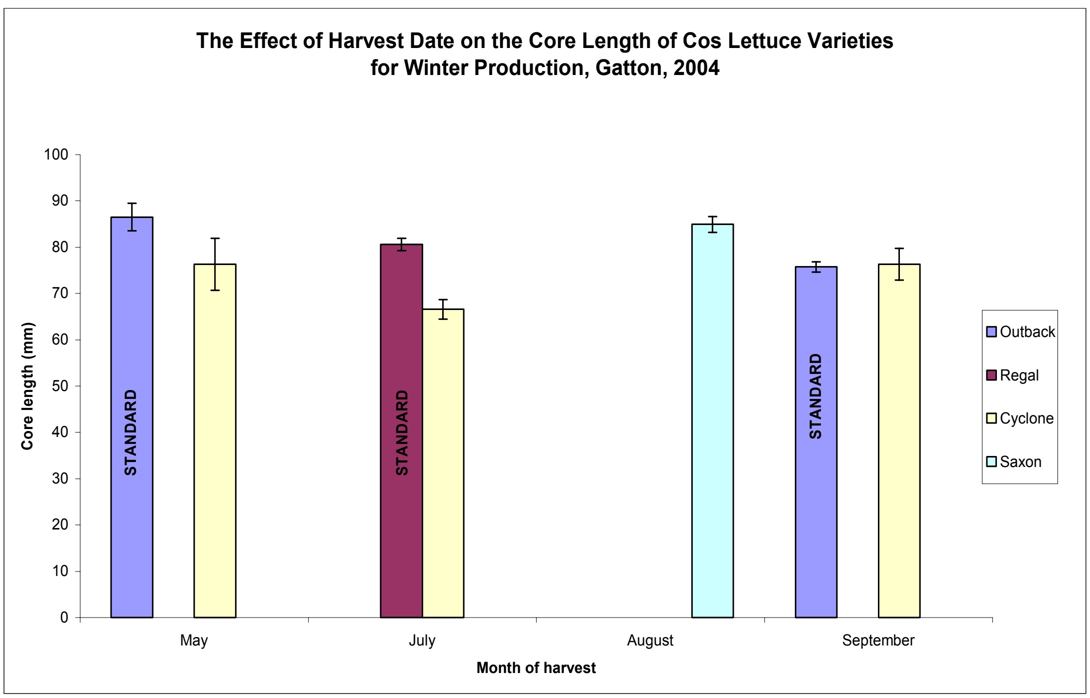



Figure 4.14. Effect of harvest date on the core length

## 4.9 Gatton – Year Two Commercial Trials – Iceberg

The highest yielding iceberg lettuce test varieties, relative to standard varieties for each month of the 2005 season, were Cartagenas and Patagonia (Figure 4.15). Cartagenas trimmed heads were found to be an average of 69% heavier than standard variety Raider in May, although not significantly different to Invader. Patagonia achieved the highest yield in July and September and produced head weights that were not significantly different to those of the standard variety (Titanic) in June and August.

These relative growth patterns are reflected, to some degree, in the core lengths displayed by these varieties in Figure 4.16. Although the highest yield obtained each month was generally associated with the longest core, this was not considered detrimental to processing quality. The highest core length for the entire season was just 71mm.

The superior performance of Cartagenas, as an early season processing variety, relative to Raider, was confirmed with shelf-life evaluation (Figure 4.17). The shelf-life for this May harvest period was extended by one day. Little difference can be observed between results for Patagonia and standard varieties from June to September, apart from August, when Titanic achieved a one day greater shelf-life than Patagonia.

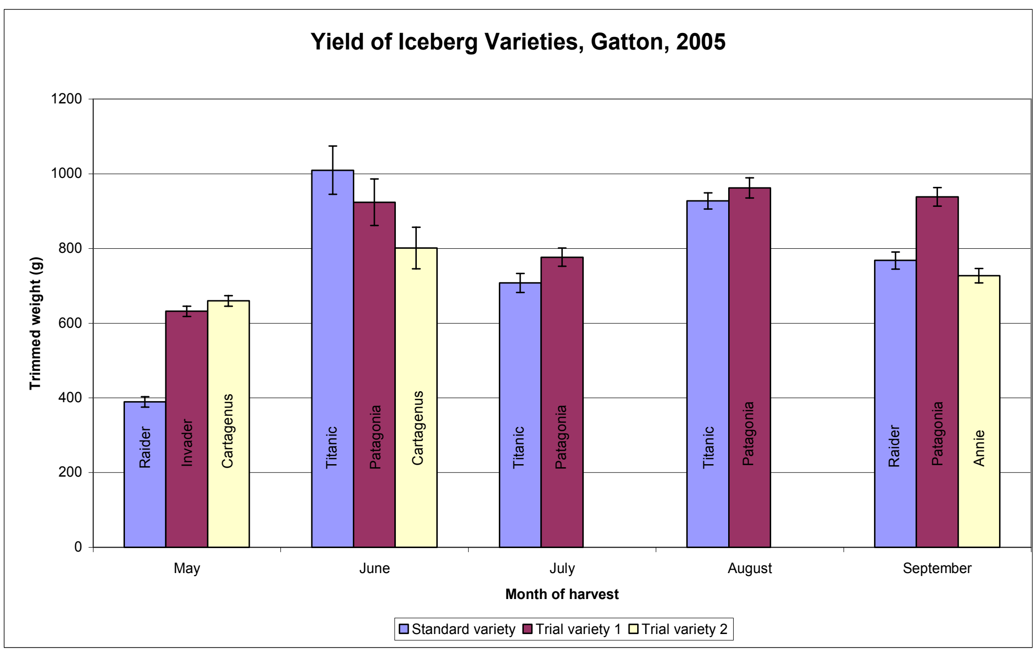


Figure 4.15. Yield of iceberg varieties, Gatton 2005

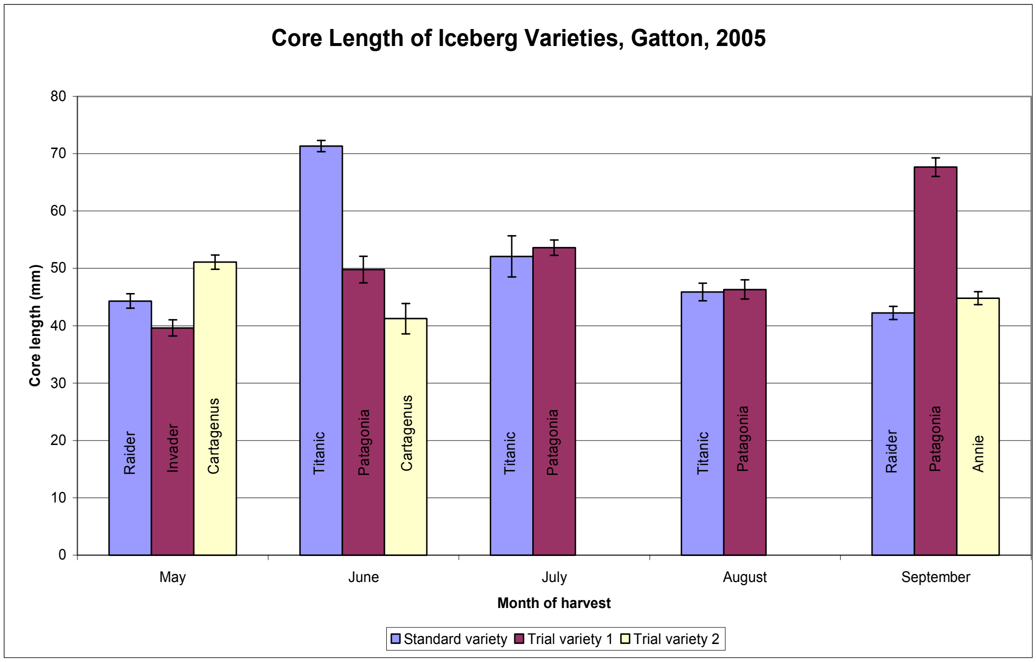



Figure 4.16. Core length of iceberg varieties, Gatton, 2005

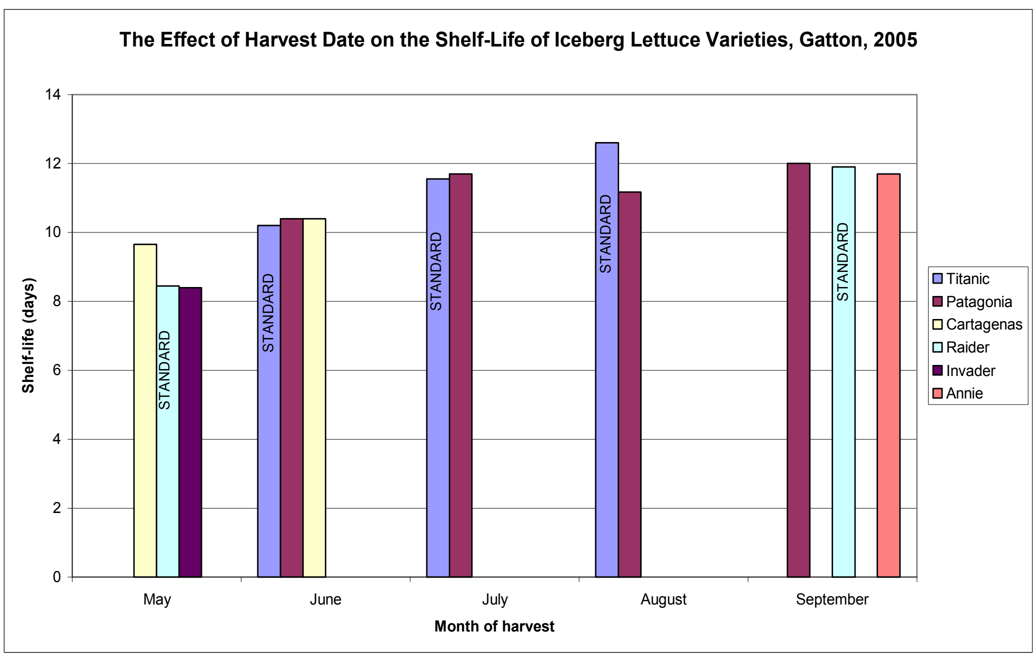



Figure 4.17. Effect of harvest date in the shelf life of iceberg lettuce varieties, Gatton, 2005.

## 4.10 Gatton – Year Two Commercial Trials – Cos

The yield results for Cos lettuce varieties grown in Gatton in 2005 (Figure 4.18) clearly demonstrate a seasonal pattern of high yields corresponding with the lower temperatures of winter. Apart from an inconsistent result for Cyclone in June, yields for both standard varieties and Cyclone are shown to increase significantly, every month through till August. There is a small average yield decrease indicated in the spring harvest (not significant). Both Cyclone and the full-size Cos varieties followed this trend, with Cyclone yielding 21-44% less than standard varieties in every trial.

Cyclone core lengths were significantly lower than standard varieties in every month except for May (Figure 4.19). There is some evidence of a trend of yield differences between varieties aligning with inter-varietal core length differences. For example, the largest yield difference occurs in June, when Saxon trimmed heads are 79% heavier than those of Cyclone. The greatest difference in core length results is also seen in this month, with Cyclone cores measuring, on average, nearly half that of Saxon cores. In May however, when there is no significant difference between average core lengths, Outback produced a yield that was just 27% greater than that of Cyclone.

Shelf-life differences between Outback and Cyclone were negligible in early and late season trials (Figure 4.20). Saxon shelf-life was 1-2 days greater than Cyclone in July but the differences were smaller in June and August. In these months, Cyclone shelf-life was greater but by less than 24 hours.

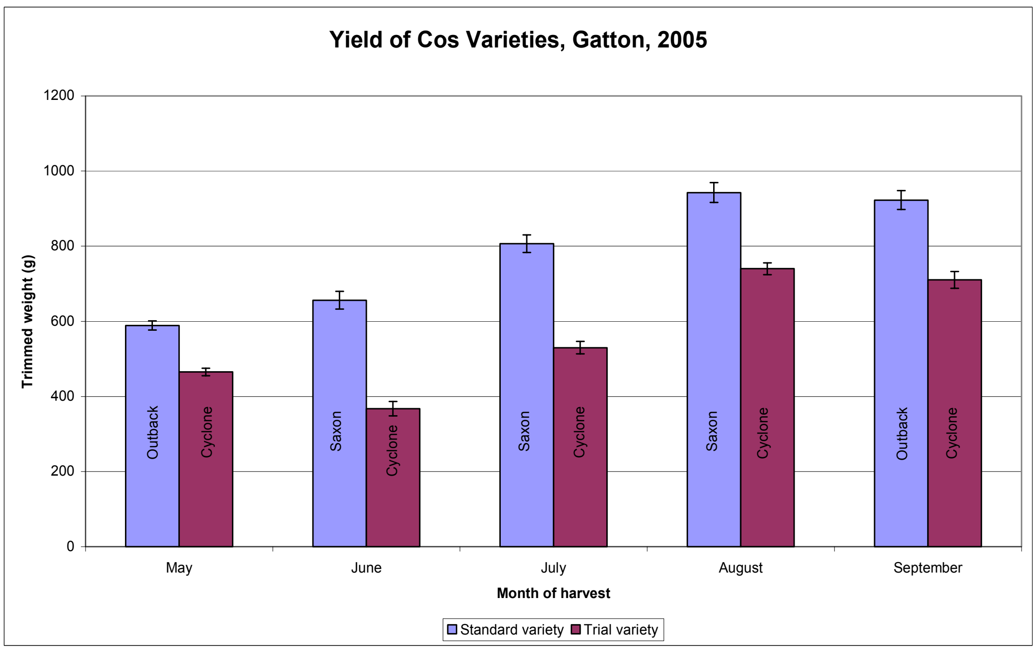



Figure 4.18. Yield of Cos varieties, Gatton 2005

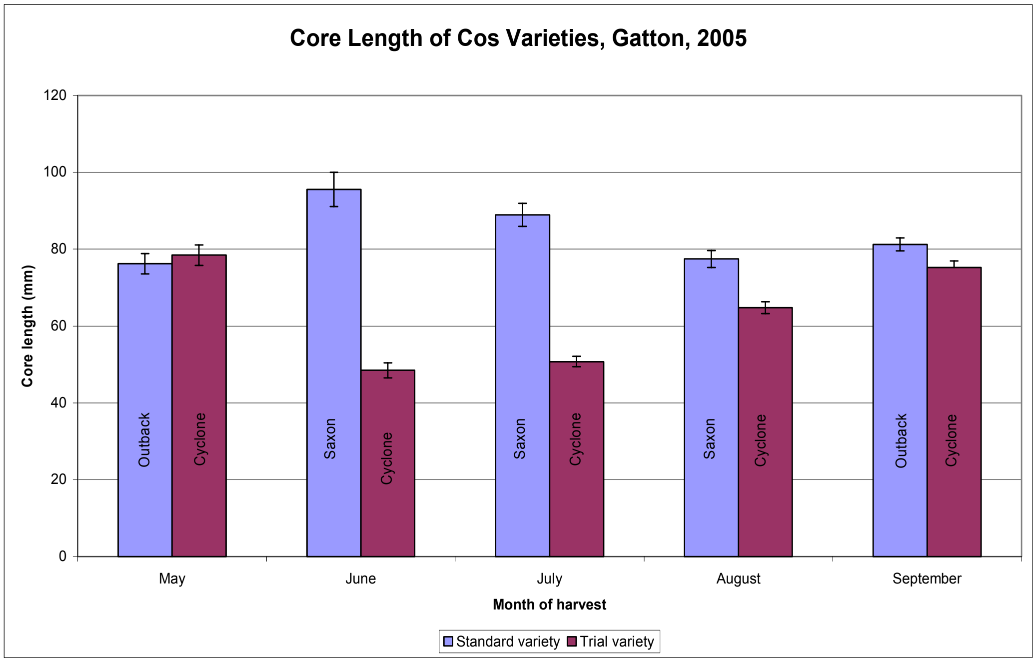



Figure 4.19. Core length of Cos varieties, Gatton, 2005

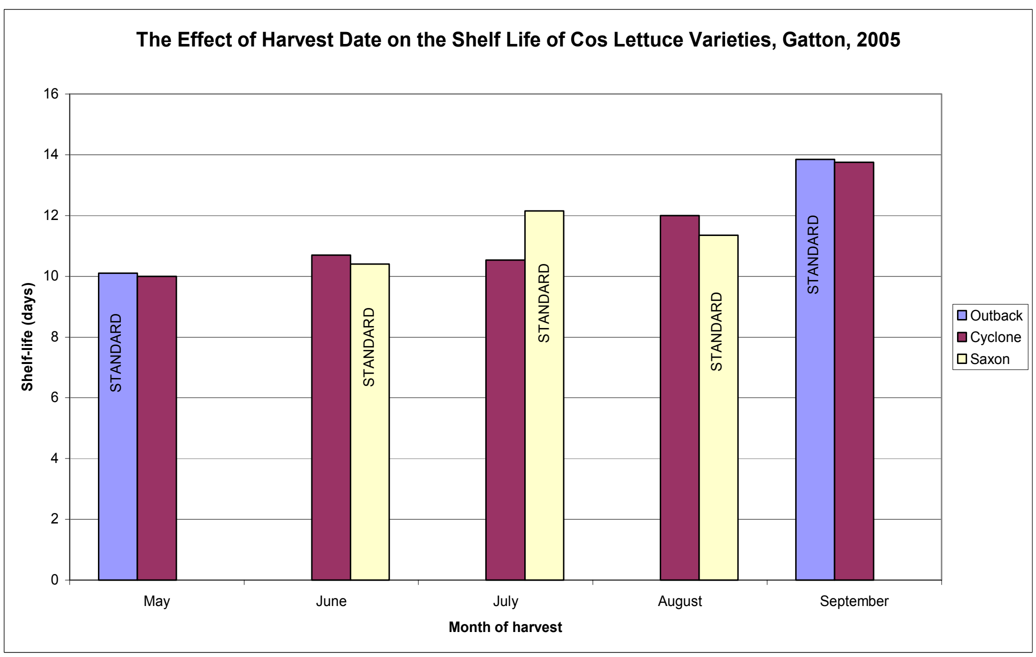



Figure 4.20. Effect of harvest date on the shelf life of Cos lettuce varieties, Gatton, 2005.

## 4.11 Robinvale – Year One Screening Trials

In an iceberg lettuce variety trial harvested in October of 2004 in Robinvale, the majority of test varieties grew heads that were not significantly different in weight to those of standard varieties Frigo and Patagonia, shown as shaded bars on the following graphs (Appendix 3). Only LEC4227 and SPS varieties 072-4, 073-4 and 837-3 were found to yield below this standard. A third standard variety, Marksman, achieved the highest yield of 903 g/trimmed head, which was significantly different to all other values.

Considerable core length variation can be noted in Appendix 3. The highest average core length belongs to the variety with the greatest yield, Marksman, however this was not considered to be disproportionate at 70mm.

Cos lettuce varieties were also evaluated in a trial using Cosmic as a standard variety for benchmarking yield (Appendix 3) and core length (Appendix 3) for an October harvest. Only 6519619 yielded significantly greater than Cosmic although a number of varieties produced head weights that were not significantly different to this control including Conquistador, Palace and Cyclone. The performance of the latter was noteworthy, illustrating the potential for this smaller variety to yield competitively.

6519619 also produced a core which was significantly shorter than the standard variety. Of the varieties which displayed similar yields to Cosmic, only Cyclone's core length was significantly less than the control. All average core lengths were relatively long, with respect to processing specification.

# *Variety Summary*

Table 1. Classification of iceberg lettuce variety types in Australia into five major groups

| Type | Commercial Varieties 2006 |
|---|---|
| ***Summer Vanguard*** (Heat tolerant) | Raider, Sahara, Devil Sun, Aztec Sun, Invader |
| ***Salinas*** (Main Season) | Casino, Target, Silverado, Foxtrot Nr, Cartagenas Nr, Barcelona Nr |
| ***Salinas x Vanguard*** (Intermediate) | Patagonia, Titanic, Lily Nr, Kong Nr |
| ***El Toro*** (Cool Season) | Greenway, Marksman, Gatlin |
| ***Winter Vanguard*** (Cold season, frost tolerant) | Winguard |

Table 2. Classification of Cos lettuce variety types in Australia into five major groups

| Type | Commercial Varieties 2006 |
|---|---|
| ***Paris Island Cos-PIC*** (Full traditional cos warm season) | Cosmic, Verdi, Outback, Saxon, Julius, Challenger |
| ***Paris Island Cos-PIC*** (Full traditional cos cool season) | Saxon |
| ***Slow closing*** (Intermediate) | Shrek Nr, Goblin Nr |
| ***¾ Cos*** (Slow bolting) | Cyclone |
| ***Mini Cos*** (Compact) | Amadeus |

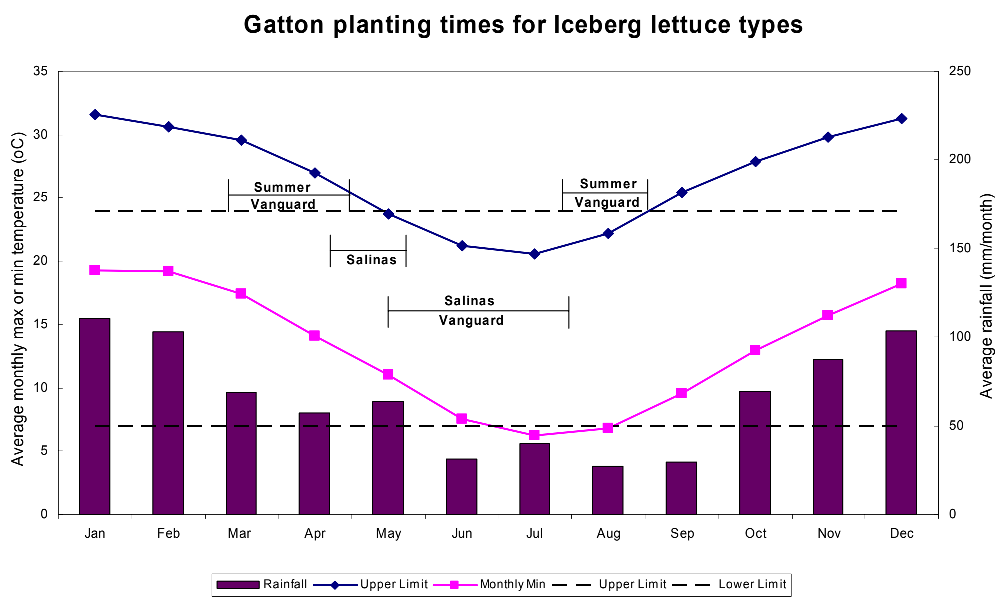



Figure 4.21. Winter iceberg lettuce planting sequence

The winter production of iceberg lettuce in the Lockyer Valley (south east Queensland) highlights the need to do variety x time of sowing x location to ensure continuity of supply of lettuce from May to October. This is a 22 – 24 week harvest period commencing in early May and continuing through until early October.

The challenge in this environment is that you have to transplant summer Vanguard types in mid-March that will cope with extremely high temperatures and decreasing days that will be harvested in May. Growers then transition to Salinas types in June, then move to winter Vanguard types for July/August harvest and then returning to the summer Vanguard types for late September/early October harvest (Figure 4.21). This involves a coordinated approach with the selection of the correct variety and the growing of an optimum sized seedling to ensure that there is a minimum amount of bolting (Figure 4.22).

The time from transplanting to harvest varies from as little as 42 – 49 days for the March transplant extending out to 70 – 77 days for the mid-winter harvest and then decreasing back to 63 and 56 days for September/October harvesting. The other factor to consider is that during this time yield can vary from 30 t/ha in the May and October period, up to 45 – 50 t/ha in the optimum harvest period in July through to August.

Figure 4.22. Bolting in Iceberg lettuce.

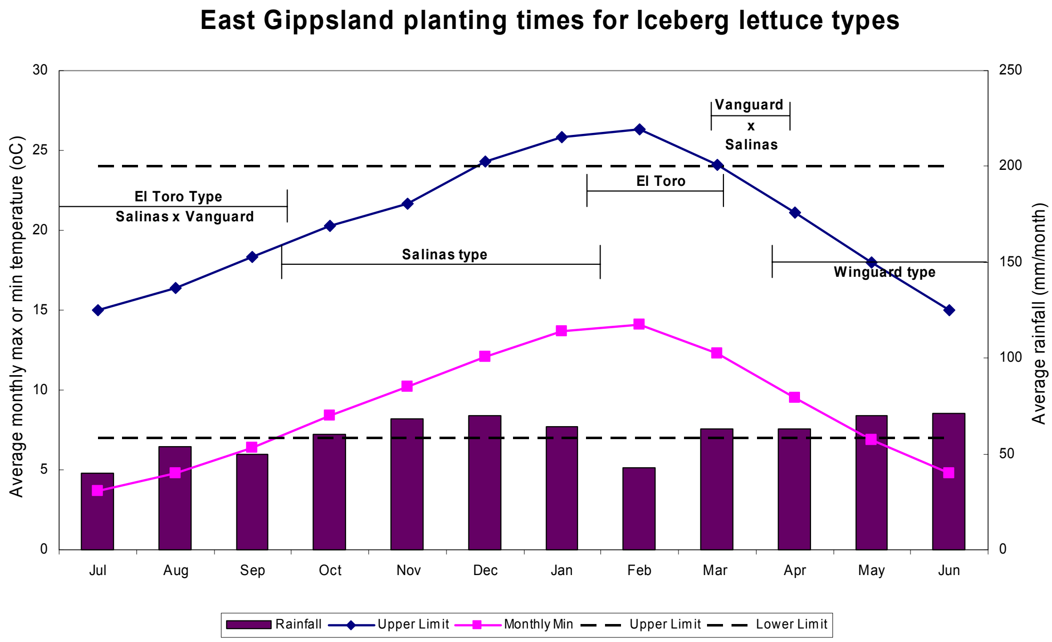



Figure 4.23. Summer iceberg lettuce planting sequence for southern Australia

The summer and autumn production of iceberg lettuce in the southern Australia (e g East Gippsland) highlights the need to do variety x time of sowing x location to ensure continuity of supply of lettuce from October to May. This is a 28 – 30 week harvest period commencing in mid October and continuing through until early May.

The challenge in this environment is that you have to transplant El Toro, Vanguard and Winguard types in mid winter (July and August) that will cope with cold temperatures, cloudy days and increasing day lengths that will be harvested in early spring October/November. The Salinas types are transplanted from mid September to early February as the main season type, then changing back to El Toro, Vanguard types to complete the southern main season (Figure 4.23). This involves a coordinated approach with the selection of the correct variety and the growing of an optimum sized seedling.

## Conclusions

- Trials with lettuce varieties are relatively ease to design, establish and grow to harvest. However, they are very time consuming in terms of making observations, collecting data, analyzing and interpreting the data before making a decision on adopting a new variety.
- Well designed replicated trials with thorough data collection are the only objective way of determining the benefits of a new variety.
- Attributes other than marketable yield (Nasonovia resistance for iceberg & slow bolting for cos) must be taken into account when adopting new varieties – see appendix 4.

# 5. Crop Nutrition

Crop nutrition has a large influence on yield and quality. Hussein Ajwa (pers. comm) found for iceberg lettuce the best quality and yield resulted from supplying balanced NPK fertiliser at rates in excess of 100 kg/ha N, P and K. He also found that if high rates of N only were applied, shelf life was reduced.

The classic nutritional work was done by Zink & Yamaguchi (1962) for direct seeded lettuce in California. This work provides the benchmark for nutrient removal of a 50 tonne/hectare crop. More research is required to tailor this benchmark to meet the needs of new varieties and new growing districts in Australia.

Surprisingly, there has been little work reported in the literature on lettuce nutrition, particularly with a focus on the effects of nutrition of shelf life and quality.

## *Methodology*

Nutrition field trials were conducted over the three year period at all sites. In all trials, a randomised block design was used with three replicates on single bed 10m plots. A standard iceberg or Cos lettuce variety was chosen for the relevant region and time of year and treatments (Figure 5.1) were applied just prior to transplanting, as basal fertiliser. During the season, the cooperating growers' usual cultural practices, including side-dressings, were administered. A pre-plant soil analysis and at least one plant analysis (at early hearting) was conducted for each nutrition trial.

The control treatment in all studies consisted of an application equivalent to 50kg of nitrogen, 60kg of phosphorus and 80kg of potassium per hectare. In each of the other treatments, two of the nutrients were kept at the same level as the control, while a third nutrient level was varied over two or three treatments, in order to investigate the effects of this nutrient in isolation.

Various levels of calcium were also applied, with the primary nutrients kept equal to the control. Treatments that applied 50% and 100% more fertiliser (in the same nutrient ration) than the control treatment were also included in the trials as well as a nil fertiliser treatment. The various applied quantities for each nutrient for each treatment are shown in Table 5.1.

At crop maturity, the standard measurements of yield and quality were taken. Samples from each treatment were processed and packaged as a fresh-cut salad product and then evaluated with respect to shelf-life (see description in the Experimental approach section).

**Table 5.1:** Treatments used in fertiliser field trials

| Treatment | Applied Quantity of Each Nutrient (kg/ha) | | | |
|---|---|---|---|---|
| | N | P | K | Ca |
| Control | 50.00 | 60.00 | 80.00 | 0.00 |
| Nitrogen 1 | 30.00 | 60.00 | 80.00 | 0.00 |
| Nitrogen 2 | 100.00 | 60.00 | 80.00 | 0.00 |
| Nitrogen 3 | 200.00 | 60.00 | 80.00 | 0.00 |
| Phosphorus 1 | 50.00 | 30.00 | 80.00 | 0.00 |
| Phosphorus 2 | 50.00 | 100.00 | 80.00 | 0.00 |
| Potassium 1 | 50.00 | 60.00 | 0.00 | 0.00 |
| Potassium 2 | 50.00 | 60.00 | 40.00 | 0.00 |
| Potassium 3 | 50.00 | 60.00 | 200.00 | 0.00 |
| Calcium 1 | 50.00 | 60.00 | 80.00 | 50.00 |
| Calcium 2 | 50.00 | 60.00 | 80.00 | 100.00 |
| Calcium 3 | 50.00 | 60.00 | 80.00 | 200.00 |
| Control x 1.5 | 75.00 | 90.00 | 120.00 | 0.00 |
| Control x 2 | 100.00 | 120.00 | 160.00 | 0.00 |
| Nil fertiliser | 0.00 | 0.00 | 0.00 | 0.00 |

An experiment was also conducted in the final season in Gatton, to investigate the effect of foliar-applied calcium on the incidence and severity of tipburn. Carinus, a standard Cos lettuce variety for a late season (August) planting, was chosen. 3.5m long plots were used and treatments were replicated four times. In all other respects the trial layout reflected the complete, randomised block design, used throughout the project. A soil sample was taken prior to transplanting and leaf samples were taken from each plot just prior to harvest, for nutrient analysis.

Three weeks after transplanting, weekly sprays were commenced and continued for the life of the crop. Plots were sprayed with a solution of calcium chloride or an organic chelate of calcium. In either case, calcium was delivered at an equivalent rate of 600 g/ha, each application. Control plots received only water and the standard surfactant which was used throughout the trial.

All plants were grown for slightly longer than usual (by approximately one week) to advance tipburn to a stage where visual differences between treatments were reasonably apparent. The usual yield and quality assessment used for all trial harvests were carried out with a particular emphasis on scoring each plant for tipburn (score was 1 to 10, 10 = maximum damage).

## *Results*

### 5.1 Balanced Nutrition is the Key to Higher Yields

The general trends observed in trial results were generally consistent across sites and seasons. Figures 5.1 and 5.2 show results for one experiment which was indicative of the other sites. These figures illustrate the two key findings in the area of plant nutrition, i.e. the need to supply nutrients in the correct balance and the detrimental impact of excessive rates of nitrogen. Figure 5.2 shows the highest head weight obtained with an application of 75:90:120

kg/ha of basal NPK fertiliser. The head weight (yield) is higher for this balanced fertilizer application than it was any level of N alone up to 200 kgN/ha.

This 43% yield increase, relative to the control, displays the potential to improve yields through increasing applied nutrition, when the elements are kept in a suitable ratio. Figure 5.1 shows the head weight response to increasing nitrogen levels alone. There is a trend for the head weight to increase with increasing nitrogen applied up to 100 kg/Ha. Nitrogen applied at 200 kg/Ha showed a negative effect on head weight, indicating toxicity.  High levels of nitrogen also had a negative effect on shelf life (Figure 5.6) with nitrogen applied at a rate of 30 Kg/Ha giving the best result.

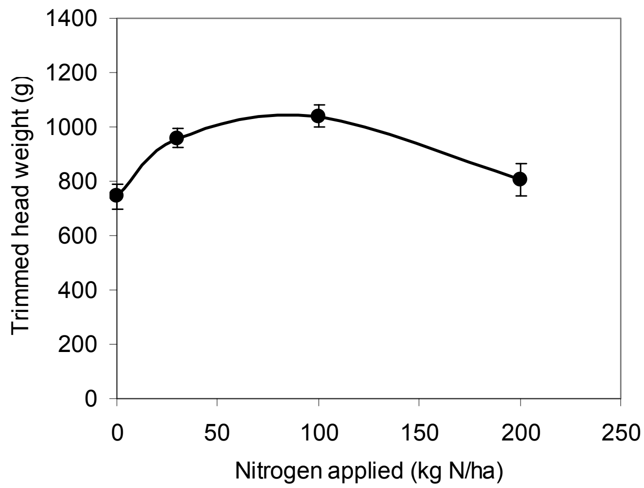



Figure  5.1. There was a significant difference between the trimmed head weight of Iceberg lettuce in response to different levels of nitrogen added.

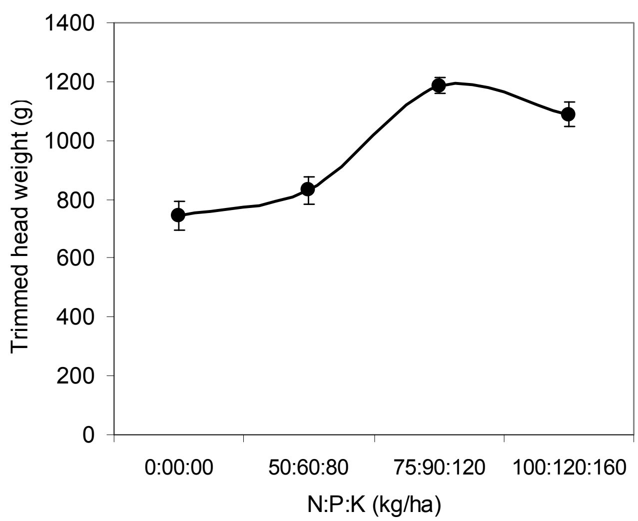



Figure 5.2.   Effect of changing fertiliser quantities with nutrient ratios constant on the trimmed head weight of Iceberg lettuce

A similar result was found for Cos lettuce (Figure 5.3). Although the overall rate of applied nutrition was increased, an appropriate ratio of key nutrients was maintained, resulting in an increase in both yield and quality.

Higher balanced fertilizer rates also surprisingly reduced core length, a key indicator of maturity for processing lettuce. Plants in the 46-51-43 treatment had an average core length which was within product specification for processed lettuce, while core lengths in the control were well outside this specification (Figure 5.2).

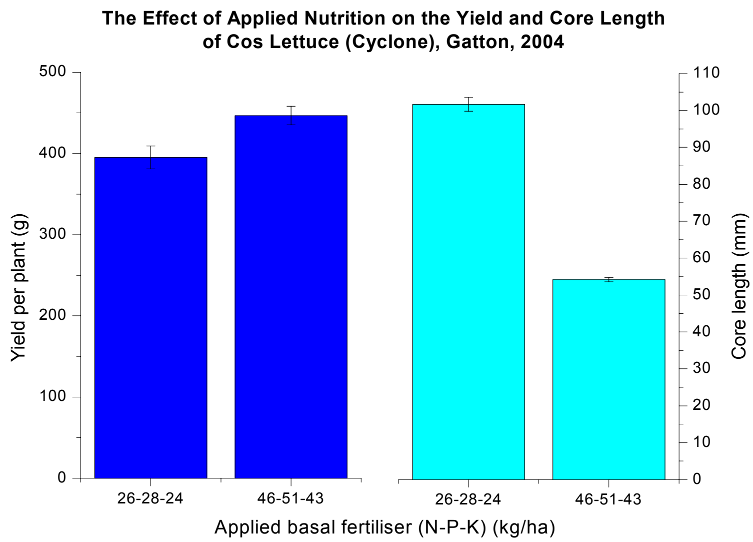



Figure 5.3. The effect of two levels of balanced NPK fertilizer on the yield per plant and core length of Cos lettuce, cv. Carinus.

## 5.2 Excessive Nitrogen Rates of Application Have a Negative Impact on Both Yield and Quality

Supplying iceberg lettuce with either different rates of N alone, or with rates of a balanced NPK fertilizer had similar effects on shelf life to that on yield. Increasing N supply, while holding other nutrients constant, reduced shelf life from 10 days at 0 kg/ha N to 7 days at 100 or 200 kg/ha N (Figure 5.4). When N was applied at up to 100 kg/ha in a balanced NPK form, the shelf life improved from 9 days at 50 kg N/ha to 10 days at 100 kg N/ha (Figure 5.5). This relationship between high nitrogen rates and reduced shelf-life, supports the work of Steenhuizen and Boon (1985).

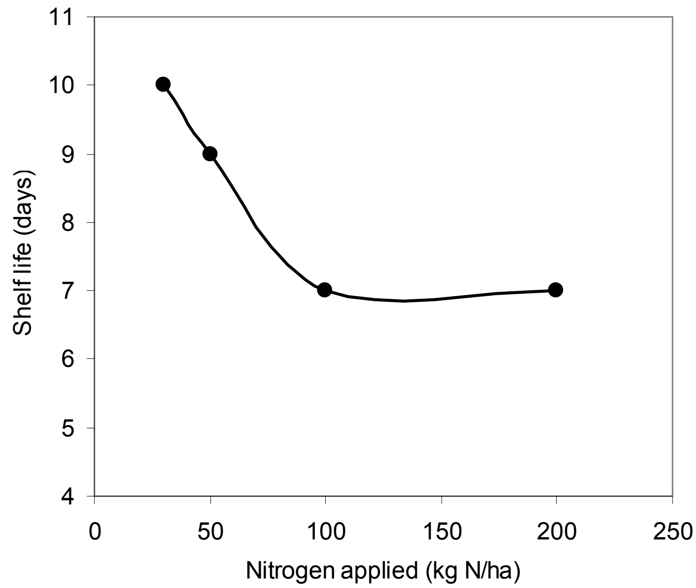



Figure 5.4. The effect of increasing the application of nitrogen on the shelf life of Iceberg lettuce.

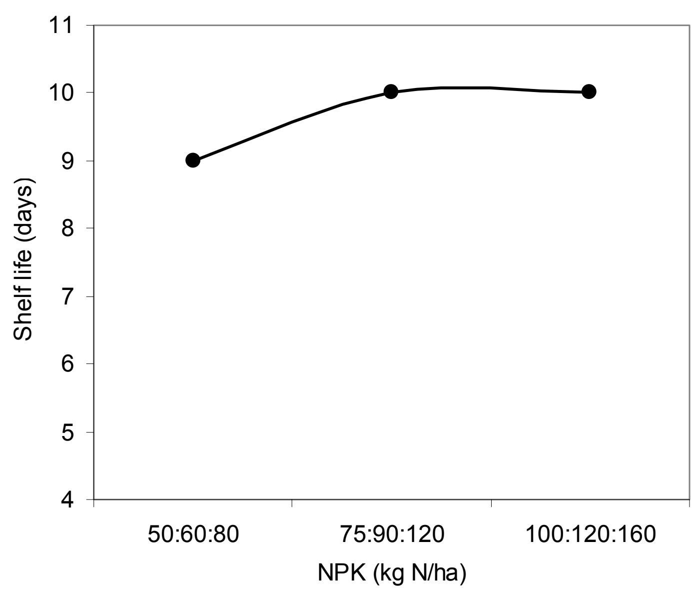



Figure 5.5 Effect of balanced NPK fertiliser on shelf life of Iceberg lettuce

## 5.3 The Importance of Adequate Phosphorus for Optimal Production

A strong plant growth response to applied phosphorus was observed in many trials throughout the project. Phosphorus removal by a lettuce crop (direct seeded) yielding 50t/ha has been estimated at 18kg P/ha (Zink and Yamaguchi, 1962). At some trial sites however, applications of phosphorus as high as 100kg/ha proved beneficial.

Such rates of application provided significant yield improvement on “new ground”, where horticultural production had not previously taken place. Phosphorus was also found to be limiting growth in some trials where soils had been double-cropped in a season or cropped continuously for a number of years without a fallow period or green manure crop.

Soils that are supplied with inadequate phosphorus for horticultural production are reasonably common in Australia. It is critical to be aware of phosphorus requirements in the situations described above, through the interpretation of a pre-plant soil analysis.

High rates of phosphorus application have also been found to improve lettuce shelf-life, in previous research (Yano and Hayami, 1978).

An example of a trial conducted on soil that had never been used for lettuce production is shown in Figure 5.6. A very significant yield increase is associated with the addition of 83kg P/ha.

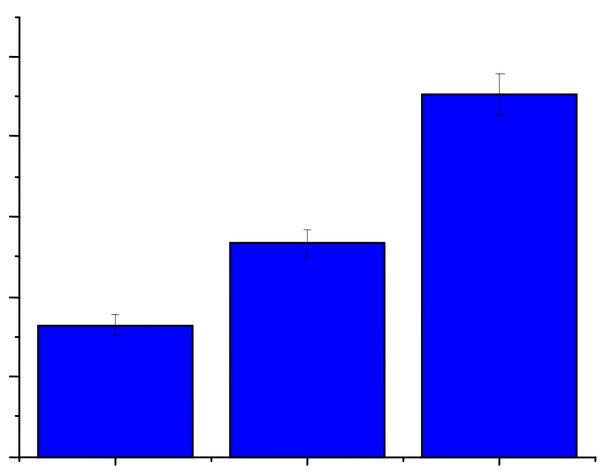


Figure 5.6. An example of the yield response to phosphorus, typically observed at sites new to horticultural production.

## 5.4 Foliar Applications of Calcium are Inefficient as a Prevention for Tipburn

Weekly foliar sprays of a calcium solution, applied to Cos lettuce, failed to provide adequate control of tip burn. Although there was a small, significant difference between the level of tip burn in untreated, control plants and those treated with foliar calcium (see Figure 5.7) this slight improvement would have made no difference in a commercial sense. From a processor's viewpoint, the level of the disorder in all plots would have appeared similar and unacceptable.

Both calcium chloride and a low molecular weight, organic chelate of calcium were tested, with the same units of calcium applied per plot in both treatments. A tank-mix of calcium chloride provides a simple solution of dissociated calcium ions while there is some evidence of superior uptake of organically chelated products. No significant difference in product performance was detected between calcium chloride and the chelated product.

This finding confirms the work of Murdoch et al. (2000). Aiming to maintain an even and moderate growth rate throughout the season remains the most effective strategy for minimising tip burn. Cultural practices such as irrigation and nitrogen applications will influence the disorder; however temperature, a factor that lies largely outside of a grower's control, can also play a large role.

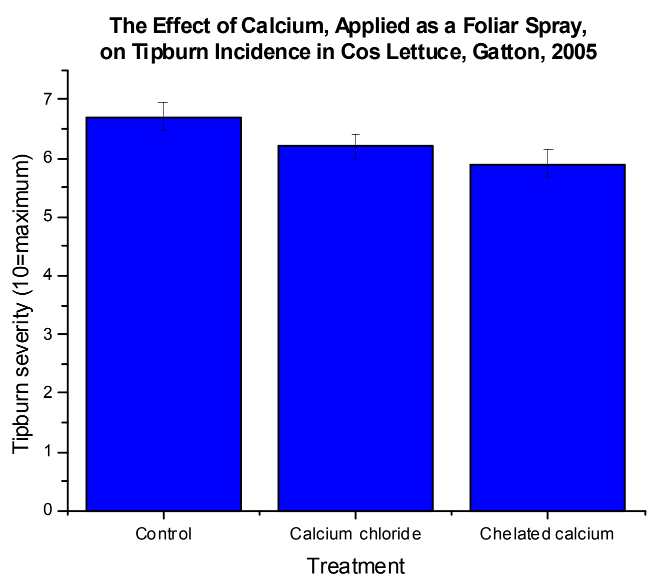



Figure 5.7. Although weekly calcium sprays provided a small, experimental reduction in tipburn severity, the treatments had no impact on the commercial outcome.

## *Key Findings for the management of soil nutrients for lettuce*

- It is essential that nutrients are applied at the appropriate ratio with other nutrients rather than simply applying elements independently if optimal yield and quality is to be achieved.
- Excessive nitrogen application can reduce both yield and quality (shelf-life)
- Phosphorous management is important for sustaining the maximum, long-term performance of the crop
- Phosphorous supply can be an issue on soils new to horticultural production, where relatively high rates may need to be applied
- Calcium foliar sprays are ineffectual in tip burn alleviation and cultural practices that aim to prevent excessive growth rates are a better strategy for reducing the incidence of tip burn

# 6. Crop Establishment

The Cos lettuce variety Cyclone is about 75% of the size of the standard Paris Island Cos, and when planted at normal densities of about 66,000 plant/hectare, yields are lower than the standard Paris Island Cos varieties. It is therefore proposed that Cyclone yields could be improved by increasing planting densities.

If the number of plants per hectare were increased, then plant size is likely to be reduced because of competition for light, water and available nutrients which would limit the overall fresh weight yield per hectare. It may be possible to partially overcome the effects of competition, by increasing crop inputs such as water and nutrients.

Most lettuce in Australia is established by growing seedlings and then transplanting them into the field. Transplanting can overcome some significant establishment issues such as high temperature induced dormancy, weed competition and pest and disease problems with seedlings. Such problems can be overcome by using transplant seedlings and efficient mechanical transplant methods which minimise transplant ‘shock’ are available for growers to use (Titley 2000).

Minimising transplant ‘shock’ is important as it has a major impact on the incidence of bolting and long cores during mid summer and early autumn. Both factors reduce the final harvest quality. The critical stage is the 10 – 14 leaf stage where heat stress during this period potentially results in long core and bolting (Kim et al. 2000). Transplanting cool stored seedlings and/or old seedlings can also increase the incidence of bolting.

The root structure of direct seeded crops is different to transplants. Cell grown seedlings and transplants have a much shallower but extensive root system in the upper 30cm of the profile compared to direct seeded crops which have a deep 1.2 – 1.5 m tap root (Jackson 1998).

In the studies reported in this chapter, the establishment of lettuce by transplants and direct seeding have been compared using two varieties of iceberg lettuce. In separate experiments, three planting densities and two levels of fertilizer inputs have been evaluated in a factorial experiment using Cos lettuce in Gatton, Qld.

## *Methodology*

**Experiment 1: Planting Density:** Cos lettuce variety Cyclone was planted using seedlings at densities of 100,000; 80,000 and 66,000 plants per hectare on beds with centres 2 m apart (4 rows per bed) on a commercial farm Gatton, Qld. Soils were well structured alluvial and the plants were irrigated using trickle irrigation. Basal nutrients were supplied at either 26-28-24 or 46-51-43 kg/ha of nitrogen, phosphorus and potassium respectively.

The experimental design was a Randomised Complete Block Design, (RCBD) with three densities and two fertilizer rates arranged in a factorial experiment with 6 replicates (n=6), and twelve plants per plot were sampled for assessment. The standard yield and quality variables were measured when the trial was harvested in late June (refer general methods section).

**Experiment 2: Direct Seeding v's Transplant Establishment:** Two varieties of Iceberg lettuce, Frigo and Patagonia were established on a commercial lettuce farm at Robinvale in the Mallee region of Northern Victoria on sandy soils either using transplanted seedlings grown in standard 144 cell seedling trays or by direct seeding. Irrigation was supplied by overhead sprinkler. The crops were established in June (winter) and harvested when mature. The lettuce established by direct seeding were harvested 23 days later than those established using transplants.

The experiment was a completely randomised design with two replicates (n=2) and 12 plants were sampled and assessed from each of four treatments. Standard yield and quality parameters were assessed (refer general methods section).

## *Results and Discussion*

### 6.1 Planting Density:

The standard planting density for conventional Cos lettuce is about 66,000 plants per hectare. When the planting density for the smaller "3/4" Cos (Cyclone) was increased to either 80,000 or 100,000 plants per hectare, the size of the head was reduced from an average weight of 630 g/head to 550 g/head and 450 g/head respectively (Figure. 6.1). This reduction in head weight was expected as the increased plant density would have increased competition between the plants for light, water, space and nutrients.

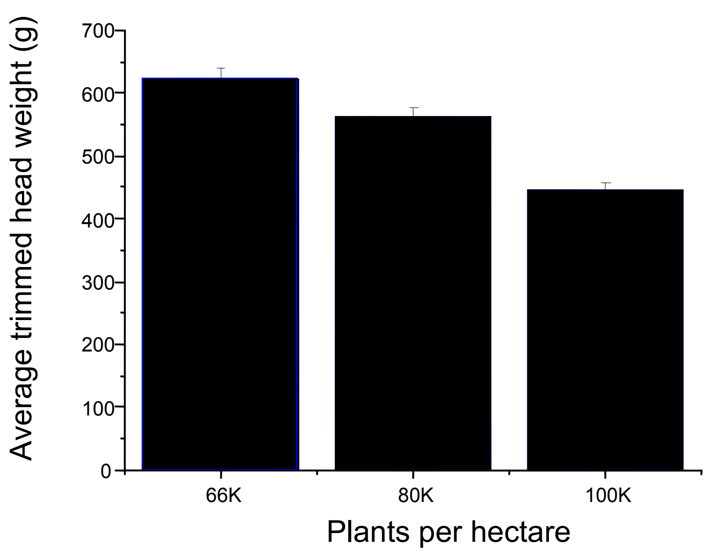



**Figure 6.1:** The effect of planting density on the average head weight of cos lettuce (Cyclone) Gatton, 2004

Increasing plant density from 66,000 plants per ha to 80,000 plants per hectare increased overall fresh weight yield by 10% from 38 t/ha to 42 t/ha, despite the reduction in individual head weights. However, when the planting density was further increased to 100,000 plants per ha, the lettuce yield per hectare was reduced to about 38 t/ha. At the highest density, the additional heads were not able to compensate for the negative effects of density on individual head weight (Figure 6.2).

More plants per unit area probably require greater inputs of water and nutrients, and so this raises the question as to whether crop inputs which are adequate at 66,000 plants per hectare, become limiting at the higher plant densities. If this is the case, increasing crop inputs along with the number of plants per hectare, may result in higher overall yields per hectare.

When the rate of basal fertilizer was increased from 26:28:24 kg NPK /ha to 46:51:43 kg NPK/ha, total yields increased at all planting densities (Figure 6.2). The higher fertilizer rates were able to overcome the effects of density on head weight so that yields of 45 t/ha were achieved at densities of either 80,000 or 100,000 plants per hectare.

Since there was no difference in total fresh weight yields between 80,000 and 100,000 plants per hectare at the higher fertilizer rate, the practical recommendation for growers in this situation would be to use 80,000 plants per ha and apply a basal fertilizer at the rate of 46:51:43 kg NPK/ha.

In determining the optimum crop density and level of crop inputs, it is important to consider the cost of these inputs, and weigh that cost against the value of the increased crop yield. It is unlikely the level of cropping inputs that results in maximum crop yield will be the same level of inputs that will give the greatest net financial return to the grower.

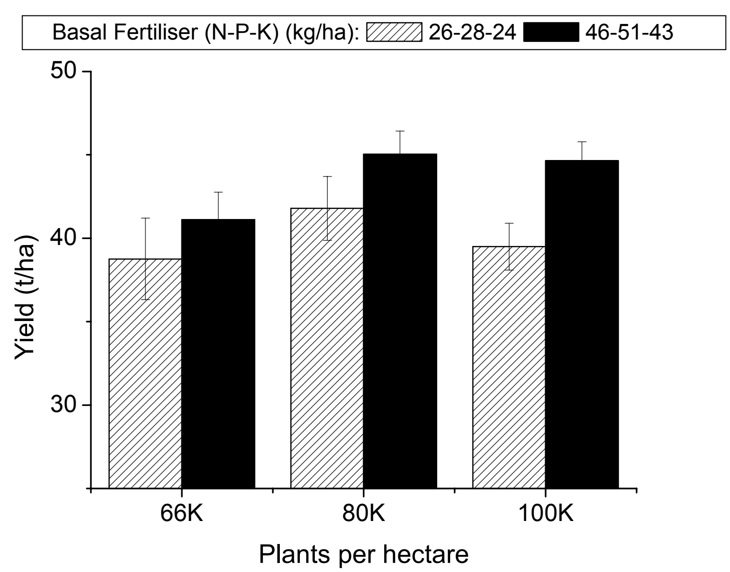
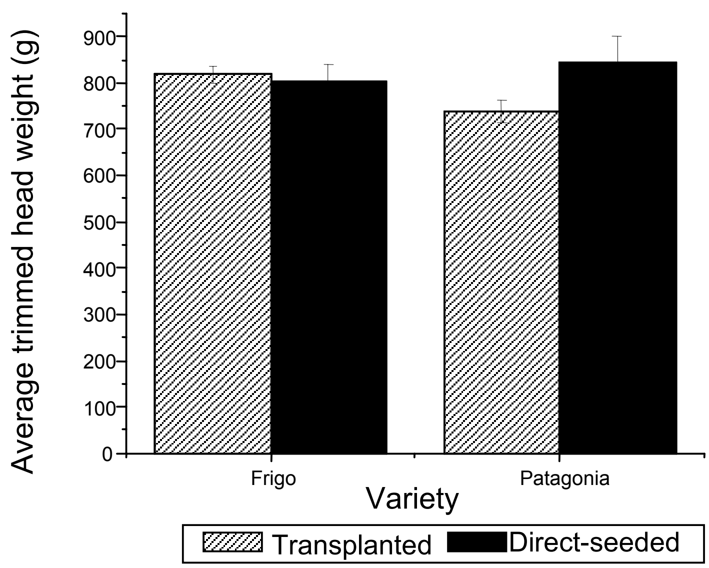



**Figure 6.2:** The effect of planting density and fertiliser management on the yield of cos lettuce (Cyclone) Gatton, 2004).

## 6.2 Direct Seeding v's Transplant Establishment

Direct seeding resulted in significantly higher yield of variety Patagonia compared to the transplanted crop, however the establishment method had no significant effect on the yields of the variety Frigo (Figure 6.3).

While transplanting is the main technique used to establish lettuce crops in Australia, it is not the same overseas. For example, in the USA, most lettuce crops are established by direct seeding. These results are therefore encouraging for the prospect of establishing more lettuce crops in Australia by direct seeding.




**6.3:** A comparison of yields for direct-seeded and transplanted iceberg lettuce, Robinvale, 2004

Direct seeding is a cheaper method of crop establishment than transplants and results in a superior deep taproot system. There are however some limitations for crop establishment by direct seeding and these include: longer crop growth period, more vulnerable to adverse weather, high temperature dormancy of the seed (> 27-30 $^{o}$C), competition for weeds, and vulnerability to insect pests during early seedling development.

## *Summary of the Key Findings from Crop Establishment Trials*

- For processing lettuce, it is essential to evaluate yield as kg lettuce/ha not heads/hectare. If you are being paid per tonne.
- Increasing plant density reduces individual head weight but applying additional fertiliser can increase total yield (kg lettuce/ha)
- Higher fertilizer inputs are required to maximise yields at higher plant densities.
- Direct seeding lettuce can result in comparable or higher yields compared to lettuce established using transplants.
- Risk factors associated with direct seeding need to be considered when choosing this as a method for establishing the crop.

# 7. Soil Moisture Management

## *Introduction*

Most of the lettuce grown in Australia is irrigated by hand shift, or solid set sprinklers. This method is popular because it applies water over the whole bed area, which is an advantage in a multi-row per bed crop like lettuce.

Sprinkler irrigation however has some limitations. These are mainly:

- low water use efficiency;
- variable coverage due to sprinkler design;
- susceptibility to wind which can affect uniformity of water;
- wets the foliage making it more susceptible to disease.

For these reasons, the alternative of trickle irrigation can be an attractive option for growers. Trickle irrigation has two major advantages over sprinkler. It places water directly into the crop root zone, increasing water use efficiency; and provide a means of utilising water resources that are too high in salts for application via overhead irrigation.

At the same time however, the challenge with trickle is to get enough lateral movement of the water across the bed for all plants to get adequate water.

The limited availability of irrigation water is another major concern for many lettuce producers around Australia. The use of trickle irrigation is a potential option for reducing water consumption in the industry but at present is poorly adopted. Trickle irrigation might also provide benefits through a decreased labour requirement for operation and the opportunity to inject dissolved fertilisers into the irrigation water for direct delivery into the root zone. As well as distributing water to the crop more efficiently, this system can, to some extent, provide a means of utilising water resources that are too high in salts for application via overhead irrigation, where leaf burn may result.

In the Gatton region, growers situated on the Lockyer Creek have had a very limited water supply for a number of years and water salinity has also been a major issue. One of the cooperating growers is situated in this area and had installed a trickle irrigation system prior to the project's commencement, as his water was unsuitable for overhead irrigation due to a high concentration of chloride ions. The project's other cooperating grower in the Gatton region produces on properties situated north-east of this site, where water is well supplied and overhead irrigation is used.

Although it was not possible to directly compare both irrigation systems as treatments within a trial at a single site in this project, the opportunity was presented to compare the two types of production over a three year period, where the same varieties of iceberg and Cos lettuce were transplanted at the same time in concurrent trials and assessed using the same methodology. In comparing the yields, shelf-life, growth period and head quality obtained by each system, the objective was to establish whether trickle irrigation is a valid alternative to the standard practice of overhead irrigation, which has a greater water requirement per unit of production.

## *Methodology*

The trial site where trickle irrigation was used for production is situated on the Lockyer Creek in Gatton. Lettuce was grown on beds with 2m centres (4 rows per bed) with two lengths of trickle tape buried 150mm below the bed surface between the first and second and also the third and fourth lettuce rows. Lettuce seedlings were initially irrigated with overhead irrigation (portable spray lines) directly after transplanting, to encourage some lateral root growth, before the trickle tape was used.

The grower using overhead irrigation provided trial sites on properties at Glenore Grove, Lockrose and Patrick Estate, all within a 25km radius and to the north-east of the trickle irrigated site. At these locations, three rows of lettuce were grown on beds with 1.5m centres, which resulted in an identical planting density to that produced by four rows on beds with 2m centres, for a given plant spacing. Portable spray lines were the sole method of irrigation.

Lettuce seedlings, grown in a nearby nursery, were supplied to both growers for transplanting into trial blocks. The soil types between sites were very similar, predominantly heavy alluvial black cracking clays, typical of the Lockyer Valley region.

Trials were conducted over the winters of 2004 and 2005. There were four plantings through 2004 and five during 2005. Each planting consisted of four trials: two iceberg lettuce varieties and two Cos lettuce varieties. For each lettuce type, one trial was grown using overhead irrigation and the other used trickle irrigation. Each trial typically included two varieties including the industry standard variety for that time of year (Table 7.1).

Table 7.1 Iceberg and Cos Lettuce Varieties Included in Irrigation Trials – Gatton

| **2004** | | | |
|---|---|---|---|
| **Iceberg Varieties** | **Cos Varieties** | **Transplant Month** | **Harvest Month** |
| Raider* | Outback* | March | May |
| Cartagenas | Cyclone | | |
| Oxford* | Regal* | April | June |
| Patagonia | Cyclone | | |
| Titanic* | Verdi* | May | August |
| Patagonia | Saxon | | |
| Raider* | Outback* | July | September |
| Brisbane | Cyclone | | |
| **2005** | | | |
| Raider* | Outback* | March | May |
| Cartagenas | Cyclone | | |
| Titanic* | Saxon* | April | June |
| Patagonia | Cyclone | | |
| Titanic* | Saxon* | May | July |
| Patagonia | Cyclone | | |
| Titanic* | Saxon* | June | August |
| Patagonia | Cyclone | | |
| Titanic* | Outback* | July | September |
| Patagonia | Cyclone | | |

* Denotes industry standard variety for a particular schedule and lettuce type

Each variety was transplanted into beds of approximately 50 plants, and were replicated twice (n=2). The first and last few metres of bed were not used. These plots were integrated into the grower's production system to maximise the commercial relevance of findings.

Sentek soil moisture monitoring equipment were used to compare moisture profiles in overhead and trickle irrigated crops. Enviroscan® units, comprising of four capacitance probes, a data logger and a solar-powered battery, were installed in a plot irrigated by an overhead system and also in trickle-irrigated plot at planting. Each probe continuously logged soil moisture values recorded at 10, 20, 30 and 50cm below the soil surface, throughout the crop cycle. The four probes were positioned across the bed to show differences in soil moisture behaviour between lettuce rows.

At crop maturity, samples of twelve randomly selected plants were collected from each plot. The weight of the trimmed lettuce head was recorded for each plant and for two plants per sample the above-ground biomass was measured (the total weight of an untrimmed head, except for the root system). Butt diameter and core length were also recorded as well as heart diameter for iceberg lettuce and heart length and width in Cos lettuce. Any diseases and disorders were also noted and rated.

The shelf-life of processed lettuce was also determined for each irrigation method for each variety, each planting. Six standard cartons of twelve lettuce heads each were harvested from each plot at maturity. This material was then vacuum-cooled to 2.5$^{o}$C within one hour of harvest and taken to a commercial vegetable processing plant in Brisbane, via refrigerated transport. In accordance with commercial practice, the lettuce heads were placed in cold storage (4$^{o}$C) for up to five days but were typically processed the day after harvest.

Trial material was subjected to the usual trimming, slicing, washing, drying and packaging processes that take place daily in the plant. Iceberg lettuce was processed as a shredded leaf and Cos lettuce leaves were cut into randomly-shaped pieces and packaged with condiment sachets as a Caesar salad mix. The non-permeable plastic bags used as retail packaging are flushed with nitrogen as they are sealed to reduce the oxygen content to less than 10%.

Immediately after packing, trial packets were refrigerated at 6$^{o}$C, which simulated the post-production environment of products in an open fridge in a retail store. Four days after production, daily assessments commence with three bags examined per day for each of the irrigation types for each variety. For each bag, carbon dioxide and oxygen levels are recorded and then seven aspects of quality are rated: visual appearance, crispiness, odour, taste, damage, consistency and overall freshness.

For each category a number between 1 and 5 was assigned where 5 indicates excellent quality and 1 denotes an unsaleable product (product failure). The scores for the seven attributes were summed to give an overall quality rating out of 35 and this was then averaged for the three bags. The product's shelf-life was determined as the time taken for the average rating to reach 12.5 or less.

## *Results*

Apart from the yields recorded for iceberg lettuce harvested in May 2004 (Figure 7.1) all iceberg and Cos lettuce grown using overhead irrigation achieved yields that were equal to or better than those obtained through production with trickle irrigation. Figures 7.1 and 7.5 show the yields obtained for iceberg lettuce in 2004 and 2005 respectively. In most months, a larger weight was produced in heads irrigated with overhead sprinklers, however lettuce grown with both irrigation systems follow a similar trend over the course of the season.

With the exception of results shown for trickle irrigation in July 2004 and overhead irrigation in June 2005, there is a general tendency for yields to build through autumn and winter, peaking in August. Yields then decline through September. This pattern is typical of that observed for winter production areas and is related to the optimal conditions for lettuce growth that are experienced through the cooler months.

This pattern was seen more distinctly in the results for Cos lettuce in 2004 (Figure 7.3) which also shows the superior performance of overhead irrigation in every harvest except for August, where there is no significant difference. The same seasonal and irrigation type effects are evident but as weaker trends in Cos lettuce production in 2005 (Figure 7.7).

Overhead irrigation has not proven to be more effective than trickle irrigation, however, in the production of lettuce with high shelf-life. In 2005, both iceberg (Figure 7.6) and Cos lettuce (Figure 7.8) showed little difference in shelf-life between irrigation methods. A general increase in quality, however, can be seen throughout the season.

In 2004, trickle irrigation increased shelf-life relative to overhead irrigation. This was only apparent in the August harvest of iceberg lettuce (Figure 7.2) due to the smaller set of shelf-life data generated for this type of lettuce in 2004. The effect was demonstrated much more clearly in Cos lettuce (Figure 7.4) where shelf-life was higher for trickle irrigation in every harvest. In Figure 7.4, the values obtained for overhead irrigation mirror the yield trend were for the same lettuce in Figure 7.3.

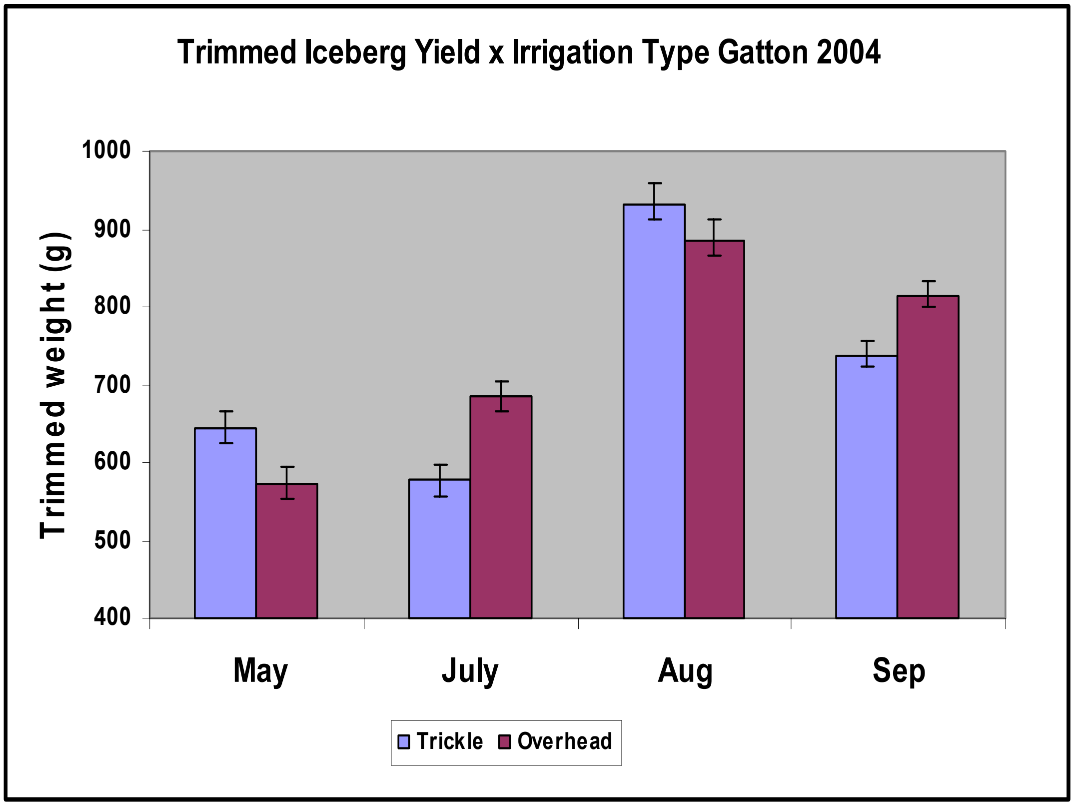



Figure7.1: The effect of irrigation type on the yield of trimmed Iceberg lettuce, Gatton 2004

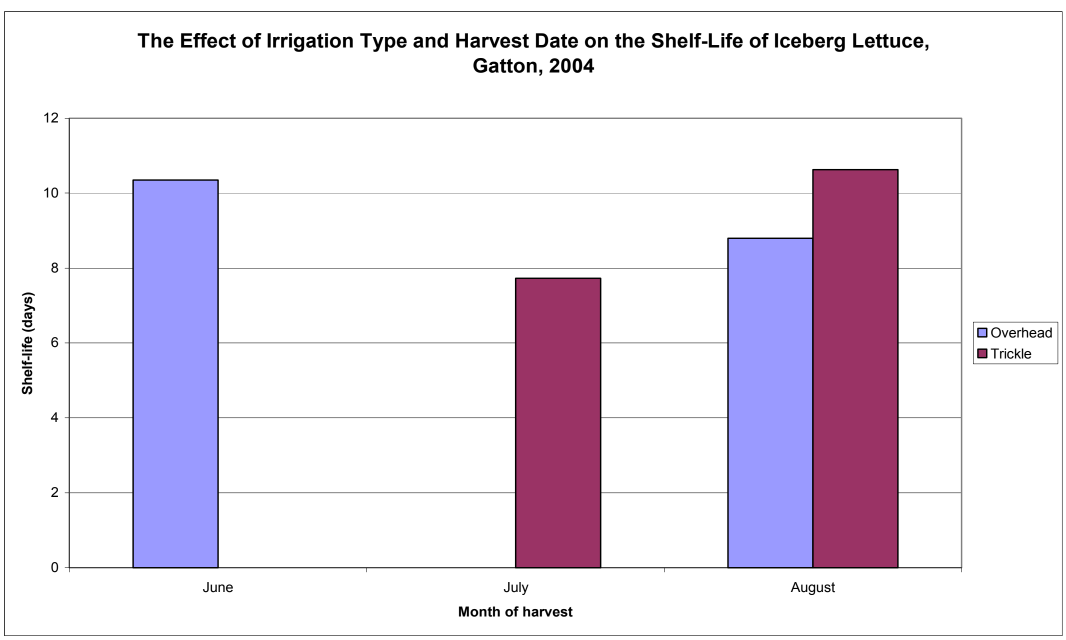



Figure 7.2: The effect of irrigation type and harvest date on the shelf life of Iceberg lettuce, Gatton 2004

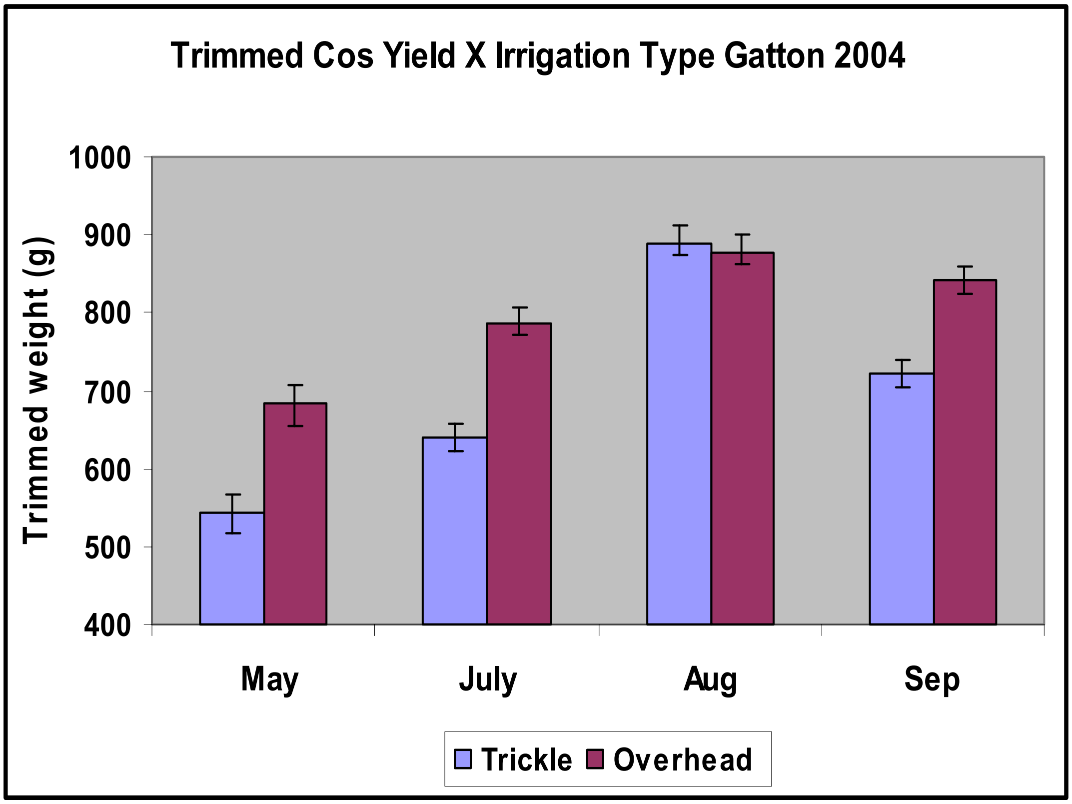


Figure 7.3: The effect of irrigation type on the trimmed yield of Cos lettuce, Gatton 2004

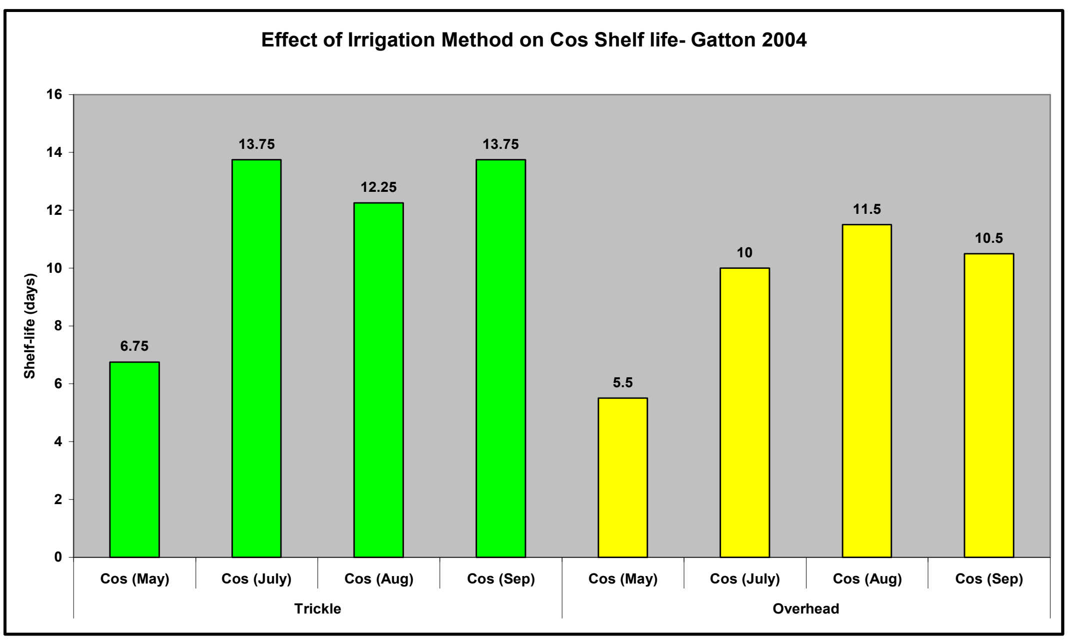


Figure 7.4: The effect of irrigation method on the shelf life of Cos lettuce, Gatton 2004

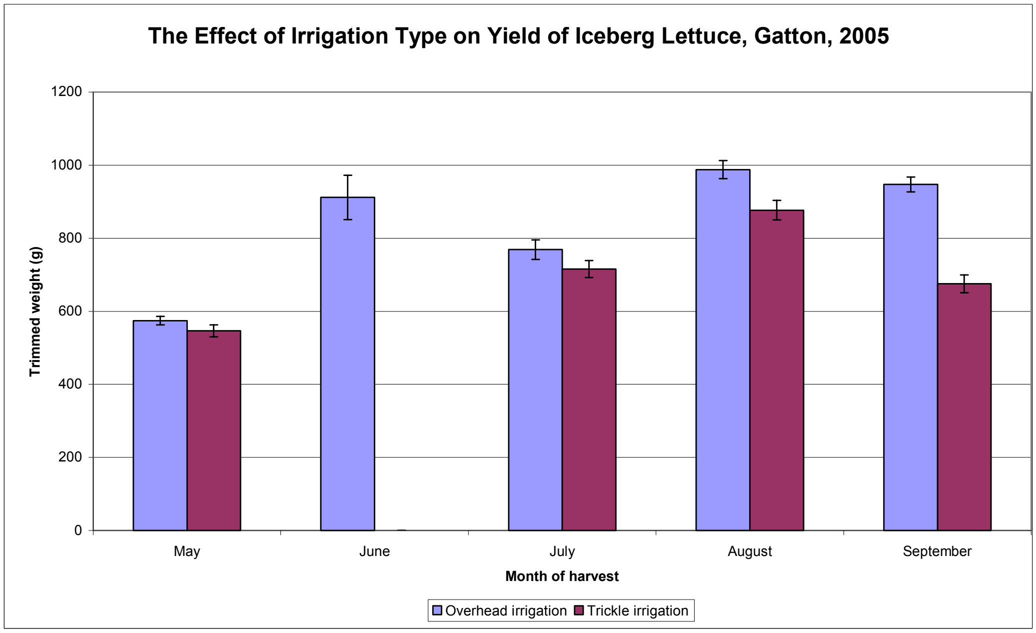



Figure 7.5: The effect of irrigation type on the yield of Iceberg lettuce, Gatton 2005

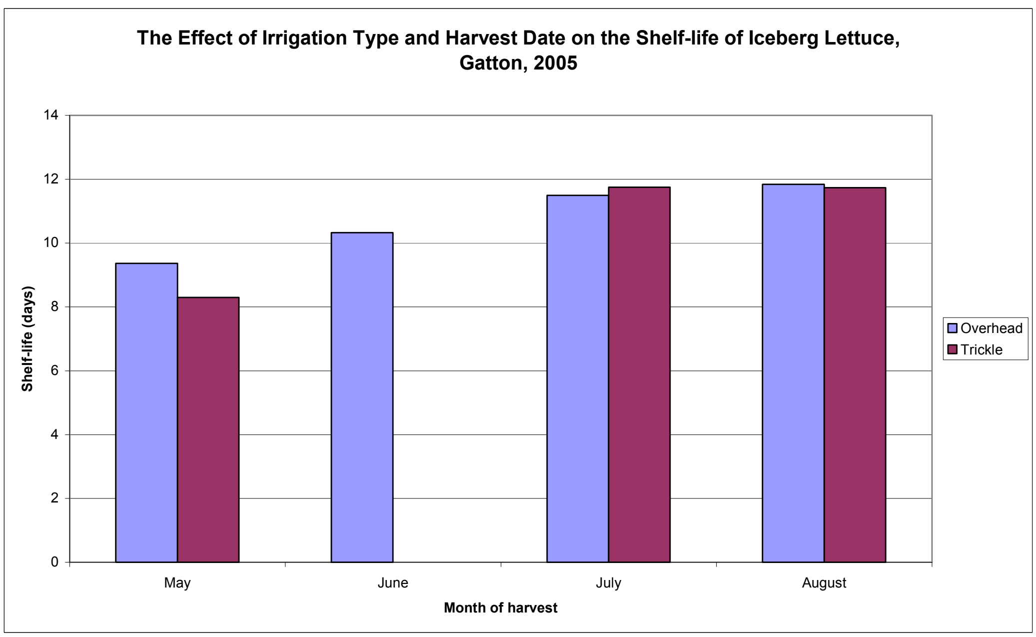



Figure 7.6: The effect of irrigation type and harvest date on the shelf life of Iceberg lettuce, Gatton 2005

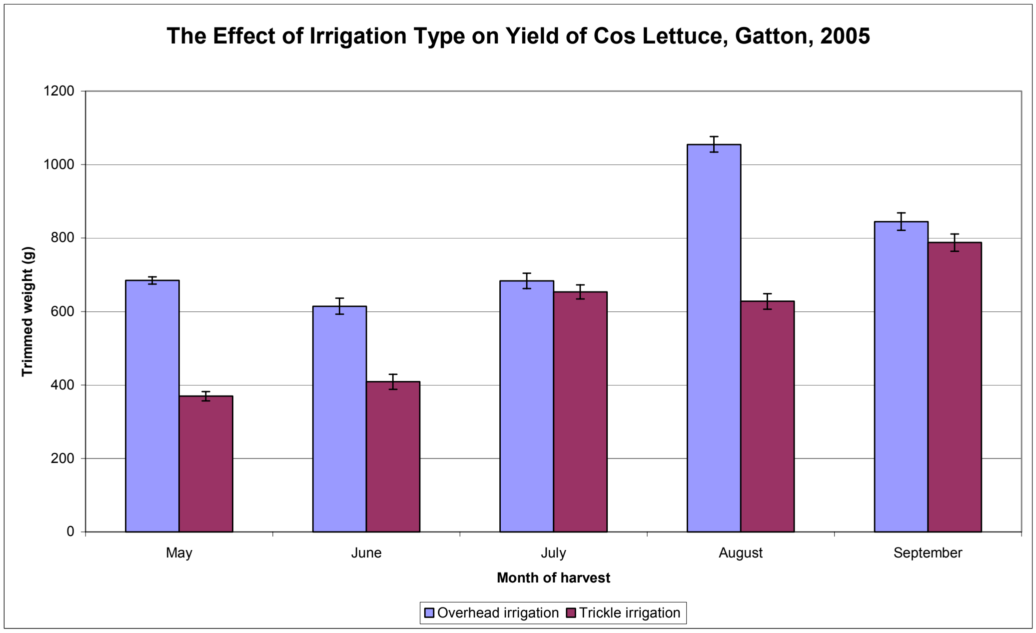


Figure 7.7: The effect of Irrigation type on the yield of Cos lettuce, Gatton 2005

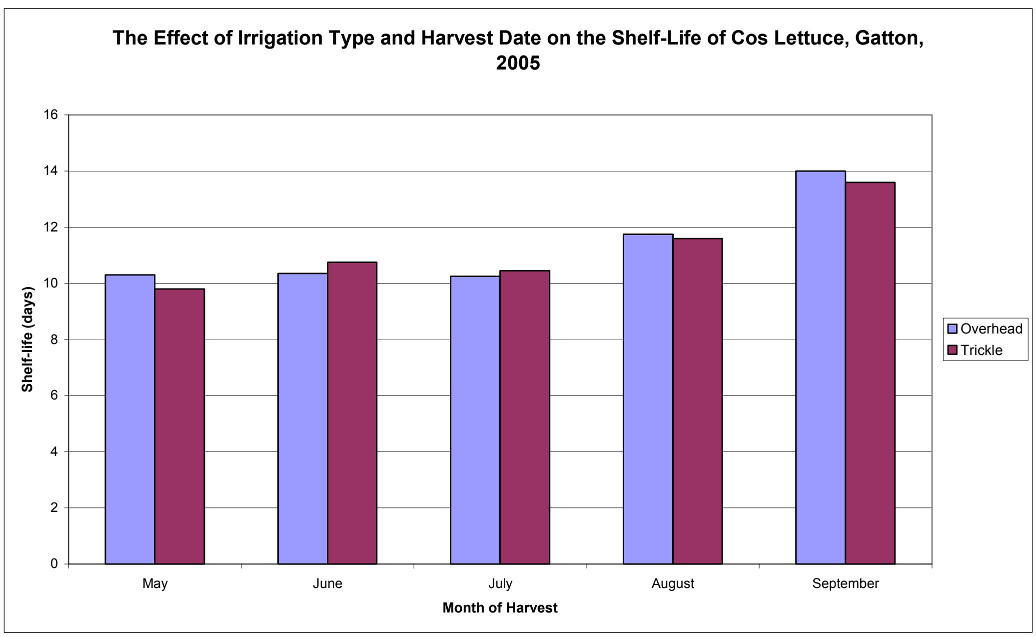


Figure 7.8: The effect of irrigation type and harvest date on the shelf life of Cos lettuce, Gattton 2005

## *Water Application and Uptake - Gatton*

The common result over all these trials was that trickle irrigation used less water to grow a crop than overhead sprinkler, but often the head weights of sprinkler-irrigated crops were greater than trickle-irrigated crops (Figures 7.9 and 7.10). In all cases however, the water use efficiency (amount of water used for a given crop yield) was much higher for trickle than sprinkler.

This means that where the amount of water available is a limiting factor, trickle use water more efficiently than sprinkler, but can still produce adequate yields of good quality lettuce.

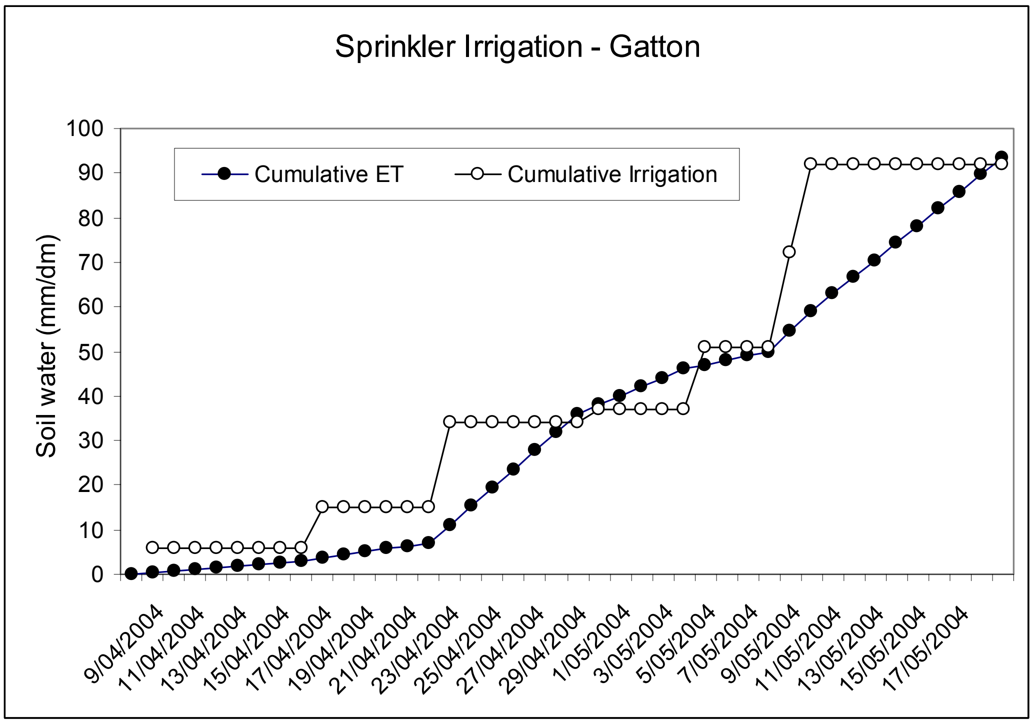



Figure 7.9. Crop water use and irrigation applied for sprinkler-Irrigated iceberg lettuce crop in Gatton, Autumn 2004.

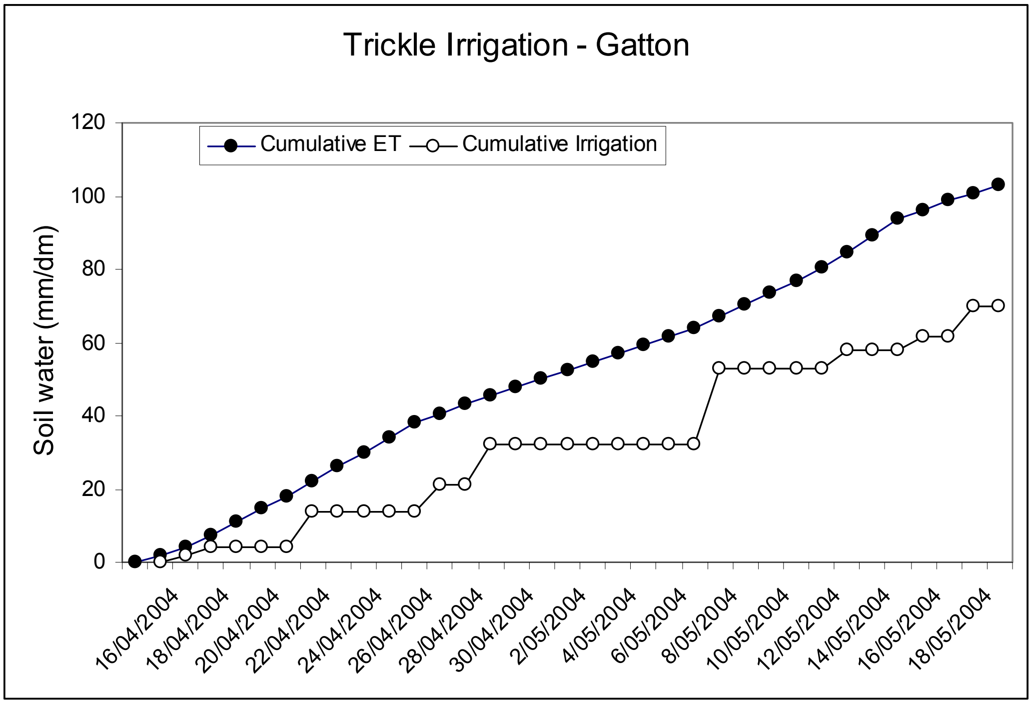



Figure 7.10. Crop water use and Irrigation applied for a trickle-irrigated iceberg lettuce crop in Gatton, Autumn 2004.

## *Discussion*

While yields for both Cos and iceberg lettuce were generally higher when irrigated with an overhead system, there was some indication that trickle irrigation can improve shelf-life, particularly of Cos lettuce (Figure 7.4). Further investigations into the value of trickle irrigation to the fresh-cut lettuce industry may benefit from addressing iceberg and Cos types separately.

The magnitude of yield response to irrigation type also indicates that Cos lettuce may be more sensitive to the choice of system. Yield differences obtained between the two systems in 2005 were higher for Cos lettuce (Figure 7.7) than iceberg lettuce (Figure 7.5). While the greatest yield increase that irrigation selection provided for iceberg lettuce was 40% in September, overhead irrigation produced yields in Cos lettuce that were 85%, 50% and 68% greater than for trickle irrigation production in May, June and August respectively.

Cos lettuce also displays a greater yield response to irrigation type in the 2004 trials where overhead irrigation provided a significant increase in head weight. Reviewing the iceberg (Figure 7.1) and Cos lettuce (Figure 7.3) yield results for that year, shows an 18% improvement for iceberg and a 23% increase for Cos lettuce in July. In September there was 10% increase in iceberg lettuce yield but Cos lettuce yielded 17% higher when grown with overhead irrigation.

The nature of the experimental design in Gatton does not allow for direct comparisons of performance between the two irrigation types. The spatial separation of plots irrigated with the different systems limits the conclusions that can be drawn from the data generated. In particular, the lesser quantity and quality of water available to the site on the Lockyer Creek supports the possibility that yields generated from trickle irrigation may compete better with those from overhead irrigation in a more controlled study at a single site.

As a long-term study of what is possible in real commercial operations, however, this aspect of the project has been successful. It has shown that trickle irrigation is a viable alternative that requires further research. Although yield was usually higher in production utilising overhead irrigation, there was occasions when trickle irrigation results were comparable or better. This variation suggests that refining the management of trickle irrigation in lettuce crops may improve the performance and consistency of this system.

When other potential benefits of this irrigation system are considered, such as reduced water consumption and improved shelf-life of fresh-cut salads, further work in this area can be justified. Studies that target better management and higher yields using this system will benefit the industry with improved efficiency and greater returns on investment.

## *Conclusion*

- Trickle irrigation can be used successfully to grow lettuce with higher water use efficiency than using sprinkler irrigation.
- Lettuce plants should be maintained free of water stress right up to harvest for maximum yields.

## Appendix 1. References


Adamicki, F. (1997) Effect of ultra low oxygen on the storage and quality of some vegetables. Postharvest Horticulture Series - Department of Pomology, University of California. Department of Pomology, University of California, Davis, USA. No. 18, 26-33

Barry-Ryan, C. and O'Beirne, D. (2000) Novel high oxygen and noble gas modified atmosphere packaging for extending the quality and shelf-life of fresh prepared produce. Advances in the refrigeration systems, food technologies and cold chain, Sofia, Bulgaria, 23-26 September, 1998. International Institute of Refrigeration (Institut International du Froid),Paris, France: 2000. 417-424.

Beaudry, R. M. (2000) Responses of horticultural commodities to low oxygen: limits to the expanded use of modified atmosphere packaging. HortTechnology.. 10: 3, 491-500

Cantell, M. and Suslow, T. (2002) Postharvest Handling Systems: Fresh-Cut Fruits and Vegetables. In Postharvest Technology of Horticultural Crops. Kader, A.A (Editor) Publication Number 3311 University of California Agriculture and Natural Resources

Jackson, L.E (1998) 'Plant-Soil relationships in lettuce'. Annual Report of California Iceberg Lettuce Advisory Research Board. pp. 213 – 227

Jacxsens, L., Devlieghere, F., Falcato, P. and Debevere, J (1999) Behavior of Listeria monocytogenes and Aeromonas spp. on fresh-cut produce packaged under equilibrium-modified atmosphere. Journal of Food Protection. 1999. 62: 10, 1128-1135.

Jacxsens, L., Devlieghere, F., et al. (1999b). Spoilage and safety of fresh-cut vegetables packaged under equilibrium modified atmosphere. Mededelingen - Faculteit Landbouwkundige en Toegepaste Biologische Wetenschappen, Universiteit Gent **64**(4): 7-11.

Kim, H.H., Chun, C. and Kozai, T. (2000) The Potential Use of Photoperiod during Transplant Production under Artificial Lighting Conditions on Floral Development and Bolting, Using Spinach as a Model. HortScience 35(1): 43-45

Kraker, J. de (1996) Influence of weather conditions during harvesting and handling on keeping quality of leafy vegetables. Lelystad. 1996. No. 81B, 110-117.

Lipton, W. J. (1987). "Carbon dioxide-induced injury of romaine lettuce stored in controlled atmospheres." HortScience **22**(3): 461-463.

Lopez-Galvez, G., Saltveit, M., et al. (1996). "The visual quality of minimally processed lettuces stored in air or controlled atmosphere with emphasis on romaine and iceberg types." Postharvest Biology and Technology **8**(3): 179-190.

Martinez, J. A. and Artes, F. (1999) Effect of packaging treatments and vacuum-cooling on quality of winter harvested iceberg lettuce. Food Research International.. 32: 9, 621-627.

Murdoch et al. (2000) Decreasing tipburn in lettuce. Australian Lettuce Industry Conference, Hay, New South Wales, Australia, 6-8 June, 2000. NSW Agriculture, Orange, Australia: 69-75.

Nam SangYong and Kwon YongWoong. (1999) Quality changes of hydroponically produced leaf lettuce (Lactuca sativa L., cv. Cheongchima) during postharvest storage. Acta Horticulturae. No. 483, 173-183.

Nobile, M. A. d., Baiano, A., et al. (2006). Respiration rate of minimally processed lettuce as affected by packaging. Journal of Food Engineering **74**(1): 60-69.

O'Hare, T. J. Wong, L. S. Prasad, A. and Able, A. J. (2000) Atmosphere modification extends the postharvest shelf life of fresh-cut leafy Asian brassicas. Acta Horticulturae. 2000. No. 539, 103-107.

Reyes, V. G. (1996) Improved preservation systems for minimally processed vegetables. Food Australia. 48: 2, 87-90.

Rosenfeld, H. J. and Sundell, H. A. (1992) Colour, taste, texture and shelf life of crisphead lettuce packed in PP-bags. COST 94. The post-harvest treatment of fruit and vegetables: modified atmosphere packaging. Proceedings of a workshop, Istanbul, Turkey, 1-2 Oct.. DG XIII-A, Commission of the European Communities, Luxembourg: 1995.

Salter, P.J. and Goode, J.E. (1967)Crop responses to water at different stages of growth Research Review No. 2 East Malling Commonwealth Agricultural Bureau pp. 87-89

Saltveit, M. E. (2000) Wound induced changes in phenolic metabolism and tissue browning are altered by heat shock. Postharvest Biology & Technology. 21: 61-69.

Saltveit, M. E. (2001) A new way to prevent browning of fresh-cut lettuce. Fresh Cut. July 10-11.

Sanchez, C. A. Burdine, H. W. Guzman, V. L. and Hall, C. B. (1989) Yield, quality, and leaf nutrient composition of crisphead lettuce as affected by N, P and K on Histosols. Proceedings of the Florida State Horticultural Society. 101: 346-350.

Sanchez, C.A. (2000) ‘Response of Lettuce to Water and Nitrogen on Sand and the Potential for Leaching of Nitrate- N’. HortScience 35(1): 73-77

Saure, M.C. (2001) New views of the prerequisites for an occurrence of bitter pit in apple and its control by calcium sprays. International Symposium on Foliar Nutrition of Fruit Plants. Merano, Italy, September 11-15 2001.

Steenhuizen, J. W. and Boon, J. van der (1985) The nitrate content of lettuce in nutrient solution. 2. Nitrogen level and ammonium:nitrate ratio; replacement before harvest by a solution with a higher proportion of ammonium. Rapport, Instituut voor Bodemvruchtbaarheid, Netherlands. No.1-85

Titley, M. (2000) Australian lettuce production and processing - an overview. Australian Lettuce Industry Conference, Hay, New South Wales, Australia, 6-8 June, 2000. NSW Agriculture, Orange, Australia: 12-31.

Varoquaux, P. Mazollier, J. and Albagnac, G (1996) The influence of raw material characteristics on the storage life of fresh-cut butterhead lettuce. Postharvest Biology & Technology. 1996. 9: 2, 127-139

Wurr, D. C. E.: Fellows, J. R.: Suckling R.F. (1988). ‘Crop continuity and prediction in the crisp lettuce variety Saladin’ Journal of Agricultural Science, 111:481-486

Wurr, D. C. E.: Fellows, J.R. (1991) ‘The influence of solar radiation and temperature on the head weight of crisp lettuce’ Journal of Horticultural Science 66: 183-190

Yano, M. Hayami, (1978) A Studies on the improvement of storage ability in head vegetables. I. The relationship between cultivar, stage of maturity and fertilizers and the storage ability of lettuce and cabbage. Bulletin of the Vegetable and Ornamental Crops Research Station, 1978. No. 4, 77-88.

Zink, F.W. and Yamaguchi, M. (1962) ‘Studies on the Growth Rate and Nutrient Absorption of Lettuce’. Hilgardia 32(11): 471 – 500

# Appendix 2. Crop Scheduling Models

## 1. Variation in Crop Growth Period and Yield in Gatton – Cos

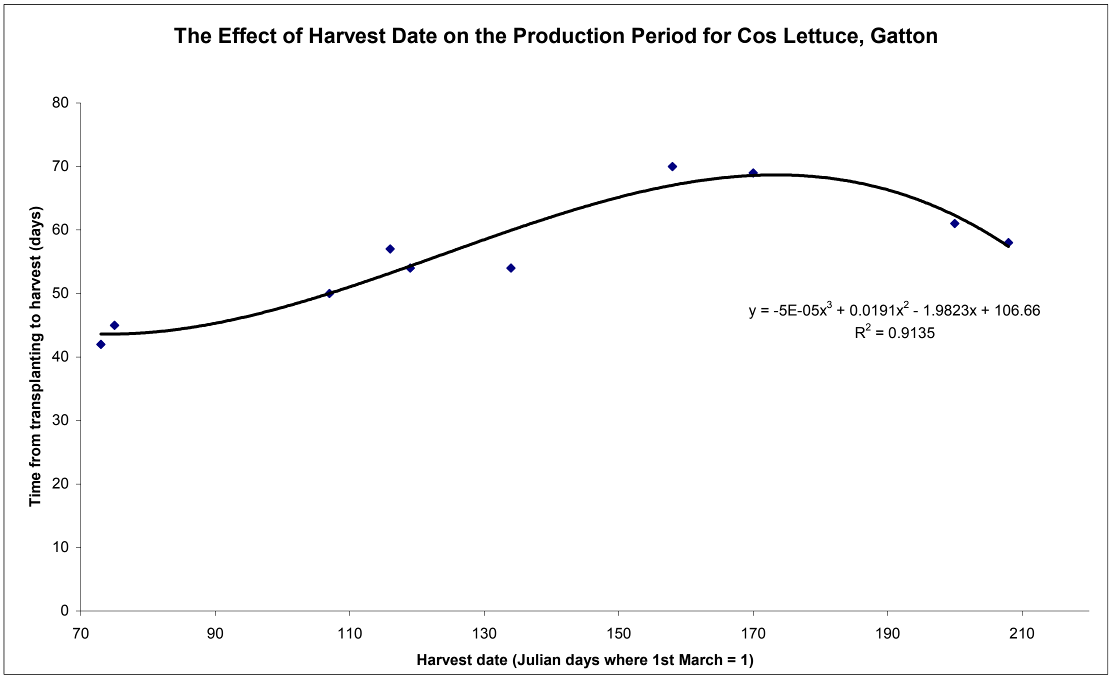



Figure 1:

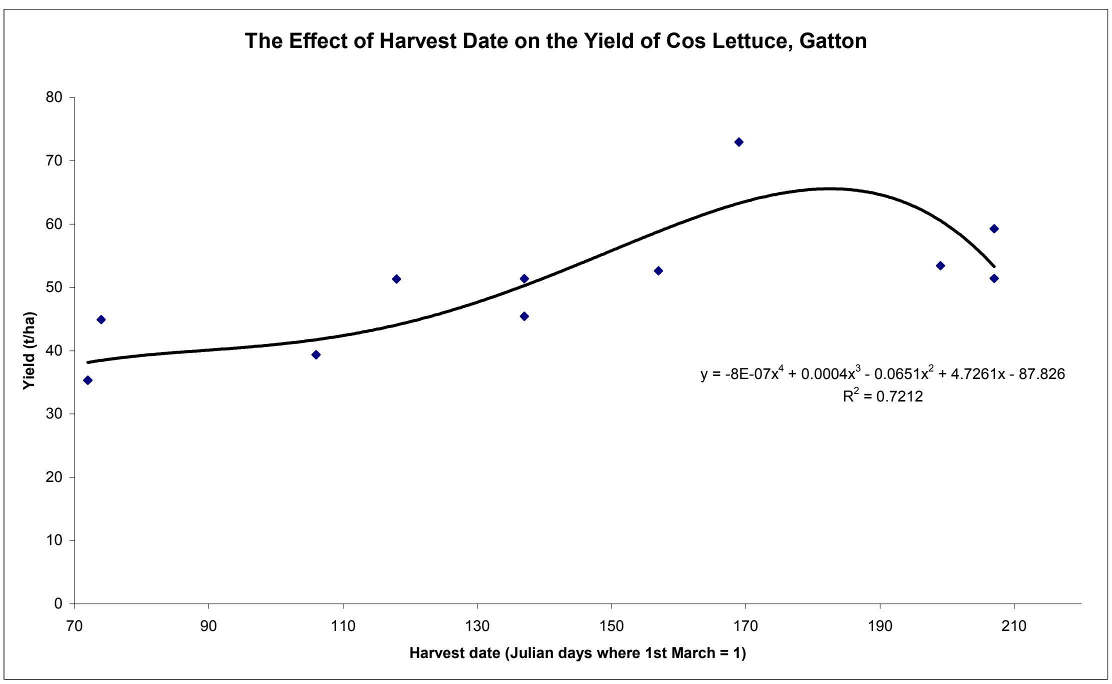



Figure 2:

**Table 1. Gatton Cos Schedule**

| Harvest Date | Number of Days to Harvest | Planting Date | Yield (t/ha) | Plants Required per Tonne |
|---|---|---|---|---|
| 10-May | 44 | 27-Mar | 35 | 1714 |
| 17-May | 44 | 3-Apr | 35 | 1714 |
| 24-May | 45 | 9-Apr | 36 | 1667 |
| 31-May | 46 | 15-Apr | 36 | 1667 |
| 7-Jun | 48 | 20-Apr | 38 | 1579 |
| 14-Jun | 50 | 25-Apr | 39 | 1538 |
| 21-Jun | 52 | 30-Apr | 41 | 1463 |
| 28-Jun | 55 | 4-May | 43 | 1395 |
| 5-Jul | 58 | 8-May | 45 | 1333 |
| 12-Jul | 60 | 13-May | 47 | 1277 |
| 19-Jul | 63 | 17-May | 50 | 1200 |
| 26-Jul | 65 | 22-May | 52 | 1154 |
| 2-Aug | 67 | 27-May | 54 | 1111 |
| 9-Aug | 68 | 2-Jun | 55 | 1091 |
| 16-Aug | 69 | 8-Jun | 56 | 1071 |
| 23-Aug | 68 | 16-Jun | 58 | 1034 |
| 30-Aug | 67 | 24-Jun | 58 | 1034 |
| 6-Sep | 66 | 2-Jul | 58 | 1034 |
| 13-Sep | 63 | 12-Jul | 57 | 1053 |
| 20-Sep | 59 | 23-Jul | 56 | 1071 |

***Disclaimer**: This scheduling model is presented as a guide for growers only as it is based on two season's data for the Gatton district. Days to harvest and yield will vary with season, growing district and crop production methods.*

## 2. Variation in Crop Growth Period and Yield in East Gippsland – Iceberg

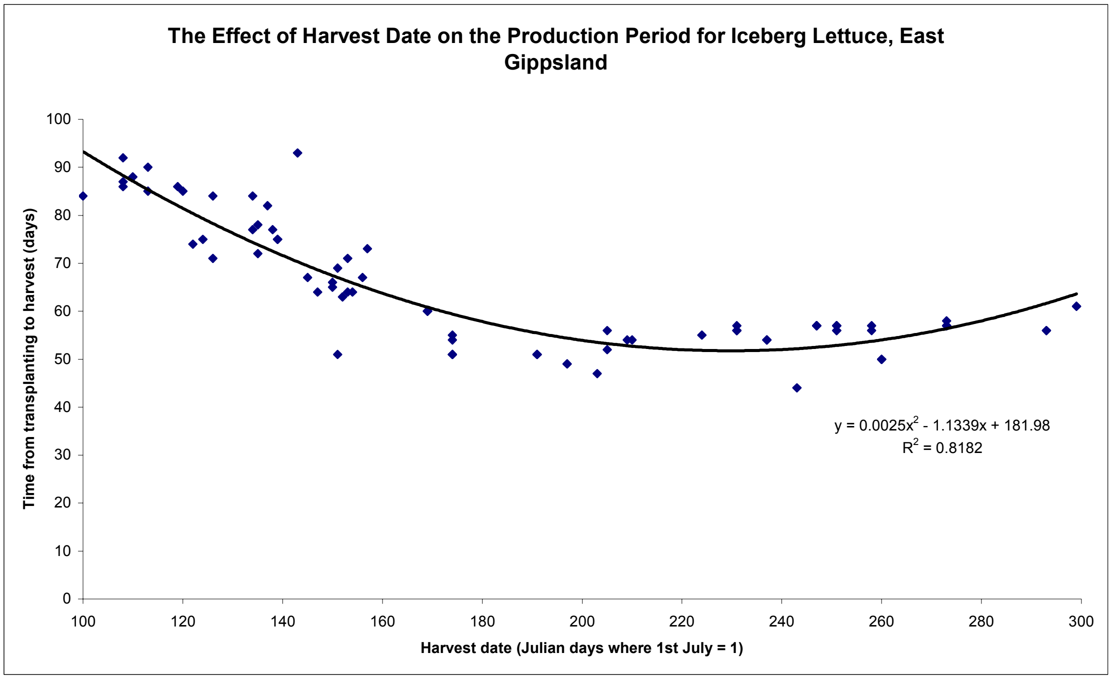



Figure 3.

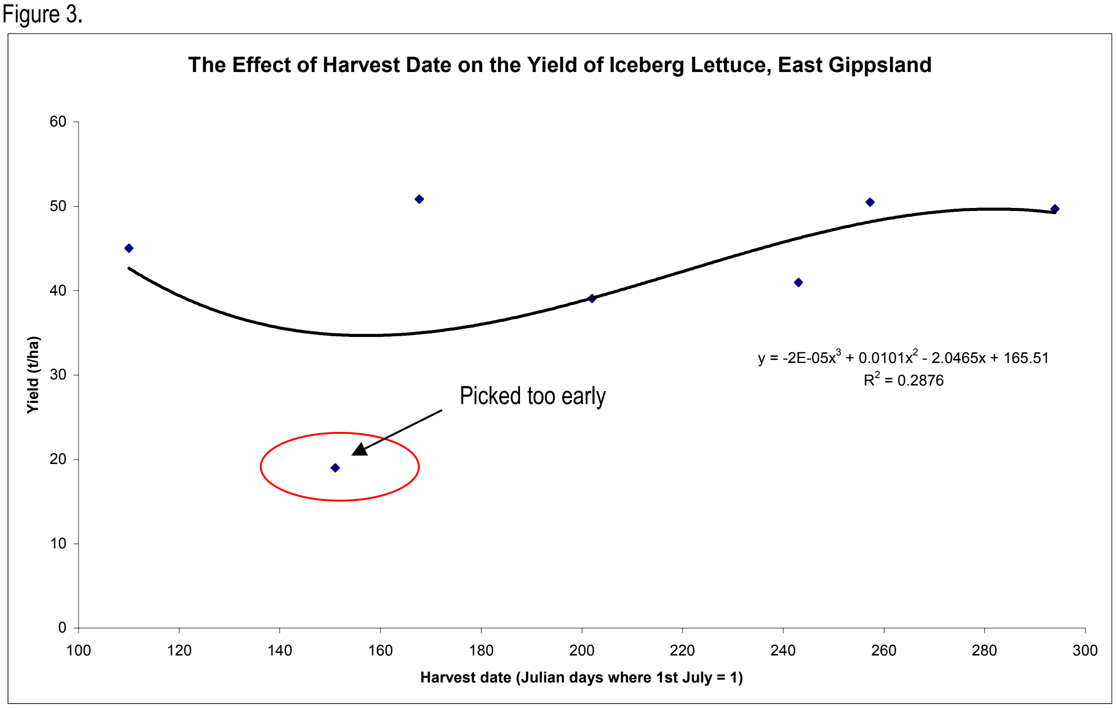



Figure 4:

**Table 2. East Gippsland Iceberg Schedule**

| Harvest Date | Number of Days to Harvest | Planting Date | Yield (t/ha) | Plants Required per Tonne |
|---|---|---|---|---|
| 8-Oct | 96 | 4-Jul | 58 | 1034 |
| 15-Oct | 91 | 16-Jul | 57 | 1053 |
| 22-Oct | 86 | 28-Jul | 56 | 1071 |
| 29-Oct | 82 | 8-Aug | 56 | 1071 |
| 5-Nov | 77 | 20-Aug | 55 | 1091 |
| 12-Nov | 73 | 31-Aug | 54 | 1111 |
| 19-Nov | 70 | 10-Sep | 54 | 1111 |
| 26-Nov | 67 | 20-Sep | 54 | 1111 |
| 3-Dec | 64 | 30-Sep | 53 | 1132 |
| 10-Dec | 62 | 9-Oct | 53 | 1132 |
| 17-Dec | 60 | 18-Oct | 52 | 1154 |
| 24-Dec | 58 | 27-Oct | 52 | 1154 |
| 31-Dec | 57 | 4-Nov | 52 | 1154 |
| 7-Jan | 55 | 13-Nov | 52 | 1154 |
| 14-Jan | 54 | 21-Nov | 51 | 1176 |
| 21-Jan | 53 | 29-Nov | 51 | 1176 |
| 28-Jan | 53 | 6-Dec | 51 | 1176 |
| 4-Feb | 52 | 14-Dec | 51 | 1176 |
| 11-Feb | 52 | 21-Dec | 51 | 1176 |
| 18-Feb | 52 | 28-Dec | 51 | 1176 |
| 25-Feb | 53 | 3-Jan | 51 | 1176 |
| 4-Mar | 53 | 10-Jan | 51 | 1176 |
| 11-Mar | 54 | 16-Jan | 52 | 1154 |
| 18-Mar | 55 | 22-Jan | 52 | 1154 |
| 25-Mar | 56 | 28-Jan | 52 | 1154 |
| 1-Apr | 57 | 3-Feb | 52 | 1154 |
| 8-Apr | 58 | 9-Feb | 52 | 1154 |
| 15-Apr | 59 | 15-Feb | 52 | 1154 |
| 22-Apr | 60 | 21-Feb | 53 | 1132 |

***Disclaimer**: This scheduling model is presented as a guide for growers only as it is based on two season's data for the East Gippsland district. Days to harvest and yield will vary with season, growing district and crop production methods.*

## 3. Variation in Crop Growth Period and Yield in Toowoomba – Iceberg

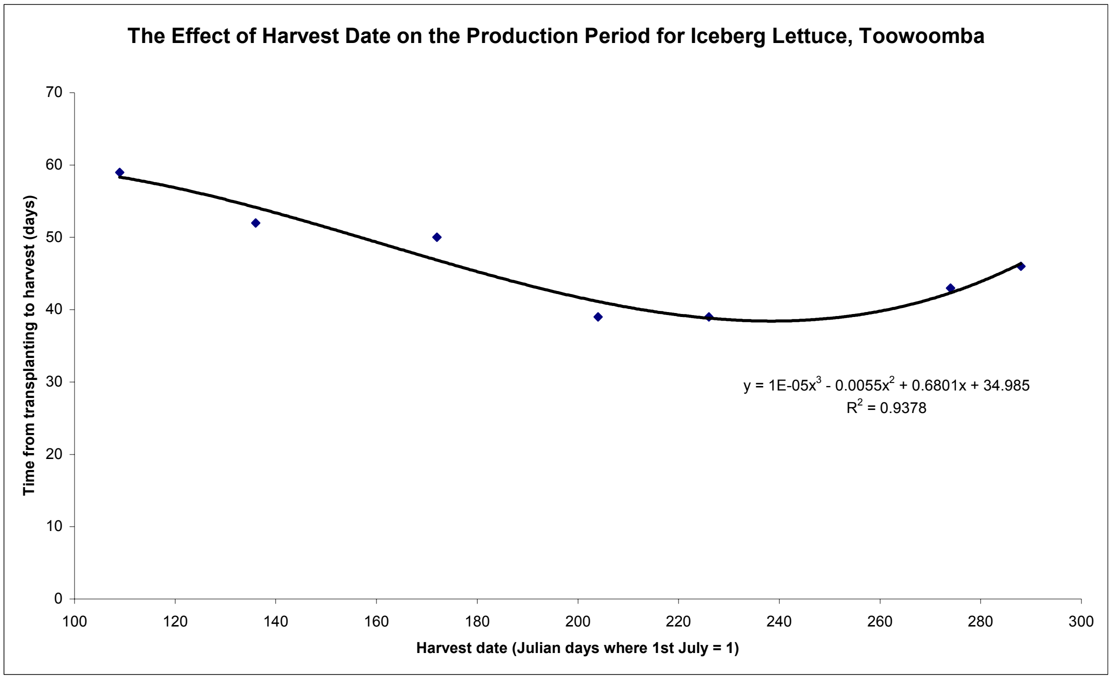



Figure 5:

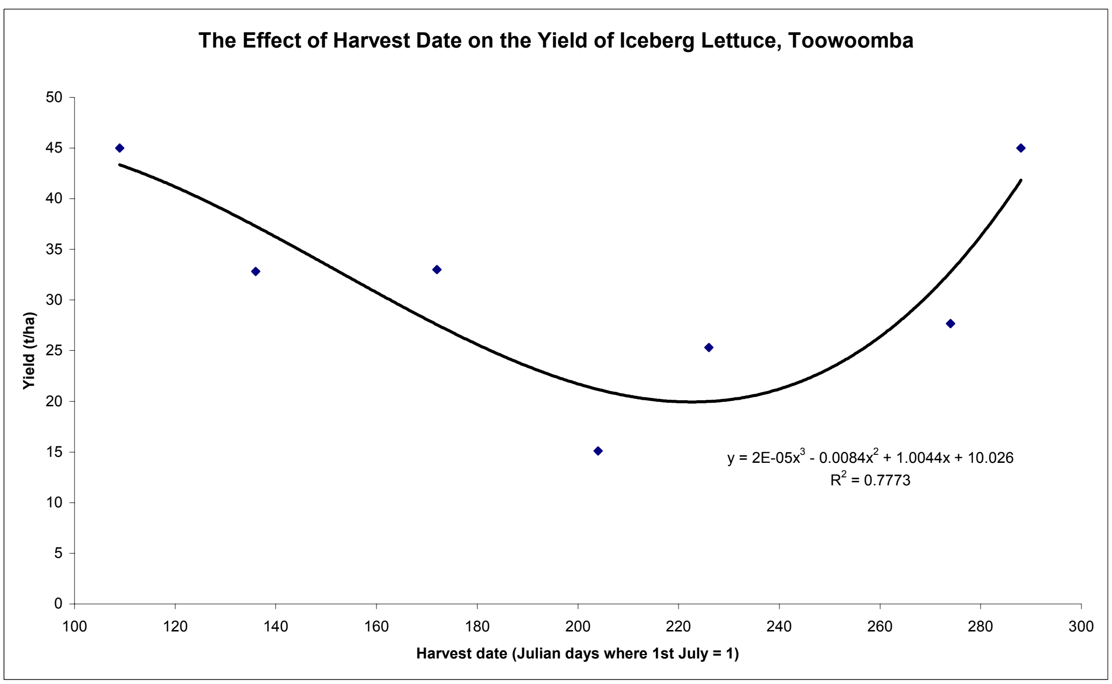



Figure 6:

**Table 3. Toowoomba Iceberg schedule**

| Harvest Date | Number of Days to Harvest | Planting Date | Yield (t/ha) | Plants Required per Tonne |
|---|---|---|---|---|
| 1-Nov | 57 | 5-Sep | 41 | 1463 |
| 8-Nov | 54 | 15-Sep | 38 | 1579 |
| 15-Nov | 52 | 24-Sep | 35 | 1714 |
| 22-Nov | 50 | 3-Oct | 32 | 1875 |
| 29-Nov | 48 | 12-Oct | 30 | 2000 |
| 6-Dec | 46 | 21-Oct | 28 | 2143 |
| 13-Dec | 44 | 30-Oct | 26 | 2308 |
| 20-Dec | 43 | 7-Nov | 24 | 2500 |
| 27-Dec | 42 | 15-Nov | 22 | 2727 |
| 3-Jan | 41 | 23-Nov | 21 | 2857 |
| 10-Jan | 40 | 1-Dec | 20 | 3000 |
| 17-Jan | 39 | 9-Dec | 19 | 3158 |
| 24-Jan | 39 | 16-Dec | 18 | 3333 |
| 31-Jan | 38 | 24-Dec | 18 | 3333 |
| 7-Feb | 38 | 31-Dec | 18 | 3333 |
| 14-Feb | 38 | 7-Jan | 18 | 3333 |
| 21-Feb | 39 | 13-Jan | 18 | 3333 |
| 28-Feb | 39 | 20-Jan | 19 | 3158 |
| 6-Mar | 40 | 26-Jan | 20 | 3000 |
| 13-Mar | 40 | 2-Feb | 21 | 2857 |
| 20-Mar | 41 | 8-Feb | 22 | 2727 |
| 27-Mar | 42 | 14-Feb | 24 | 2500 |

***Disclaimer****: This scheduling model is presented as a guide for growers only as it is based on two season's data for the Toowoomba district. Days to harvest and yield will vary with season, growing district and crop production methods.*

## 4. Variation in Crop Growth Period and Yield in Toowoomba – Cos

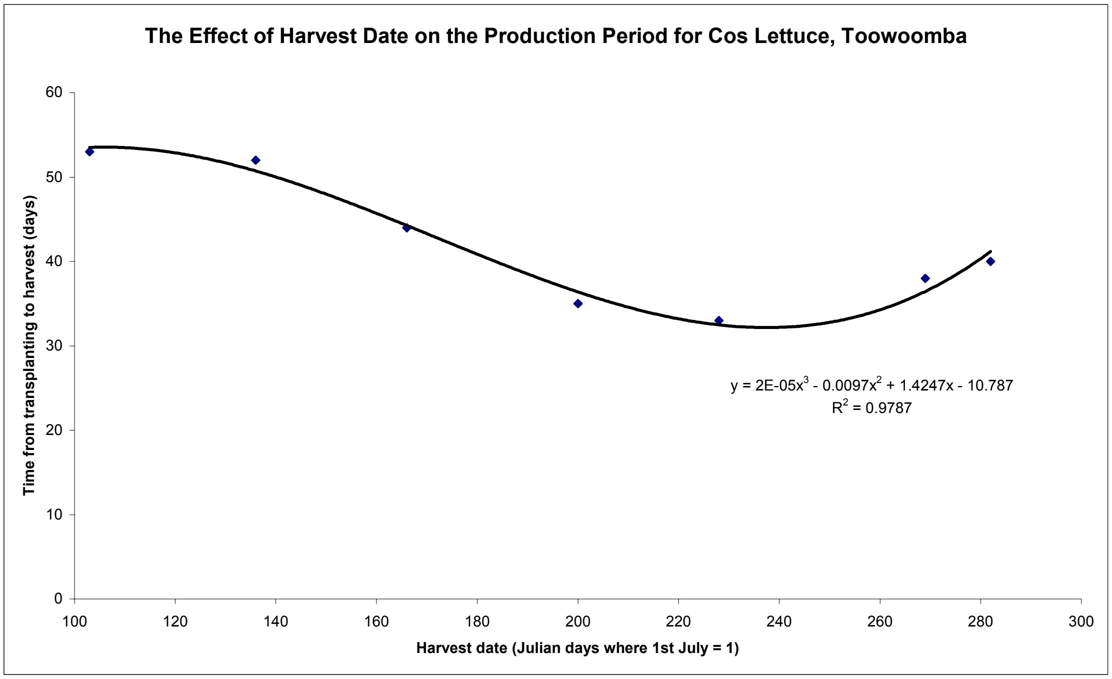



Figure 8:

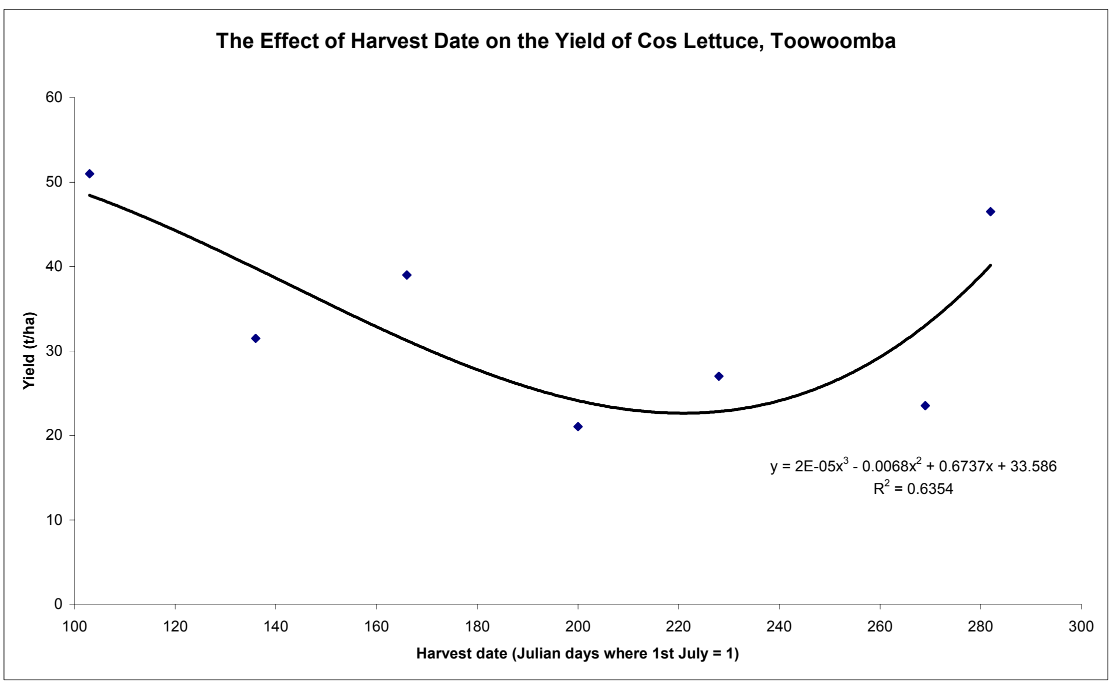



Figure 9:

**Table 4. Toowoomba Cos schedule**

| Harvest Date | Number of Days to Harvest | Planting Date | Yield (t/ha) | Plants Required per Tonne |
|---|---|---|---|---|
| 1-Nov | 58 | 4-Sep | 34 | 1765 |
| 8-Nov | 55 | 14-Sep | 31 | 1935 |
| 15-Nov | 51 | 25-Sep | 28 | 2143 |
| 22-Nov | 48 | 5-Oct | 26 | 2308 |
| 29-Nov | 46 | 14-Oct | 24 | 2500 |
| 6-Dec | 44 | 23-Oct | 22 | 2727 |
| 13-Dec | 42 | 1-Nov | 21 | 2857 |
| 20-Dec | 40 | 10-Nov | 20 | 3000 |
| 27-Dec | 38 | 19-Nov | 19 | 3158 |
| 3-Jan | 37 | 27-Nov | 18 | 3333 |
| 10-Jan | 36 | 5-Dec | 17 | 3529 |
| 17-Jan | 35 | 13-Dec | 17 | 3529 |
| 24-Jan | 34 | 21-Dec | 17 | 3529 |
| 31-Jan | 34 | 28-Dec | 17 | 3529 |
| 7-Feb | 34 | 4-Jan | 17 | 3529 |
| 14-Feb | 34 | 11-Jan | 18 | 3333 |
| 21-Feb | 34 | 18-Jan | 18 | 3333 |
| 28-Feb | 34 | 25-Jan | 19 | 3158 |
| 6-Mar | 35 | 31-Jan | 20 | 3000 |
| 13-Mar | 36 | 6-Feb | 22 | 2727 |
| 20-Mar | 37 | 12-Feb | 23 | 2609 |
| 27-Mar | 38 | 18-Feb | 25 | 2400 |

***Disclaimer**: This scheduling model is presented as a guide for growers only as it is based on two season's data for the Toowoomba district. Days to harvest and yield will vary with season, growing district and crop production methods.*

# Appendix 3 – Results from the lettuce Variety trials

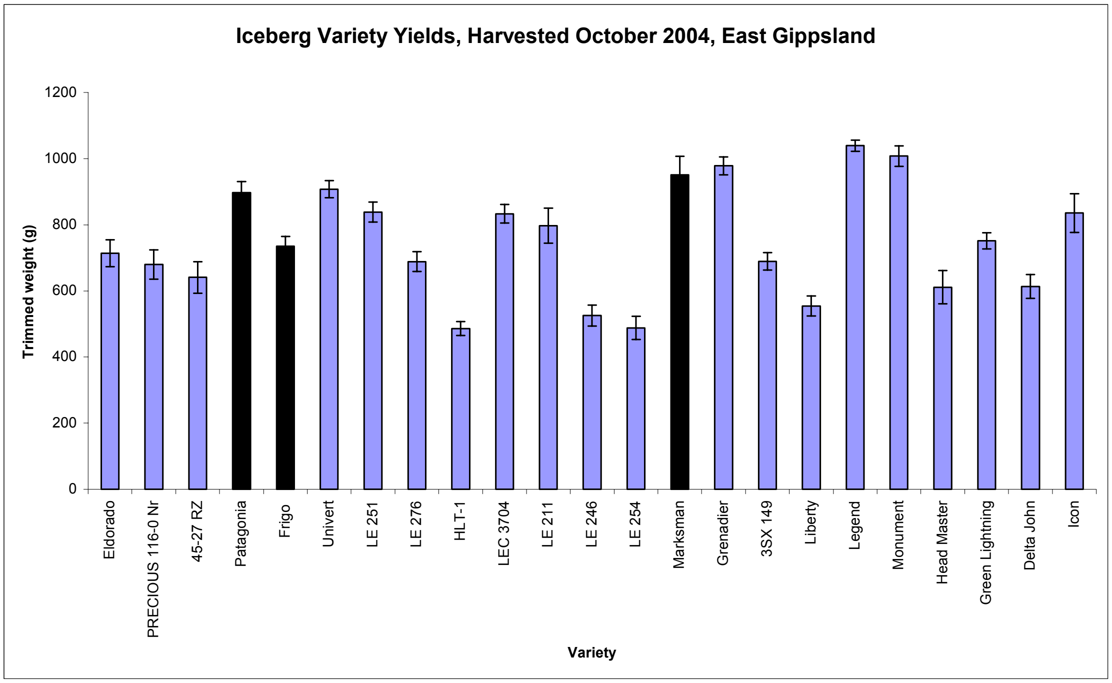



Figure 3.

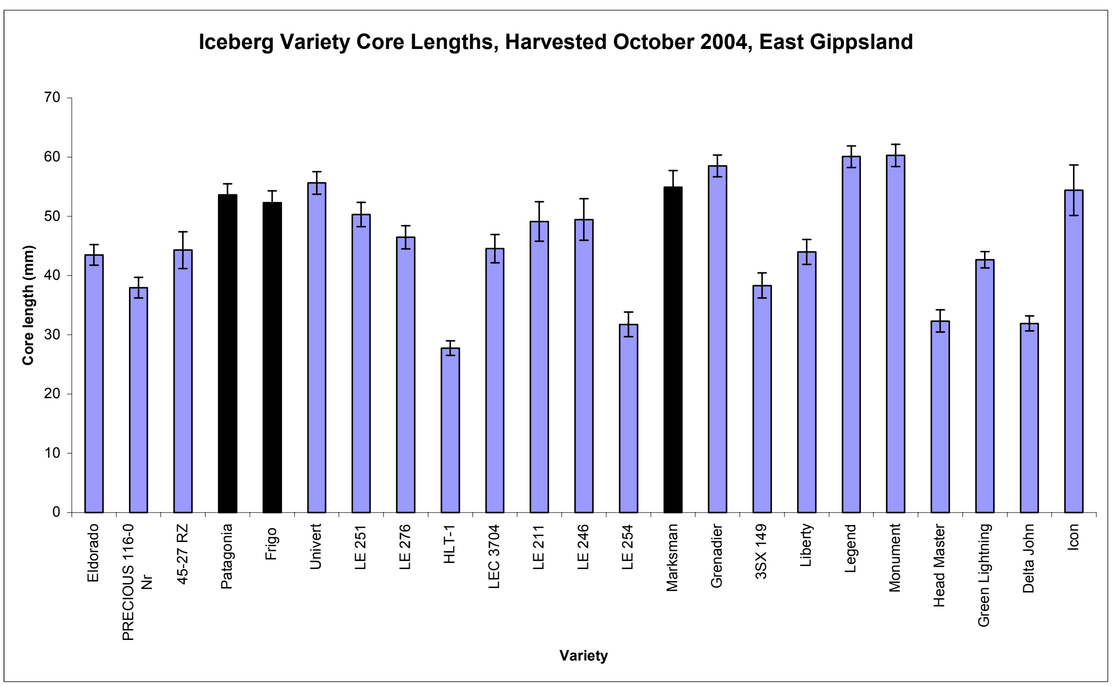



Figure 4.

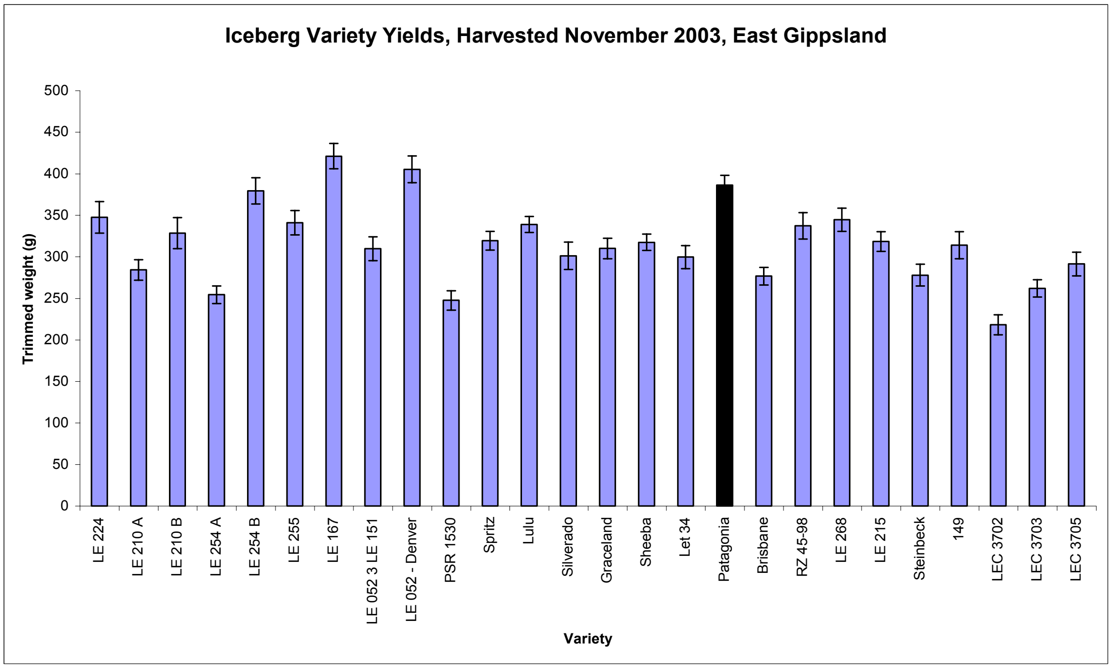



Figure 5.

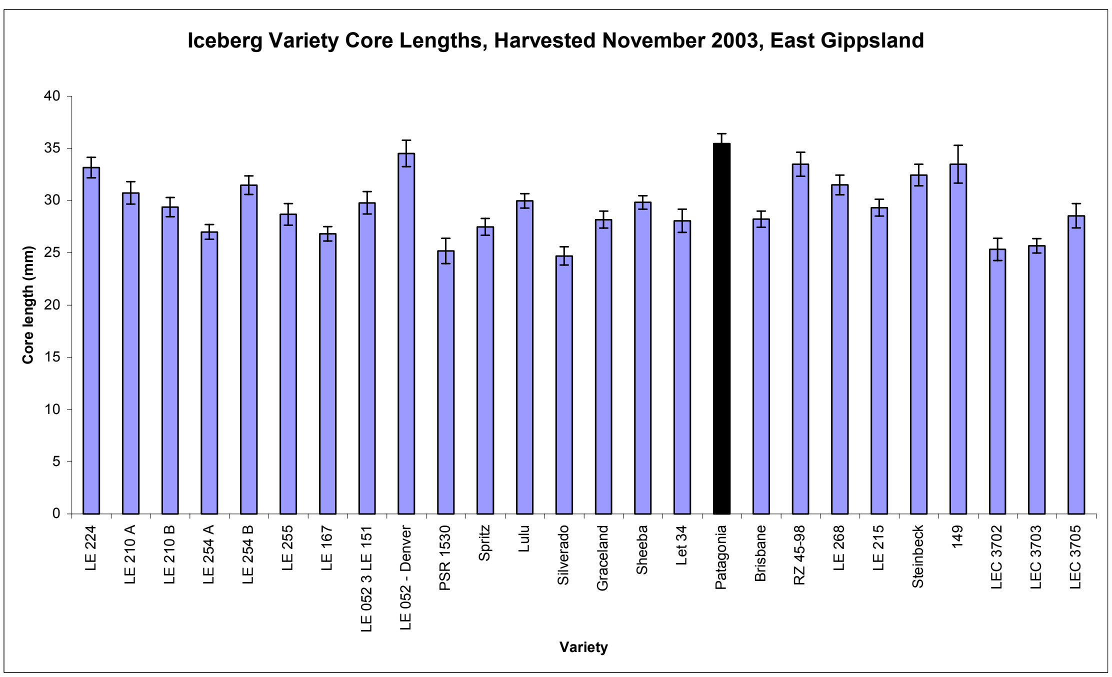



Figure 6.

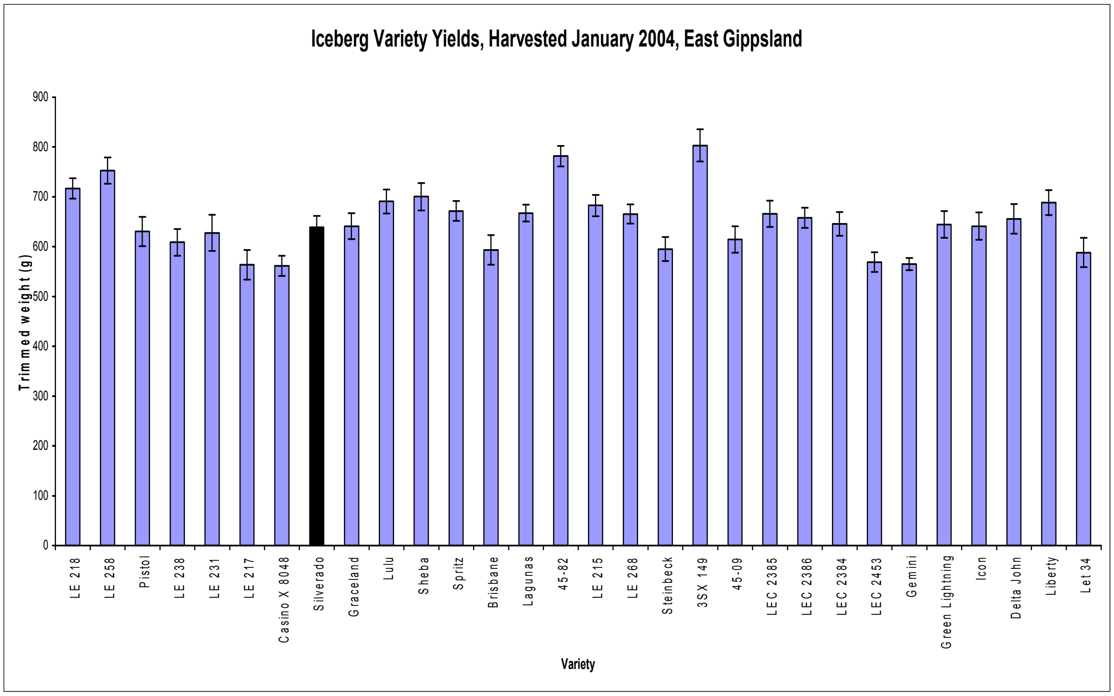



Figure 7.

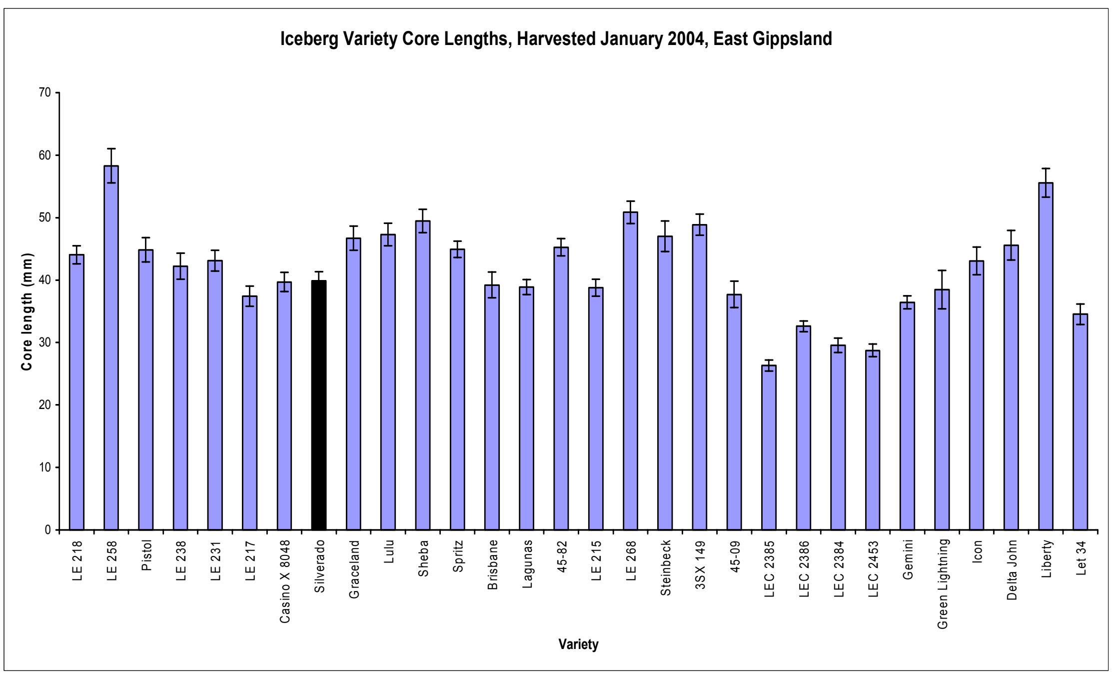



Figure 8.

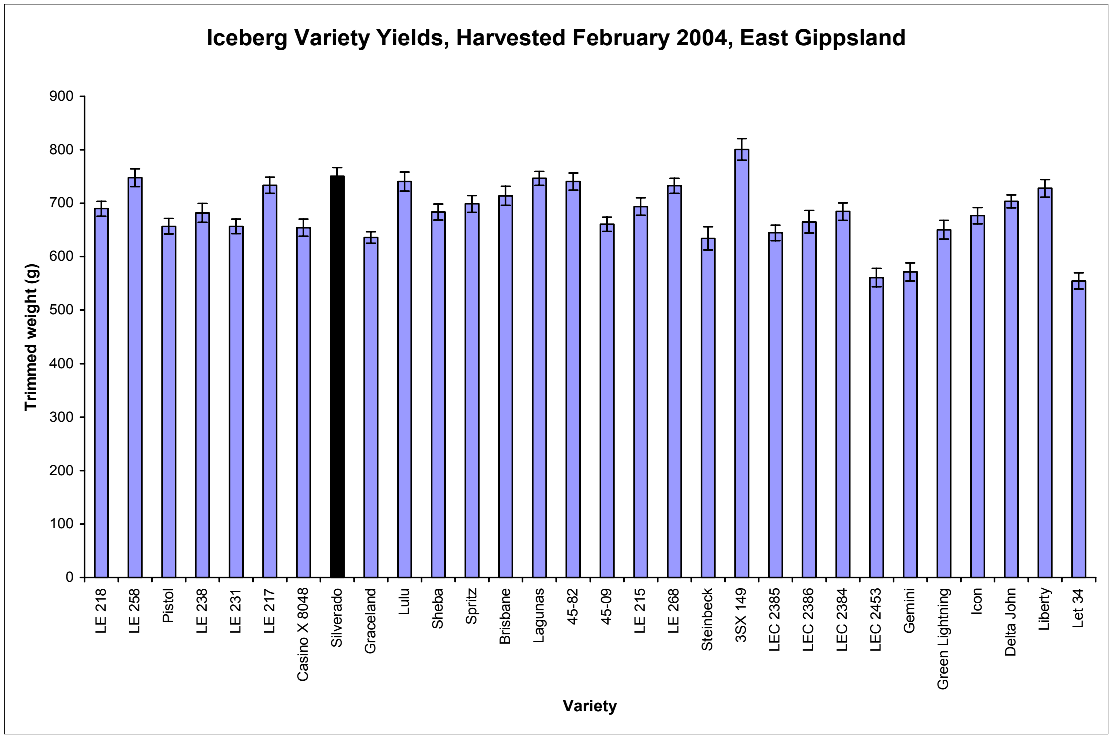



Figure 9.

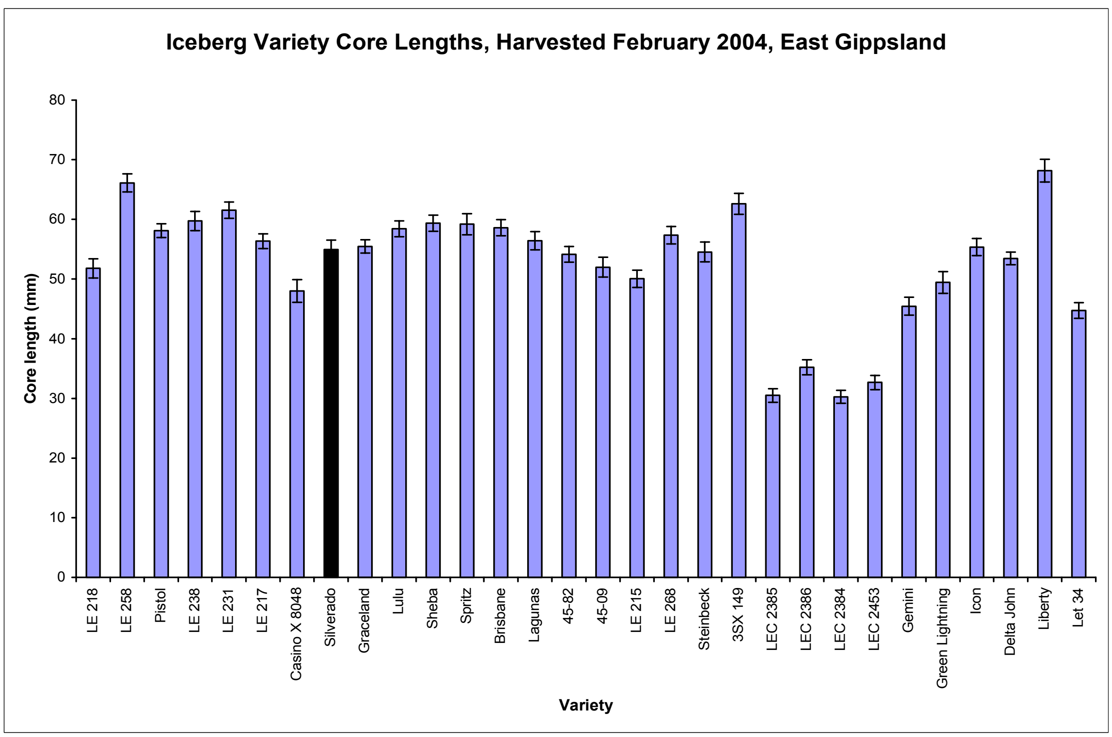



Figure 10.

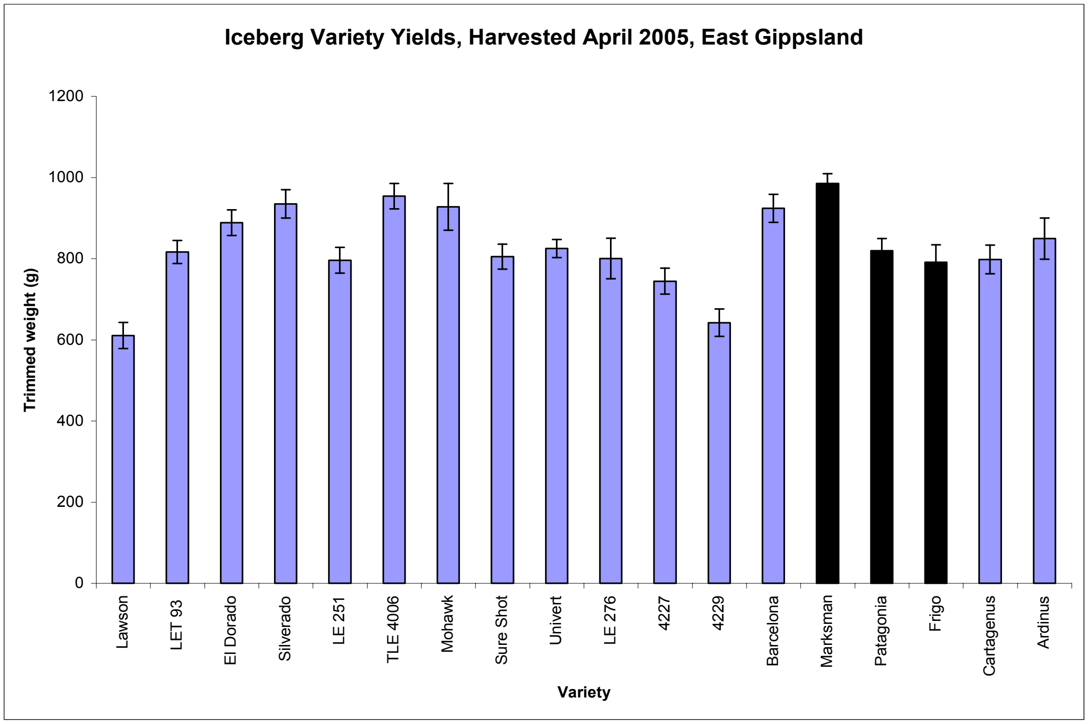



Figure 11.

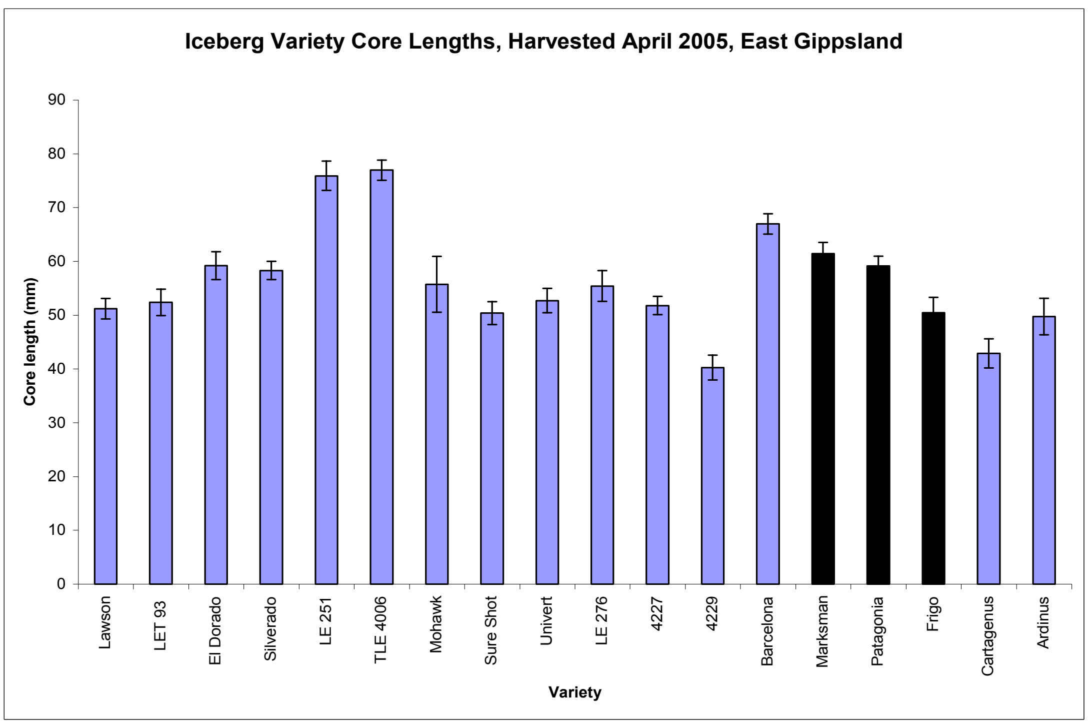



Figure 12.

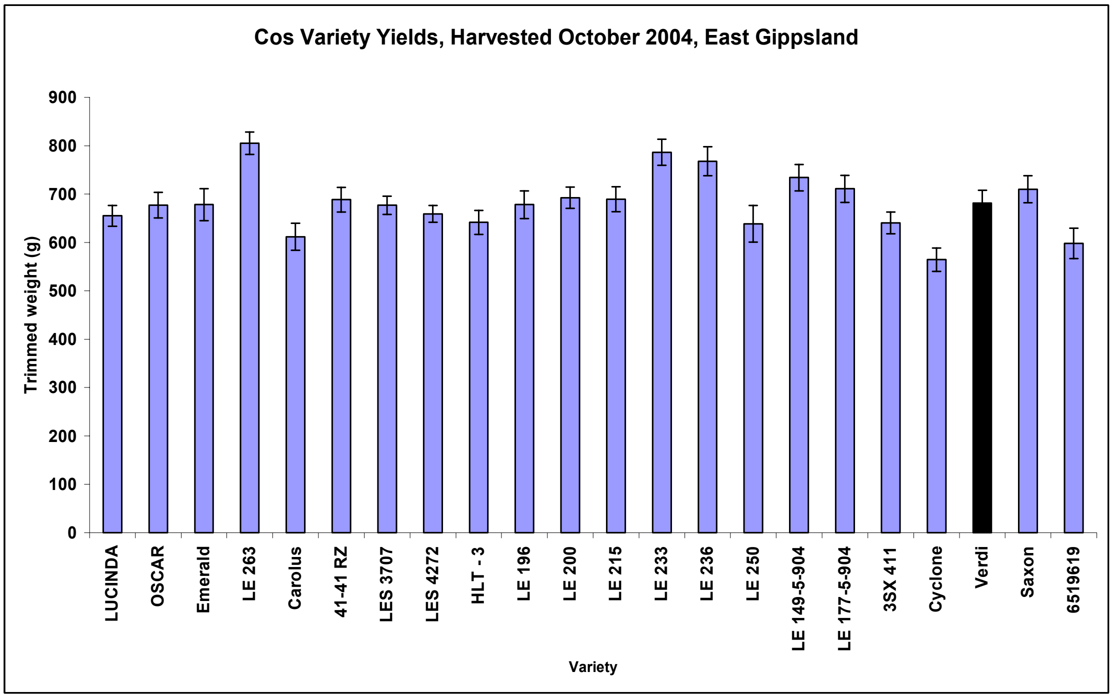



Figure 13.

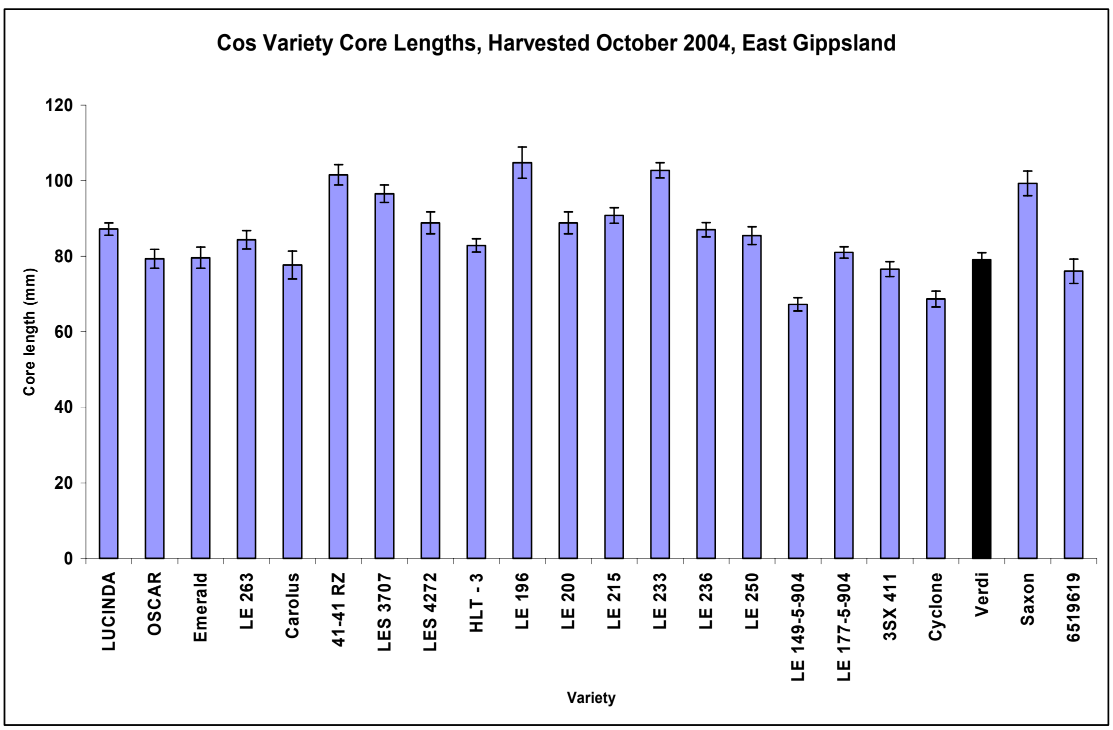



Figure 14.

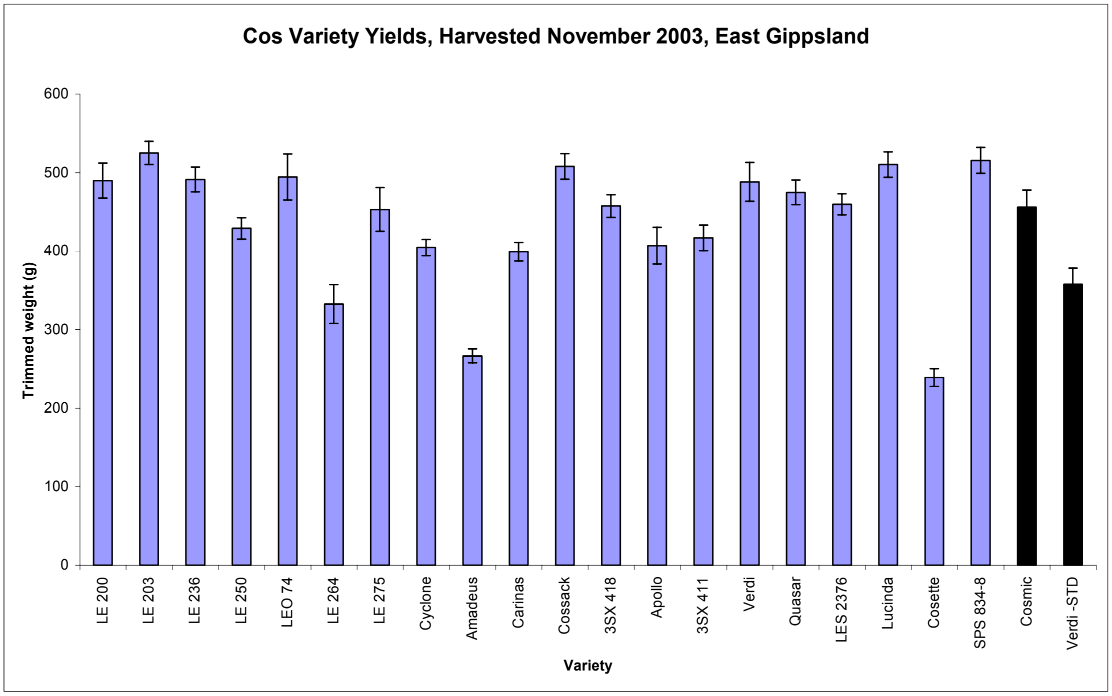



Figure 15.

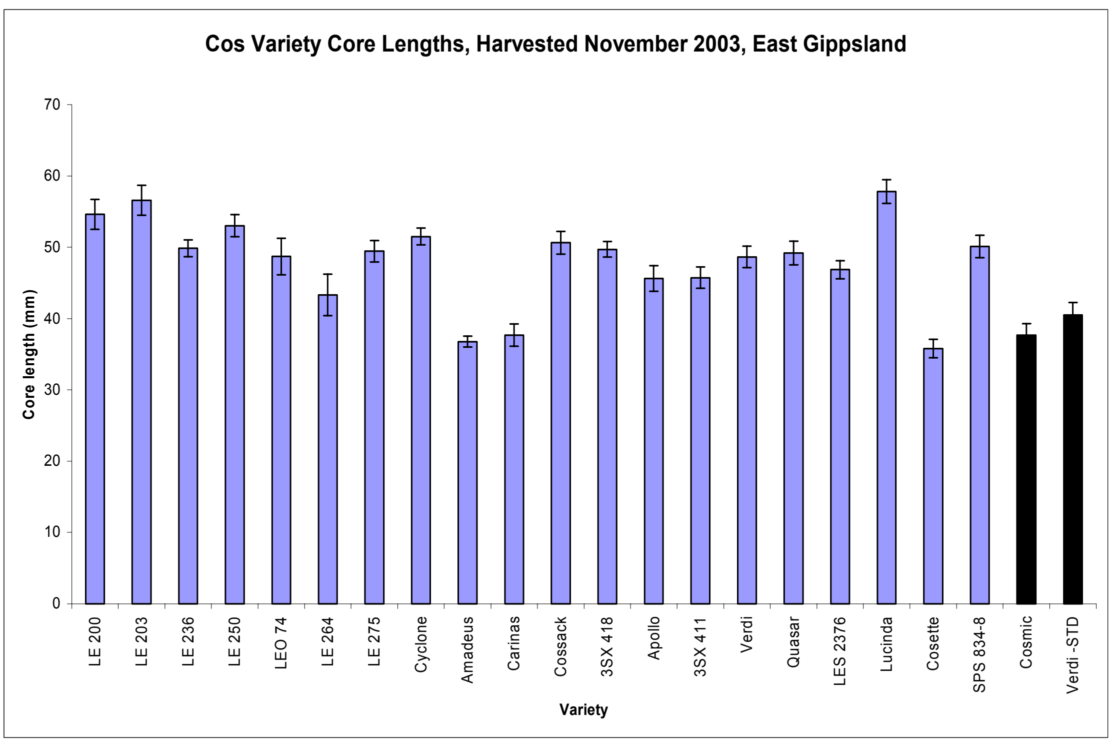



Figure 16.

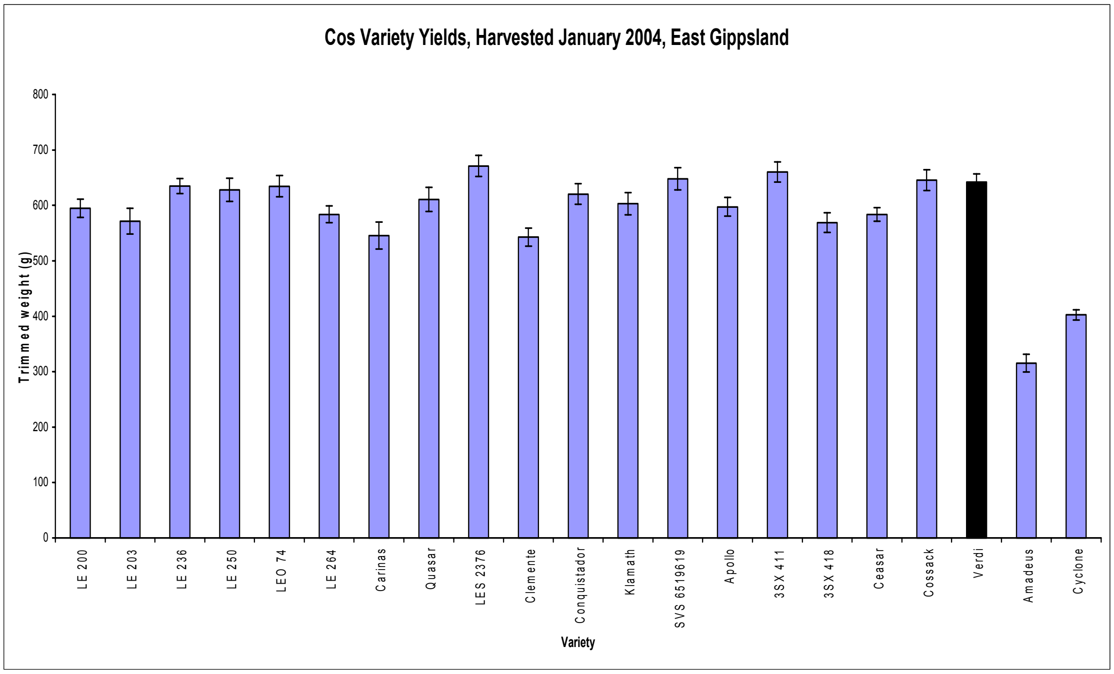



Figure 17.

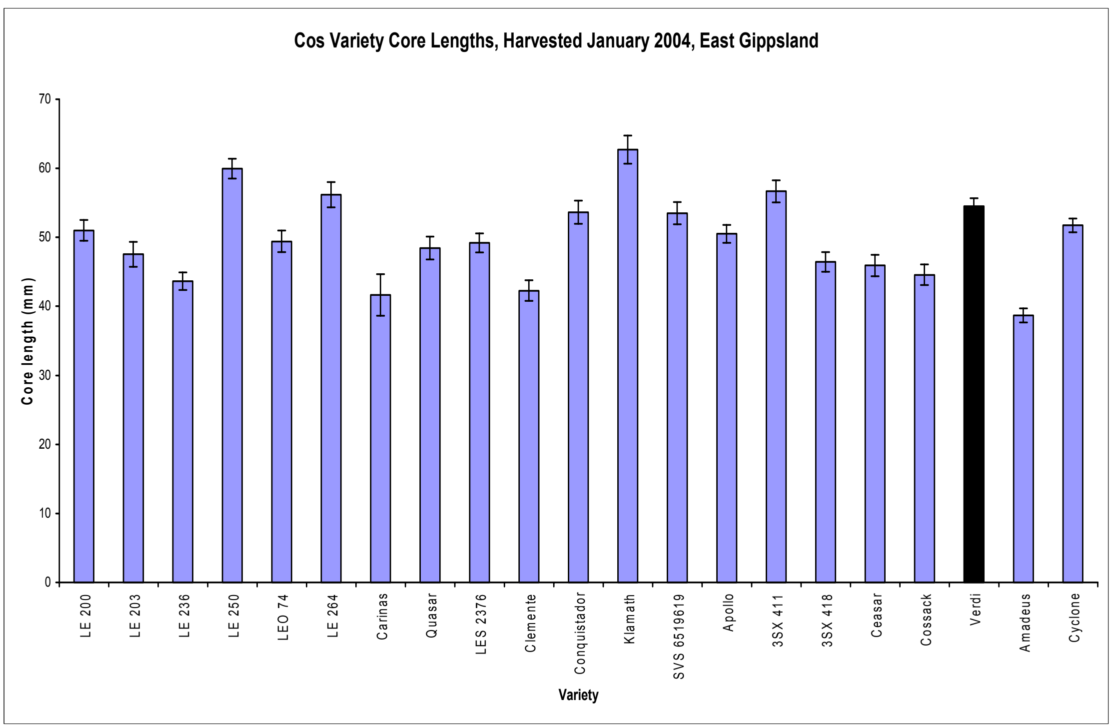



Figure 18.

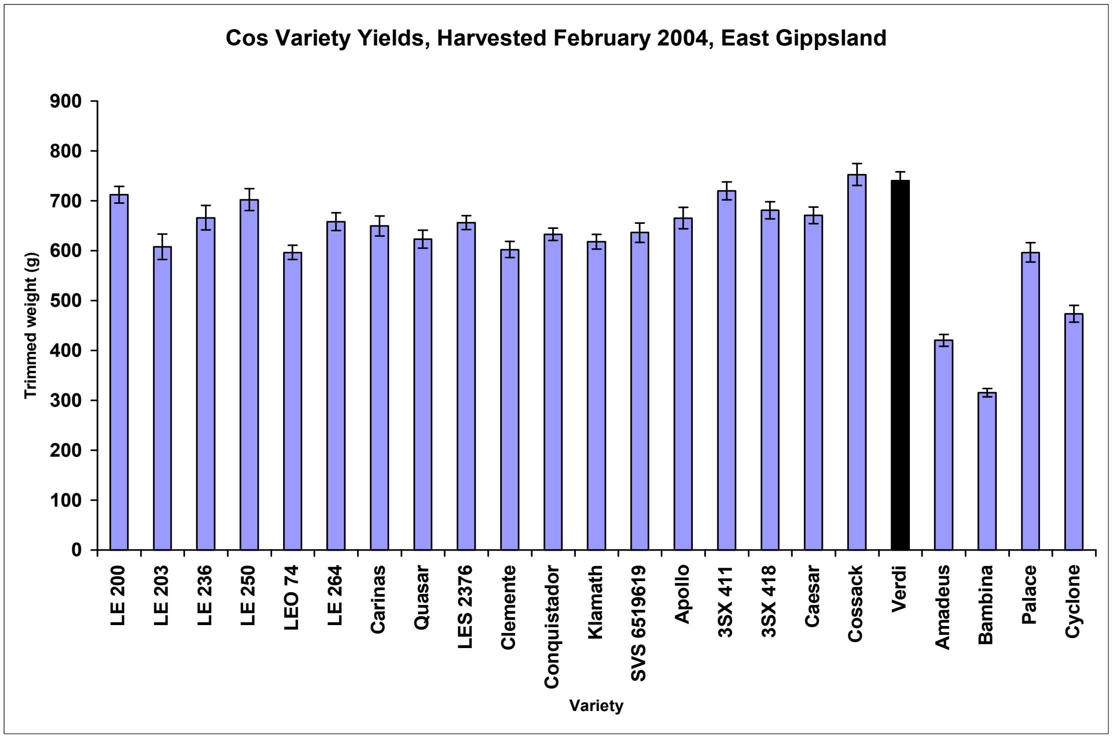



Figure 19.

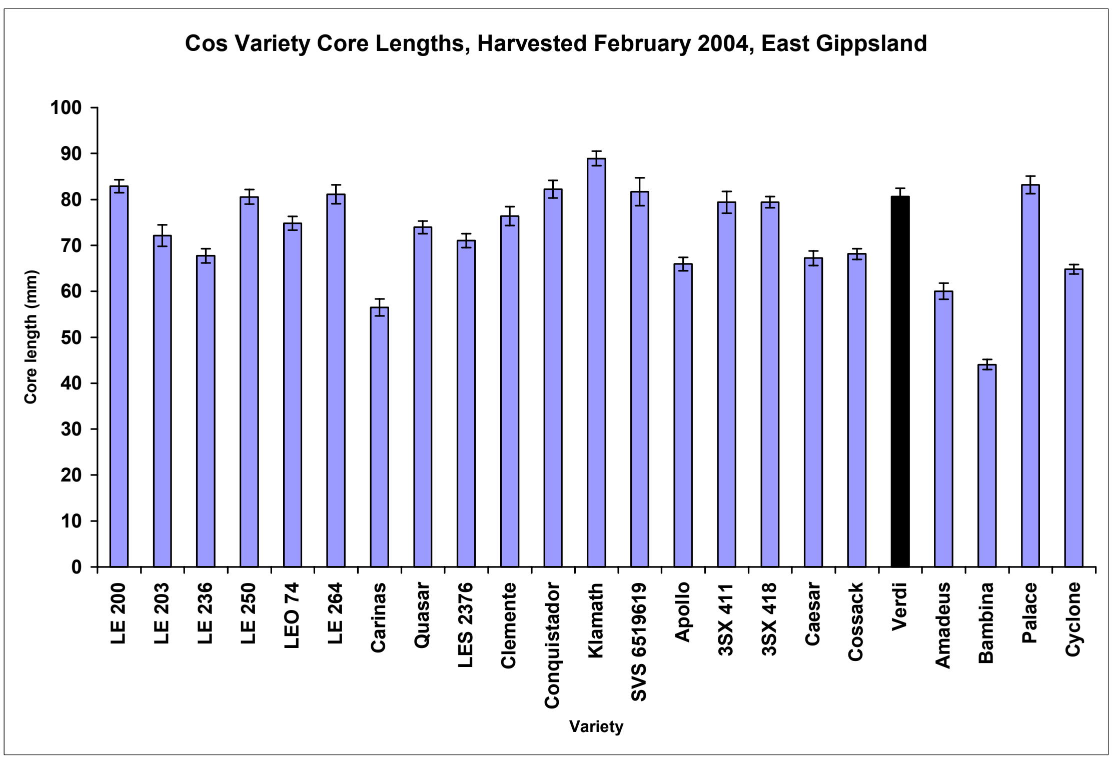



Figure 20.

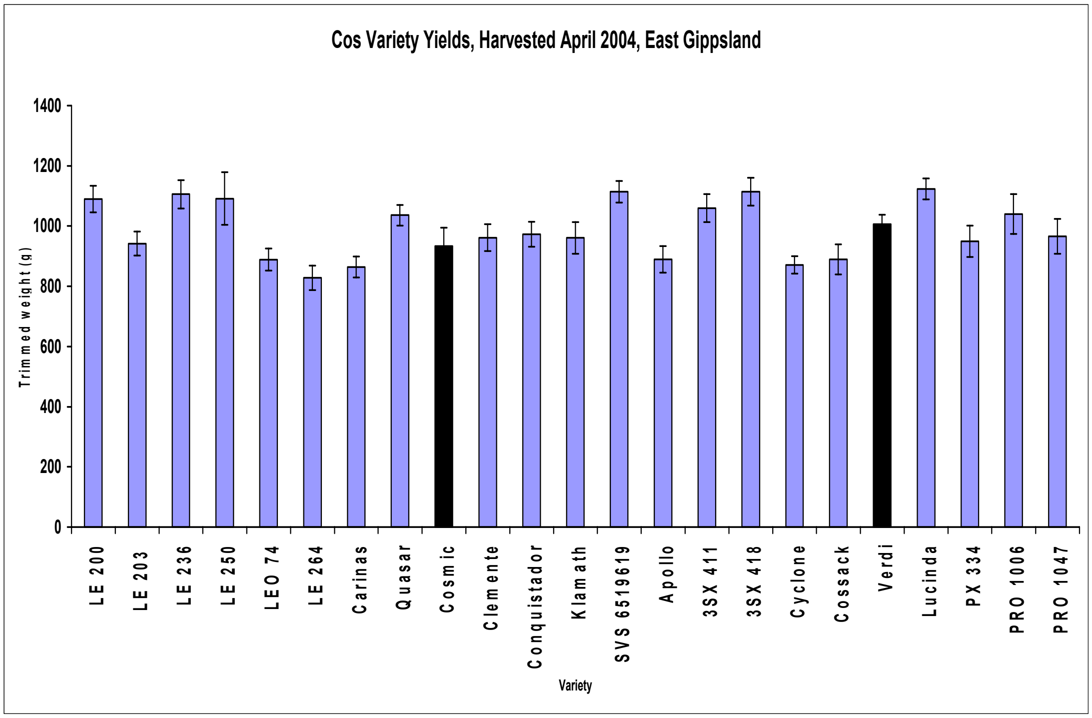



Figure 21.

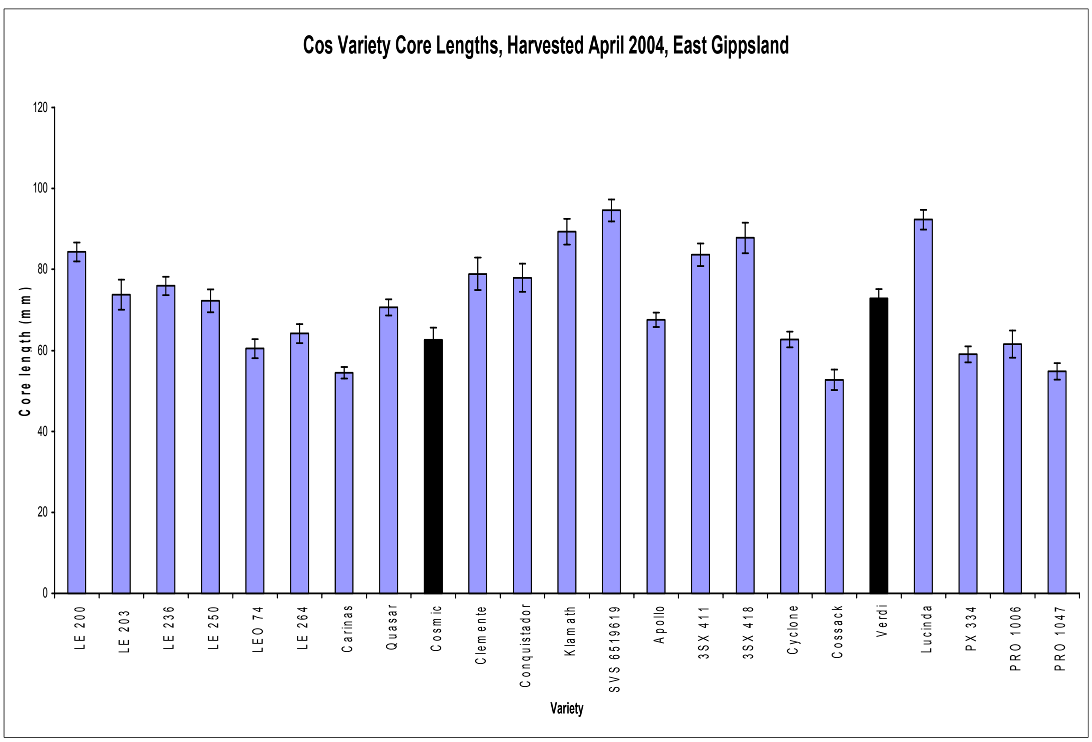
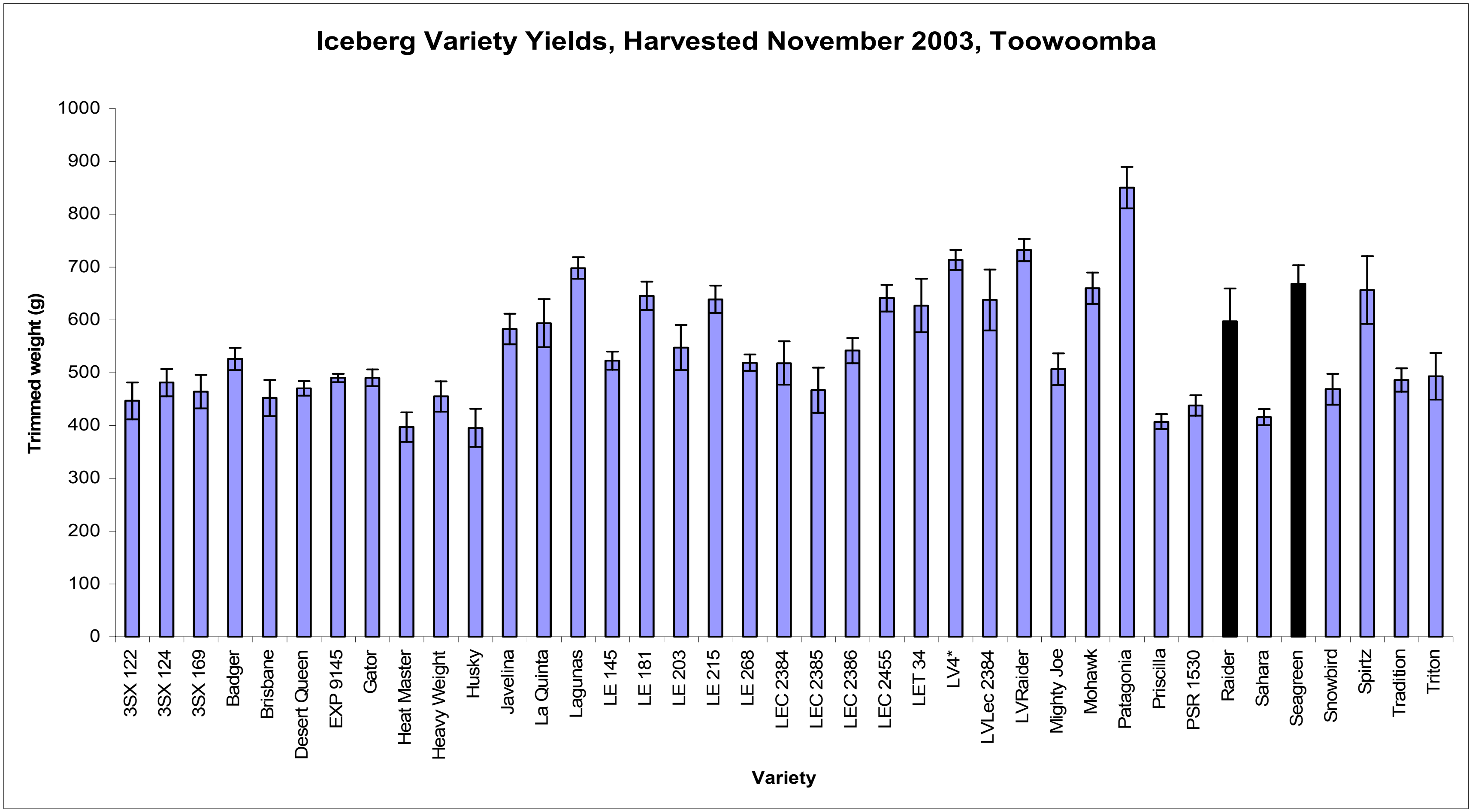



Figure 22.

Figure 23.



Iceberg Variety Yields, Harvested November 2003, Toowoomba
Trimmed weight (g)
1000
900
800
700
600
500
400
300
200
100
0
3SX 122
3SX 124
3SX 169
Badger
Brisbane
Desert Queen
EXP 9145
Gator
Heat Master
Heavy Weight
Husky
Javelina
La Quinta
Lagunas
LE 145
LE 181
LE 203
LE 215
LE 268
LEC 2384
LEC 2385
LEC 2386
LEC 2455
LET 34
LV4*
LVLec 2384
LVRaider
Mighty Joe
Mohawk
Patagonia
Priscilla
PSR 1530
Raider
Sahara
Seagreen
Snowbird
Spirtz
Tradition
Triton
Variety

Figure 24.

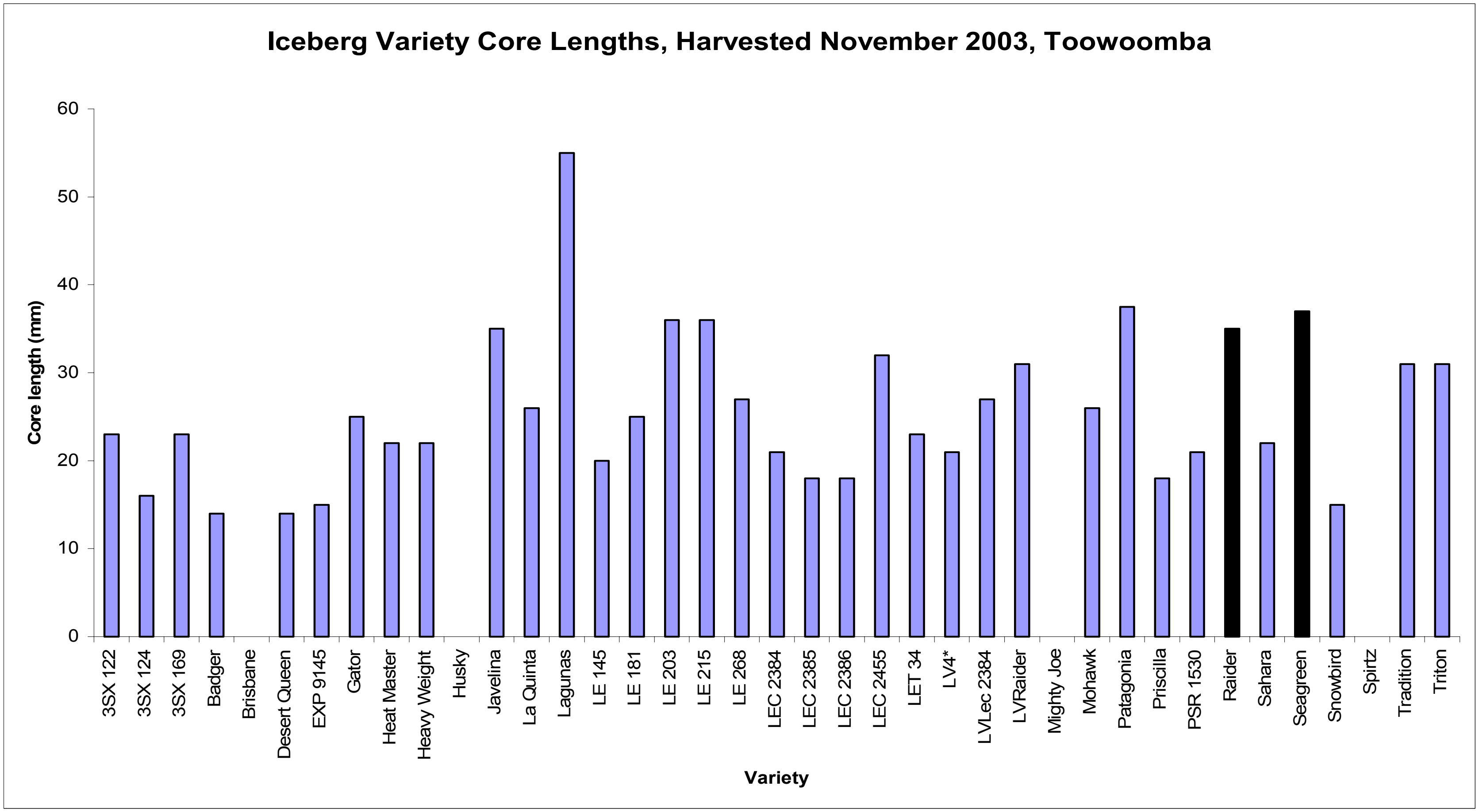
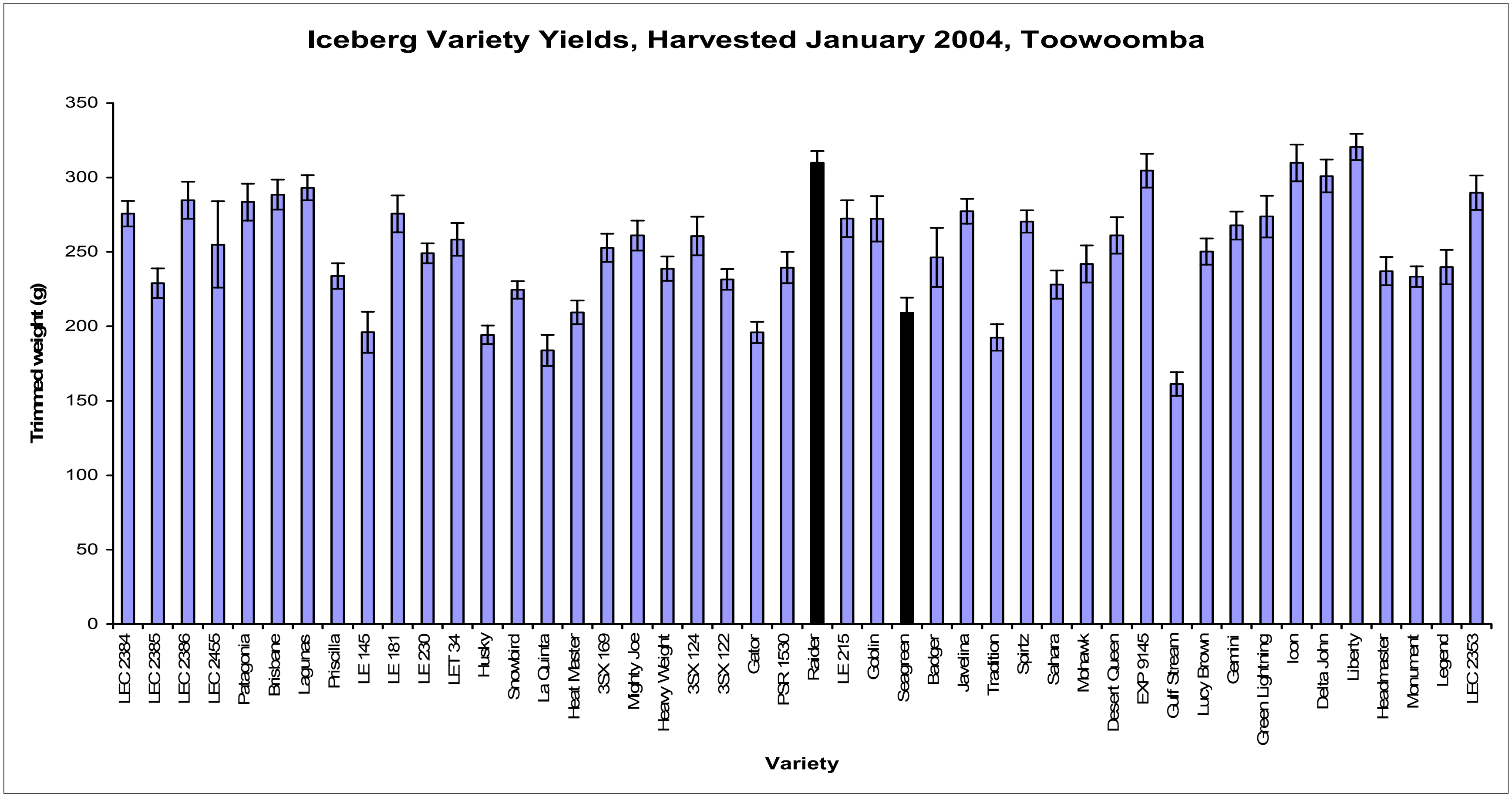
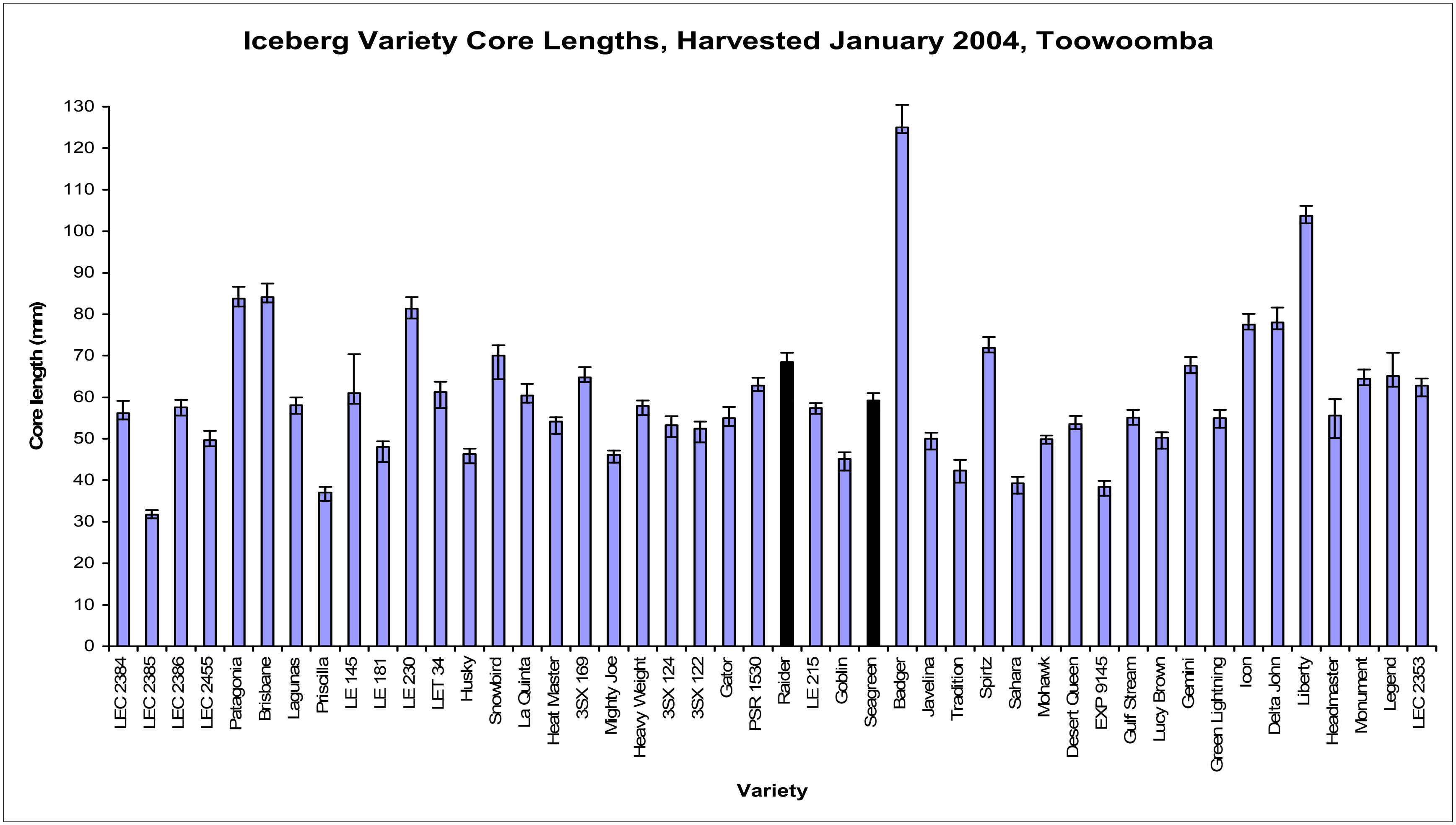

Iceberg Variety Core Lengths, Harvested November 2003, Toowoomba
Core length (mm)
0
10
20
30
40
50
60
3SX 122
3SX 124
3SX 169
Badger
Brisbane
Desert Queen
EXP 9145
Gator
Heat Master
Heavy Weight
Husky
Javelina
La Quinta
Lagunas
LE 145
LE 181
LE 203
LE 215
LE 268
LEC 2384
LEC 2385
LEC 2386
LEC 2455
LET 34
LV4*
LVLec 2384
LVRaider
Mighty Joe
Mohawk
Patagonia
Priscilla
PSR 1530
Raider
Sahara
Seagreen
Snowbird
Spirtz
Tradition
Triton
Variety

Figure 25.



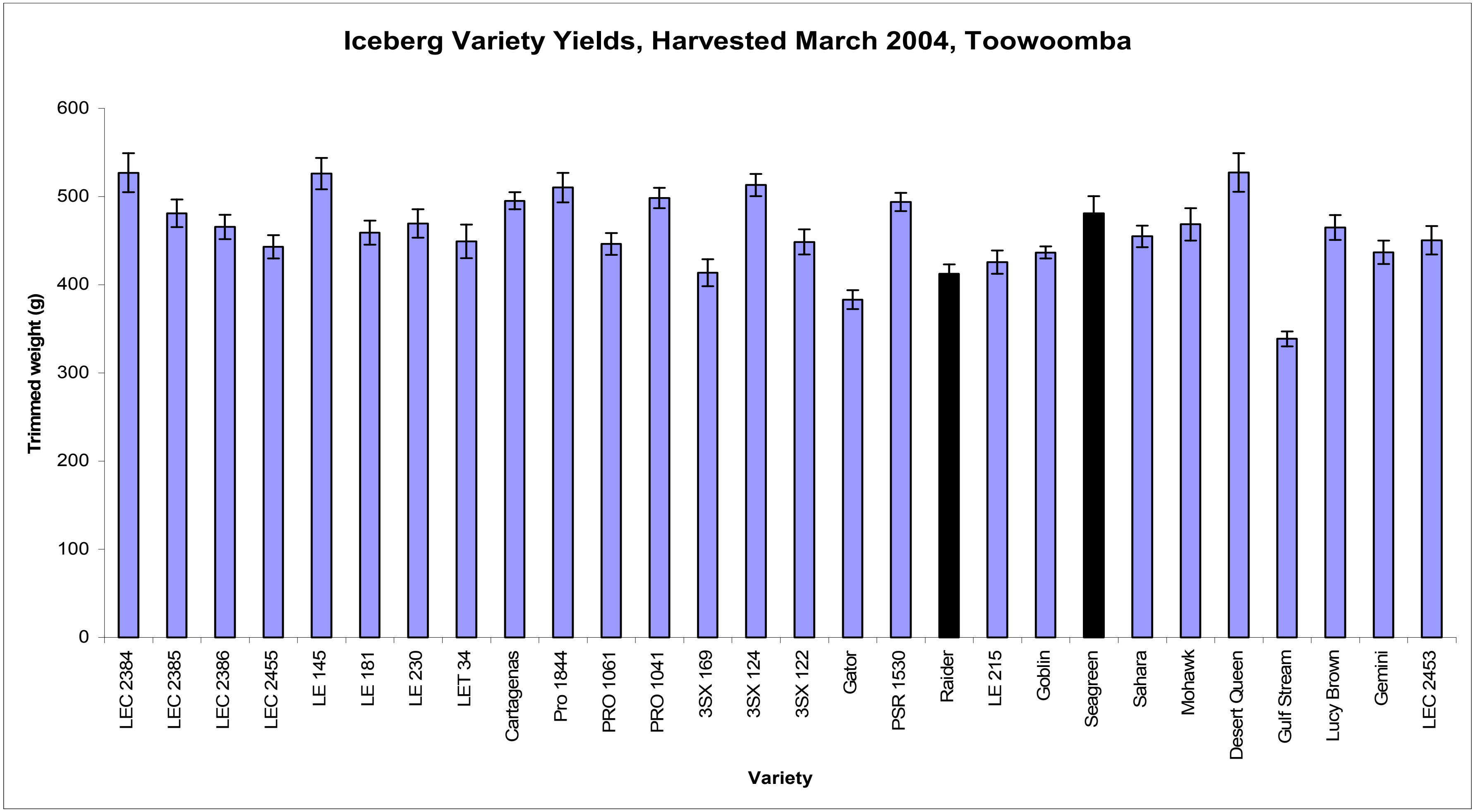
Iceberg Variety Yields, Harvested January 2004, Toowoomba
Trimmed weight (g)
0
50
100
150
200
250
300
350
LEC 2384
LEC 2385
LEC 2386
LEC 2455
Patagonia
Brisbane
Lagunas
Priscilla
LE 145
LE 181
LE 230
LET 34
Husky
Snowbird
La Quinta
Heat Master
3SX 169
Mighty Joe
Heavy Weight
3SX 124
3SX 122
Gator
PSR 1530
Raider
LE 215
Goblin
Seagreen
Badger
Javelina
Tradition
Spirtz
Sahara
Mohawk
Desert Queen
EXP 9145
Gulf Stream
Lucy Brown
Gemini
Green Lightning
Icon
Delta John
Liberty
Headmaster
Monument
Legend
LEC 2353
Variety

Figure 26.



Iceberg Variety Core Lengths, Harvested January 2004, Toowoomba
Core length (mm)
130
120
110
100
90
80
70
60
50
40
30
20
10
0
LEC 2384
LEC 2385
LEC 2386
LEC 2455
Patagonia
Brisbane
Lagunas
Priscilla
LE 145
LE 181
LE 230
LET 34
Husky
Snowbird
La Quinta
Heat Master
3SX 169
Mighty Joe
Heavy Weight
3SX 124
3SX 122
Gator
PSR 1530
Raider
LE 215
Goblin
Seagreen
Badger
Javelina
Tradition
Spirtz
Sahara
Mohawk
Desert Queen
EXP 9145
Gulf Stream
Lucy Brown
Gemini
Green Lightning
Icon
Delta John
Liberty
Headmaster
Monument
Legend
LEC 2353
Variety

Figure 27.



Iceberg Variety Yields, Harvested March 2004, Toowoomba
Trimmed weight (g)
600
500
400
300
200
100
0
LEC 2384
LEC 2385
LEC 2386
LEC 2455
LE 145
LE 181
LE 230
LET 34
Cartagenas
Pro 1844
PRO 1061
PRO 1041
3SX 169
3SX 124
3SX 122
Gator
PSR 1530
Raider
LE 215
Goblin
Seagreen
Sahara
Mohawk
Desert Queen
Gulf Stream
Lucy Brown
Gemini
LEC 2453
Variety

Figure 28.

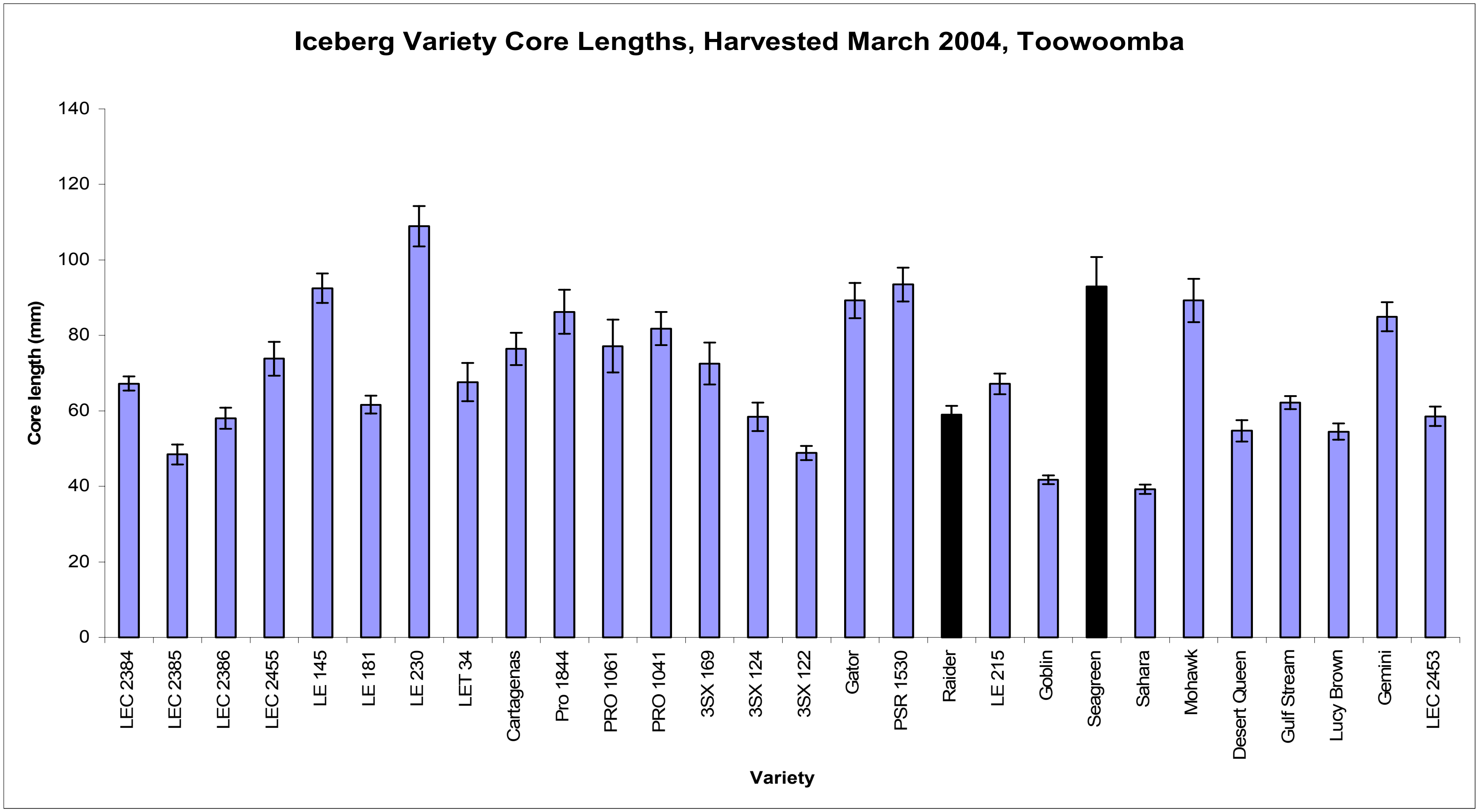
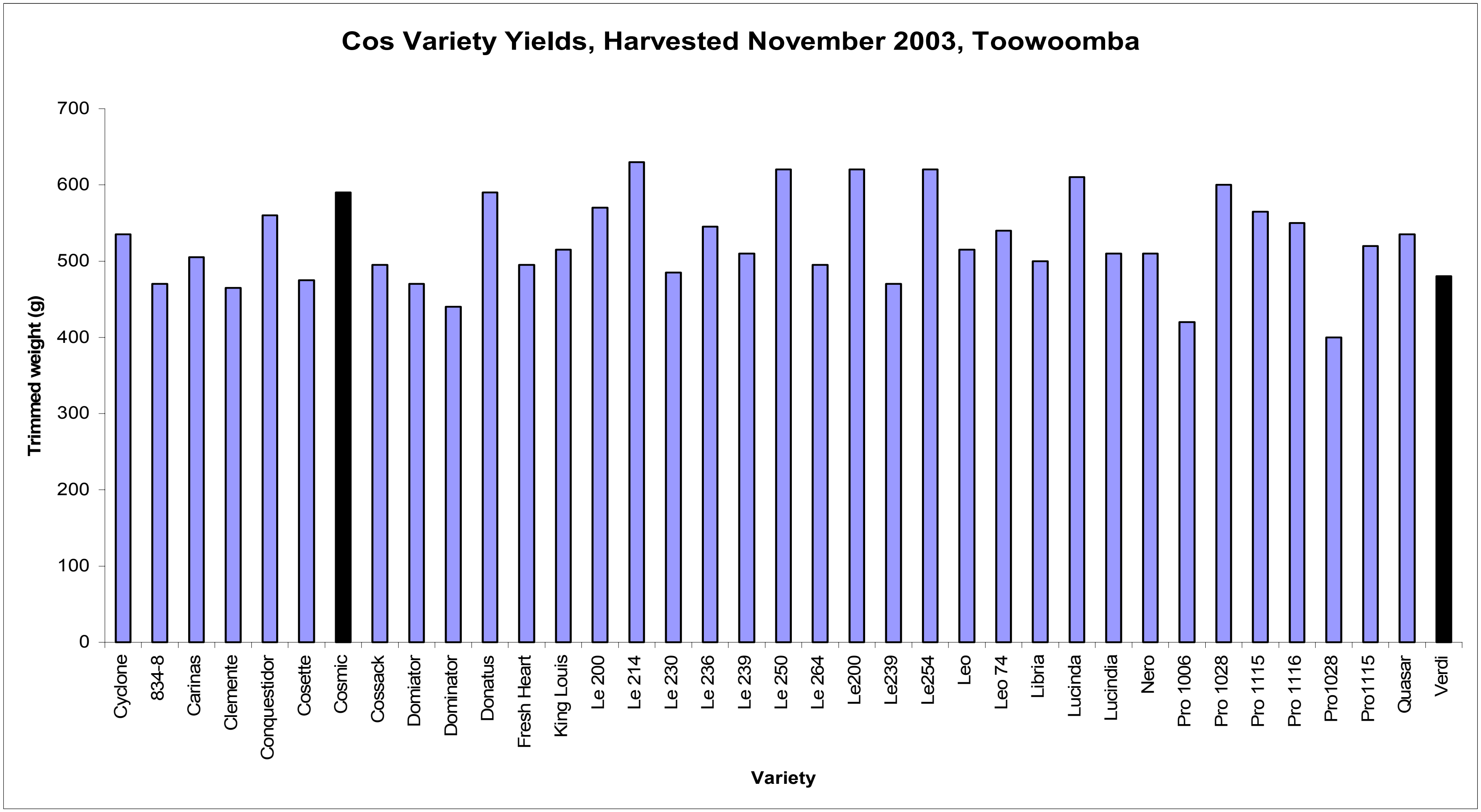
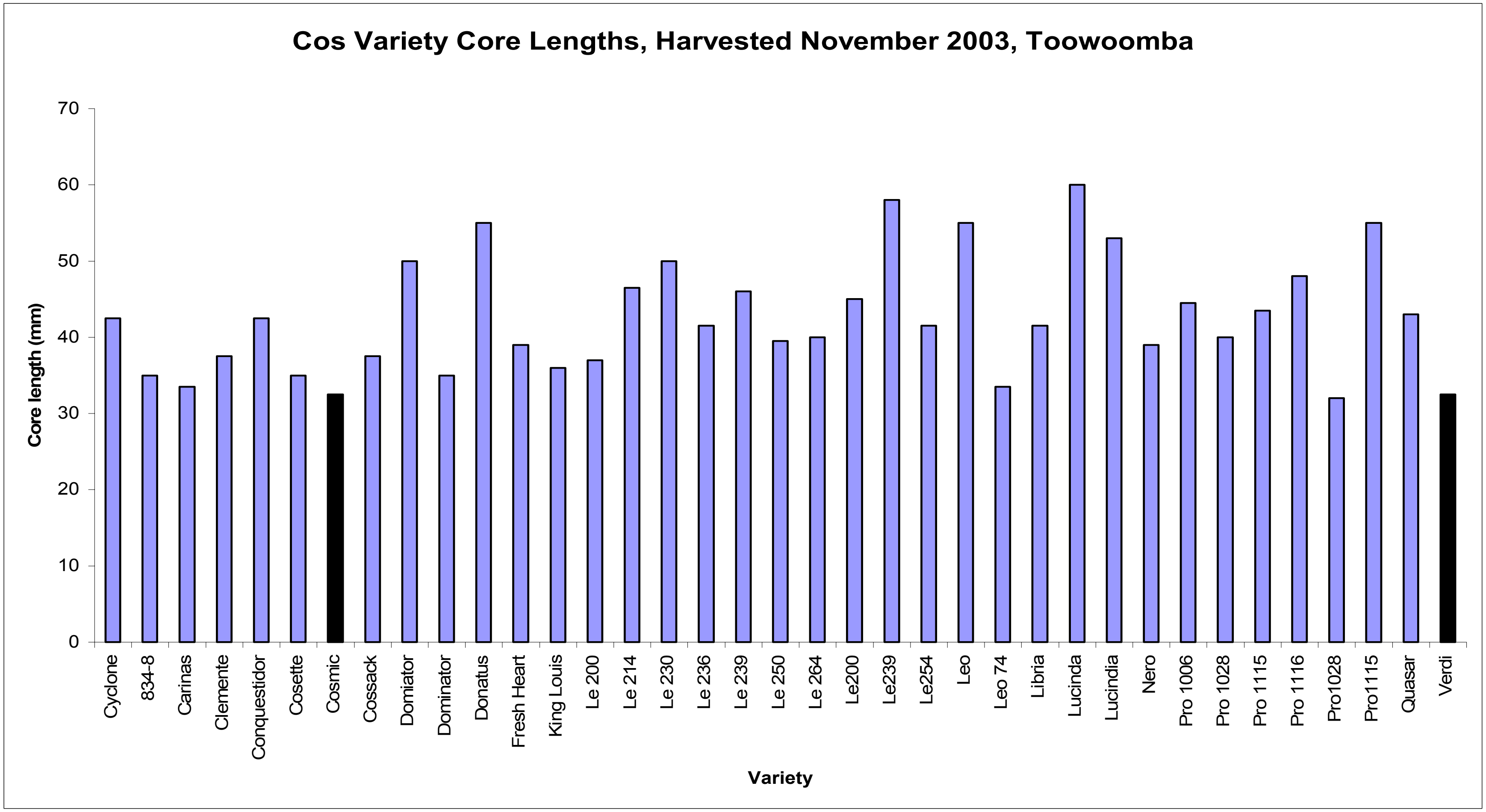

Iceberg Variety Core Lengths, Harvested March 2004, Toowoomba
Core length (mm)
140
120
100
80
60
40
20
0
LEC 2384
LEC 2385
LEC 2386
LEC 2455
LE 145
LE 181
LE 230
LET 34
Cartagenas
Pro 1844
PRO 1061
PRO 1041
3SX 169
3SX 124
3SX 122
Gator
PSR 1530
Raider
LE 215
Goblin
Seagreen
Sahara
Mohawk
Desert Queen
Gulf Stream
Lucy Brown
Gemini
LEC 2453
Variety

Figure 29



Cos Variety Yields, Harvested November 2003, Toowoomba
Trimmed weight (g)
0
100
200
300
400
500
600
700
Cyclone
834-8
Carinas
Clemente
Conquestidor
Cosette
Cosmic
Cossack
Domiator
Dominator
Donatus
Fresh Heart
King Louis
Le 200
Le 214
Le 230
Le 236
Le 239
Le 250
Le 264
Le200
Le239
Le254
Leo
Leo 74
Libria
Lucinda
Lucindia
Nero
Pro 1006
Pro 1028
Pro 1115
Pro 1116
Pro1028
Pro1115
Quasar
Verdi
Variety

Figure 30.



Cos Variety Core Lengths, Harvested November 2003, Toowoomba
Core length (mm)
70
60
50
40
30
20
10
0
Cyclone
834-8
Carinas
Clemente
Conquestidor
Cosette
Cosmic
Cossack
Domiator
Dominator
Donatus
Fresh Heart
King Louis
Le 200
Le 214
Le 230
Le 236
Le 239
Le 250
Le 264
Le200
Le239
Le254
Leo
Leo 74
Libria
Lucinda
Lucindia
Nero
Pro 1006
Pro 1028
Pro 1115
Pro 1116
Pro1028
Pro1115
Quasar
Verdi
Variety

Figure 31.

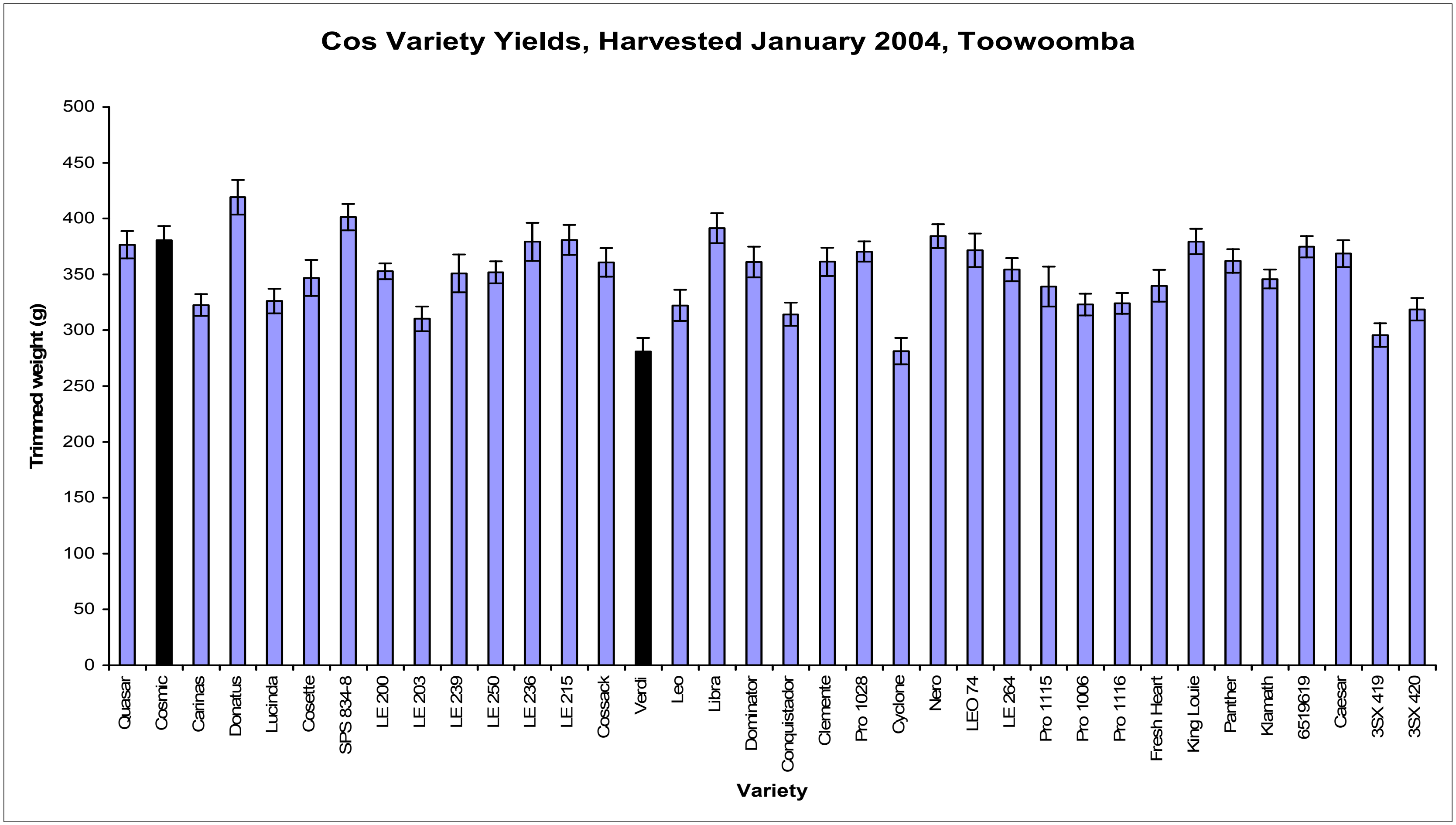
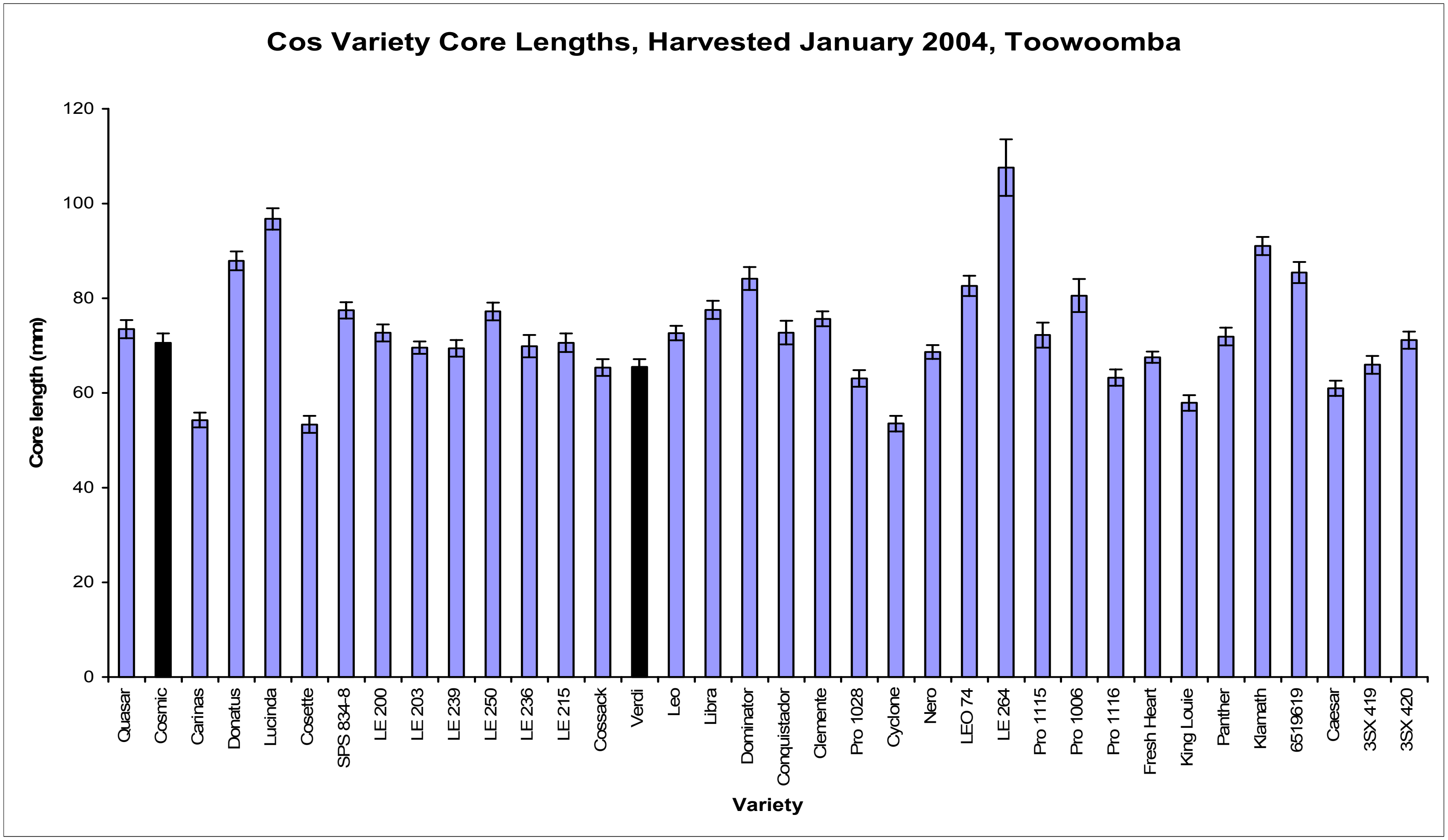
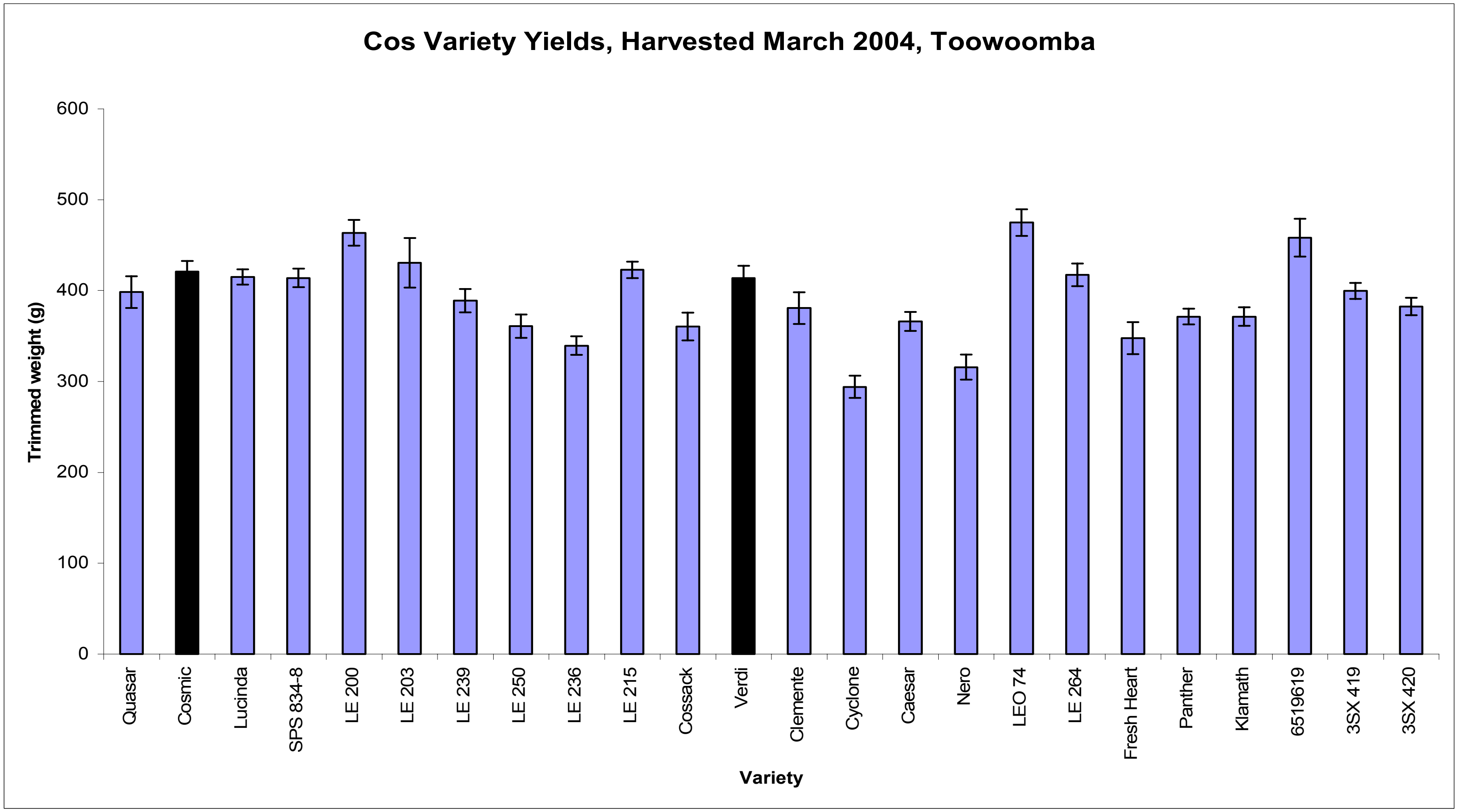

Cos Variety Yields, Harvested January 2004, Toowoomba
Trimmed weight (g)
500
450
400
350
300
250
200
150
100
50
0
Quasar
Cosmic
Carinas
Donatus
Lucinda
Cosette
SPS 834-8
LE 200
LE 203
LE 239
LE 250
LE 236
LE 215
Cossack
Verdi
Leo
Libra
Dominator
Conquistador
Clemente
Pro 1028
Cyclone
Nero
LEO 74
LE 264
Pro 1115
Pro 1006
Pro 1116
Fresh Heart
King Louie
Panther
Klamath
6519619
Caesar
3SX 419
3SX 420
Variety

Figure 32.



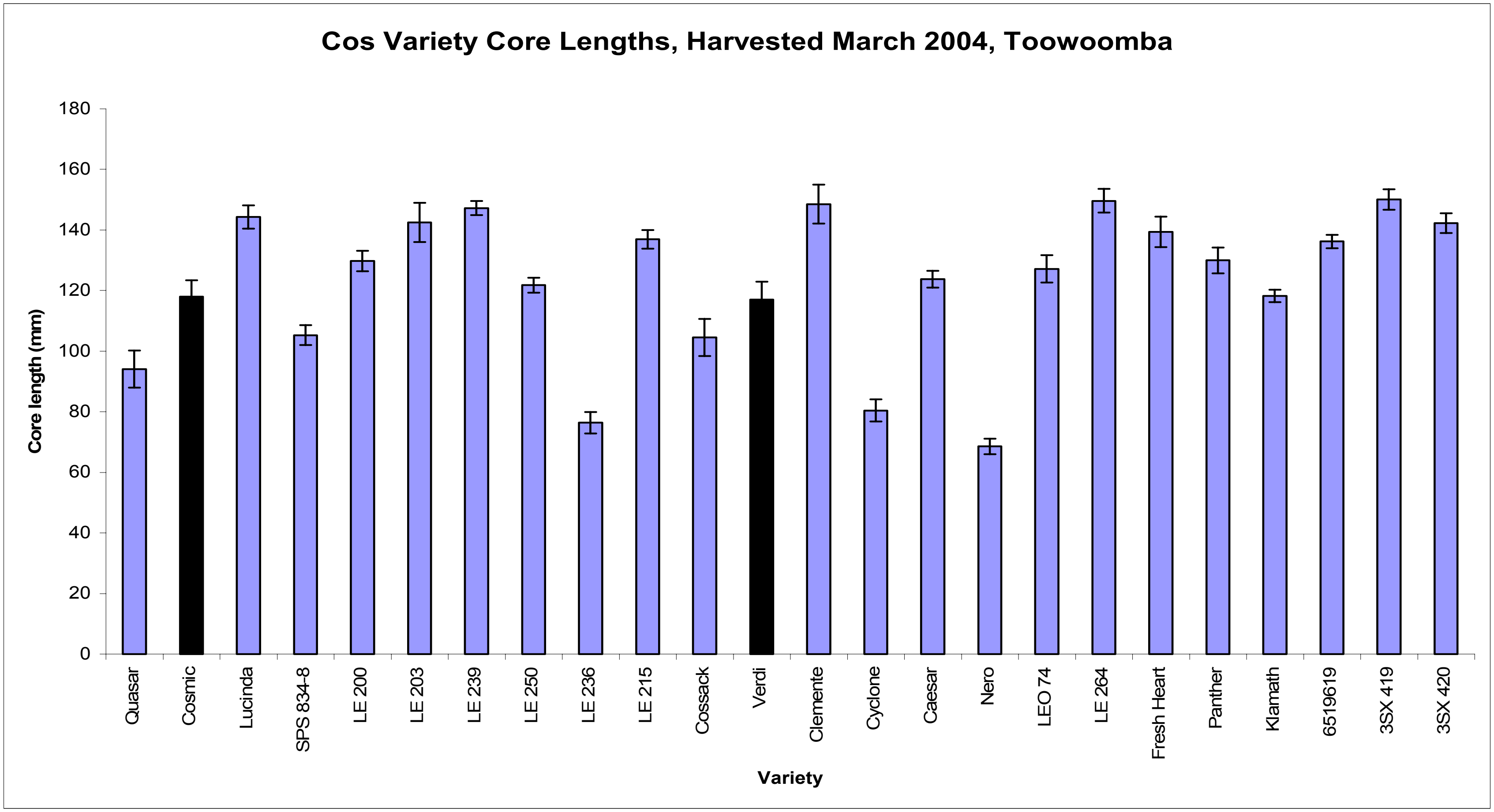
Cos Variety Core Lengths, Harvested January 2004, Toowoomba
Core length (mm)
0
20
40
60
80
100
120
Quasar
Cosmic
Carinas
Donatus
Lucinda
Cosette
SPS 834-8
LE 200
LE 203
LE 239
LE 250
LE 236
LE 215
Cossack
Verdi
Leo
Libra
Dominator
Conquistador
Clemente
Pro 1028
Cyclone
Nero
LEO 74
LE 264
Pro 1115
Pro 1006
Pro 1116
Fresh Heart
King Louie
Panther
Klamath
6519619
Caesar
3SX 419
3SX 420
Variety

Figure 33.



Cos Variety Yields, Harvested March 2004, Toowoomba
Trimmed weight (g)
0
100
200
300
400
500
600
Quasar
Cosmic
Lucinda
SPS 834-8
LE 200
LE 203
LE 239
LE 250
LE 236
LE 215
Cossack
Verdi
Clemente
Cyclone
Caesar
Nero
LEO 74
LE 264
Fresh Heart
Panther
Klamath
6519619
3SX 419
3SX 420
Variety

Figure 34.


Cos Variety Core Lengths, Harvested March 2004, Toowoomba
Core length (mm)
0
20
40
60
80
100
120
140
160
180
Quasar
Cosmic
Lucinda
SPS 834-8
LE 200
LE 203
LE 239
LE 250
LE 236
LE 215
Cossack
Verdi
Clemente
Cyclone
Caesar
Nero
LEO 74
LE 264
Fresh Heart
Panther
Klamath
6519619
3SX 419
3SX 420
Variety

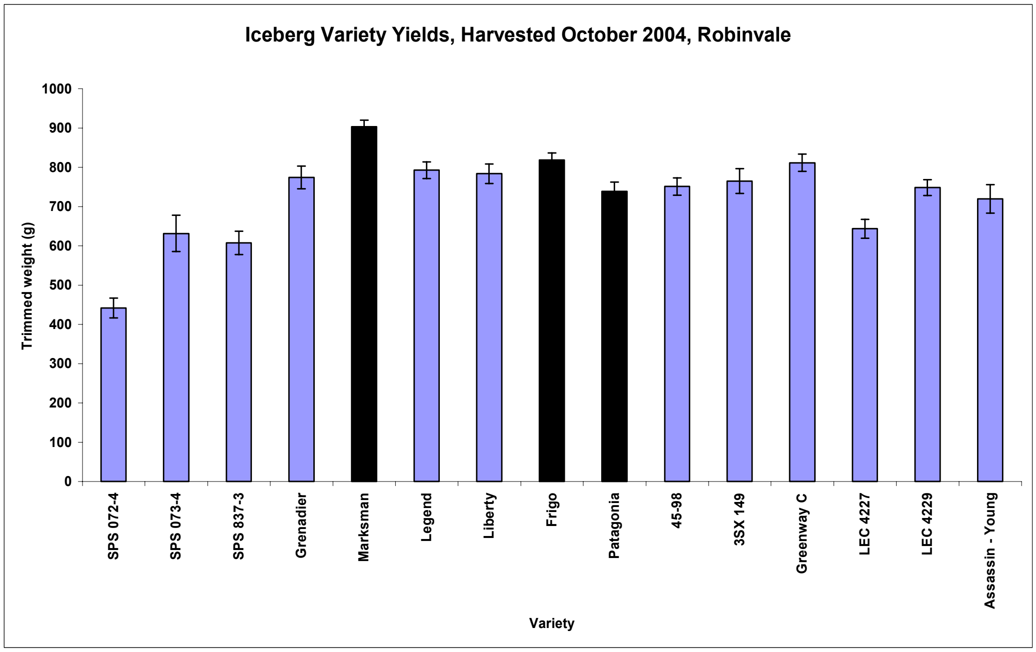



Figure 35.

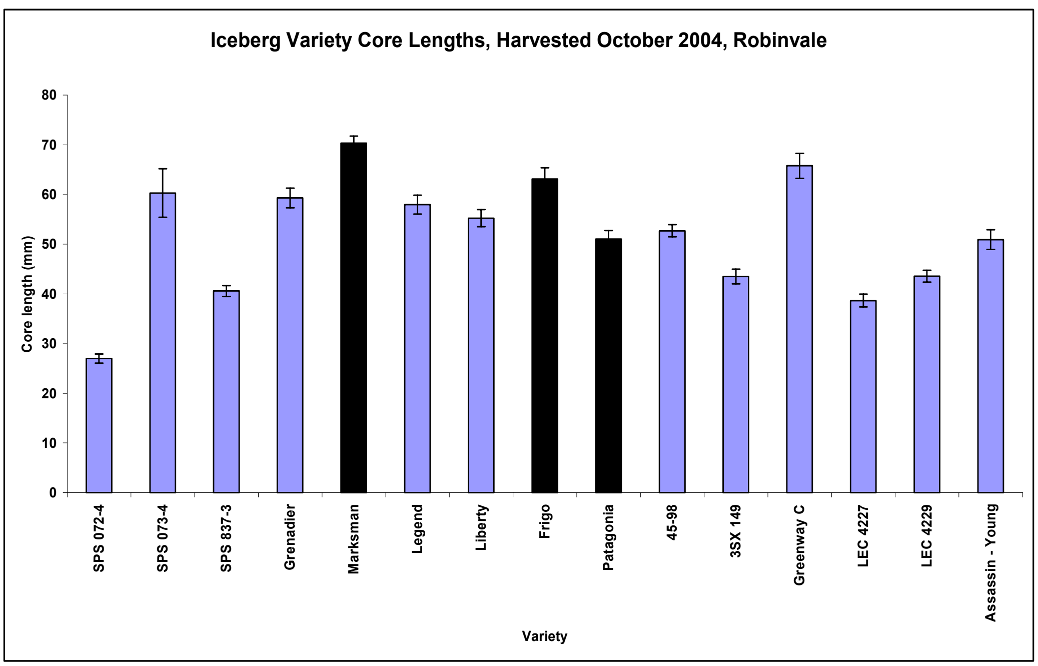



Figure 36.

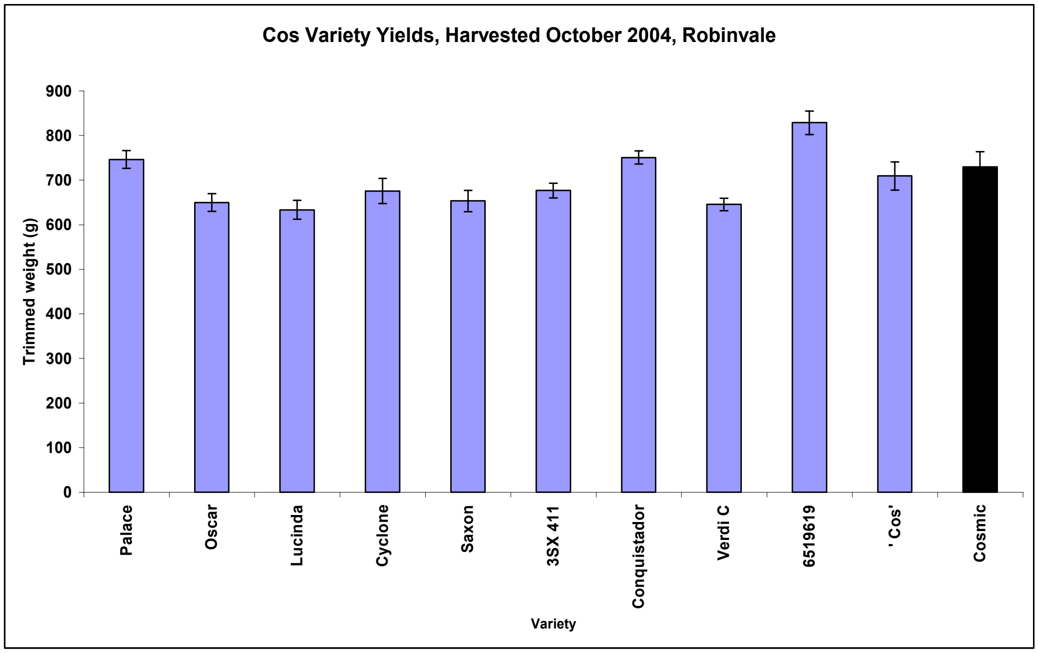



Figure 37.

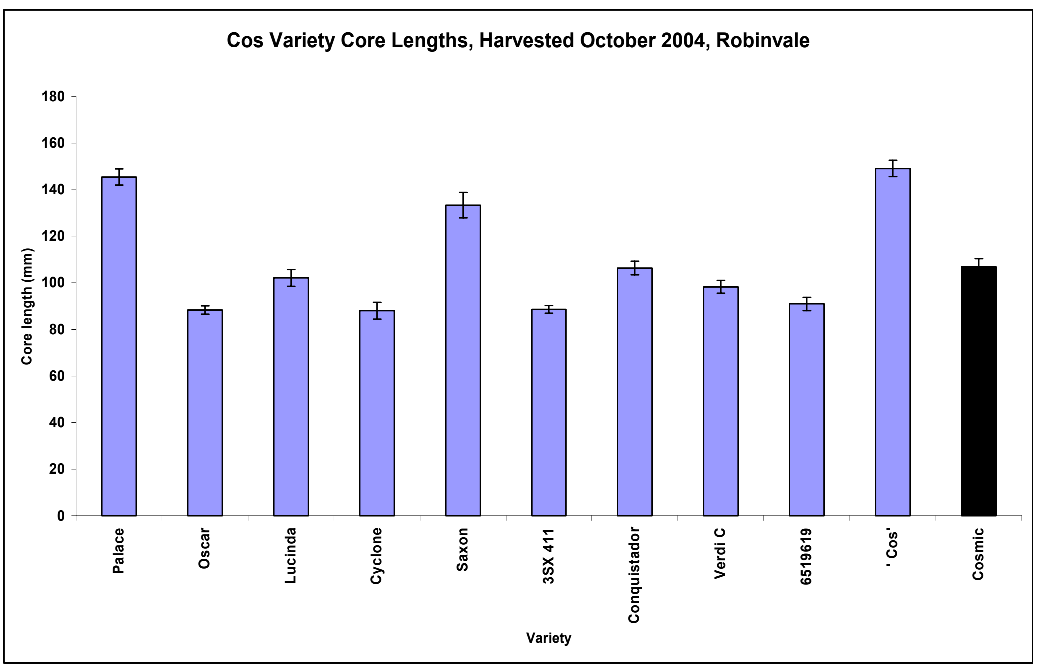
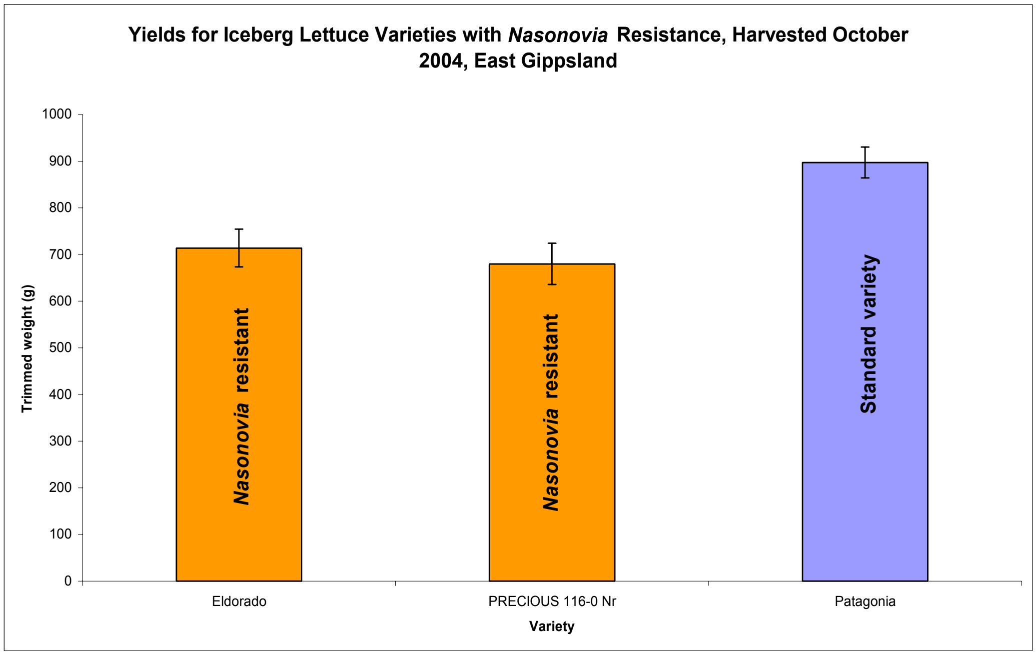
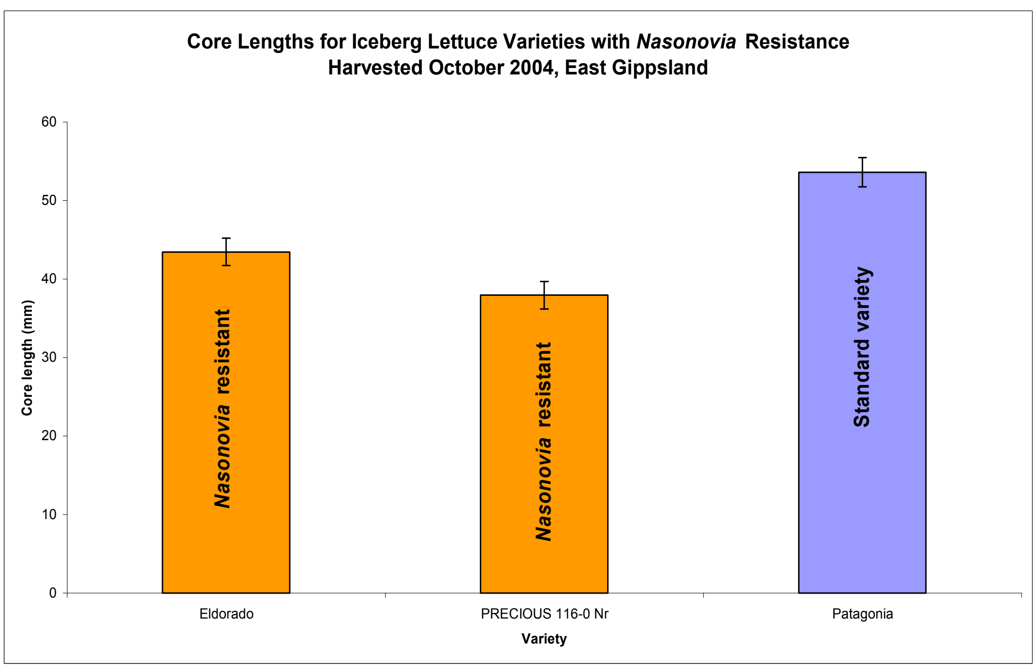


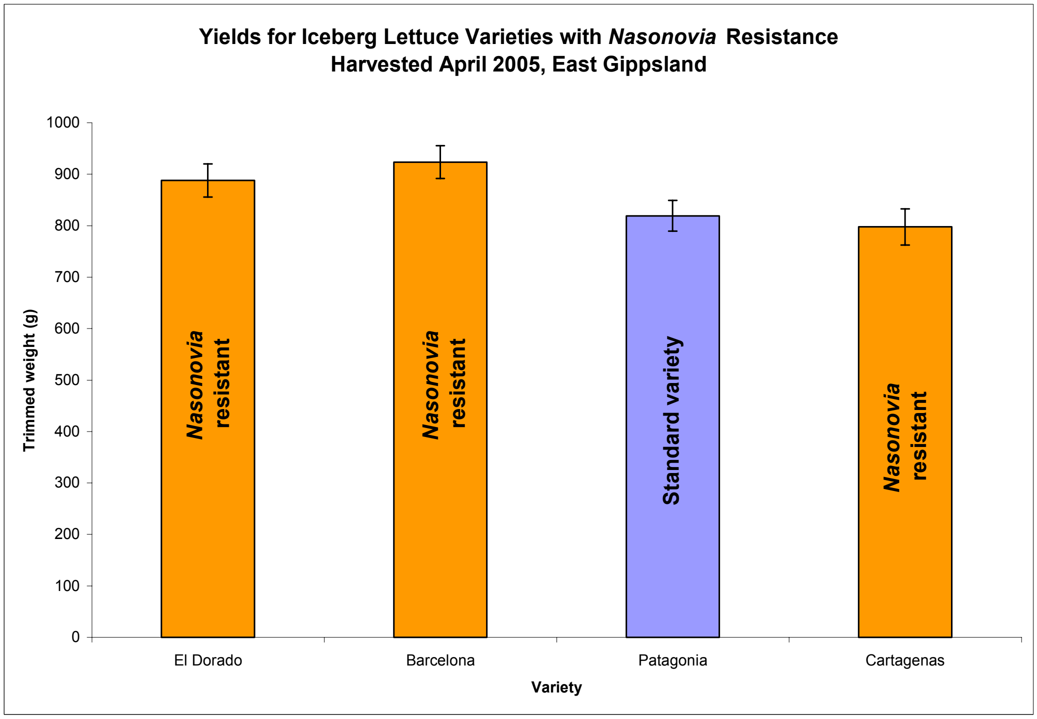

Figure 38.

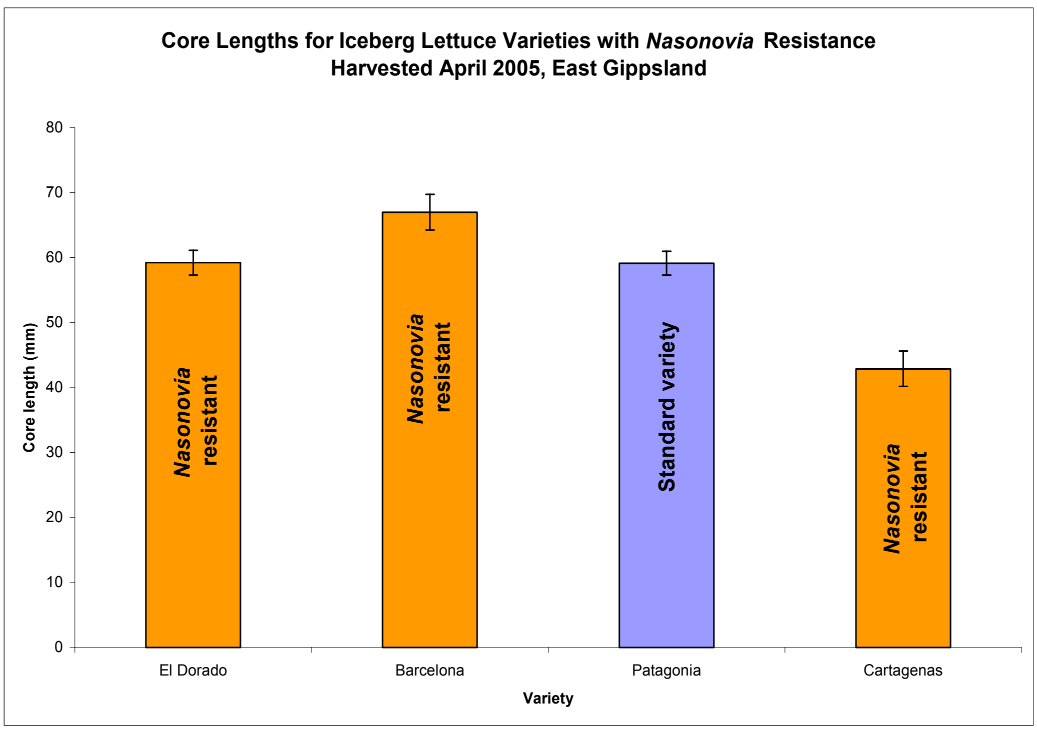
# Appendix 4 - Key Varieties

## Nasonovia Resistance - Iceberg

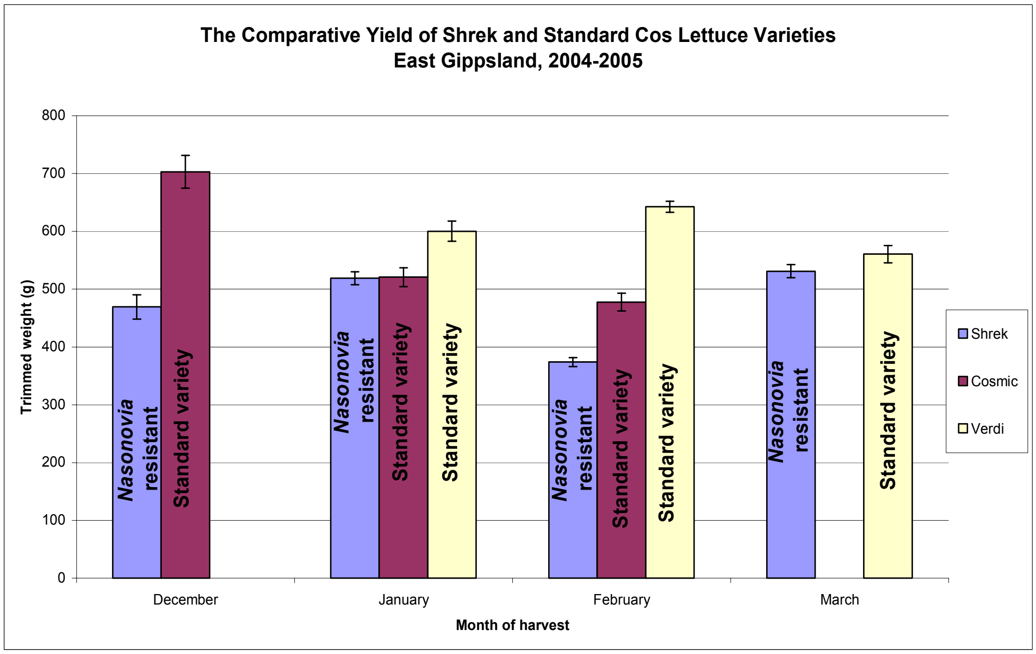


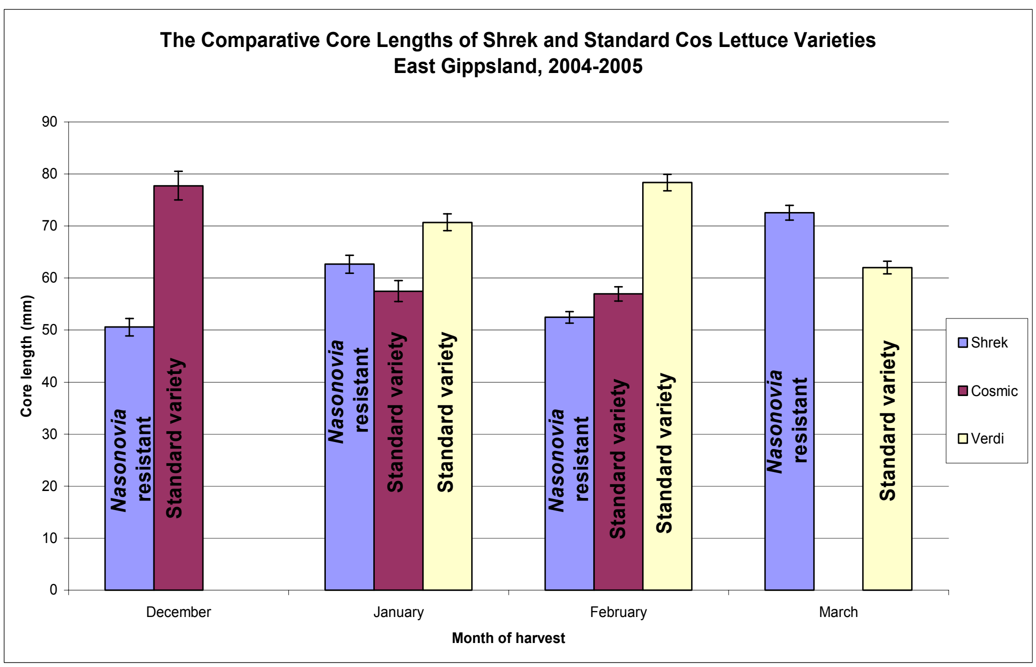



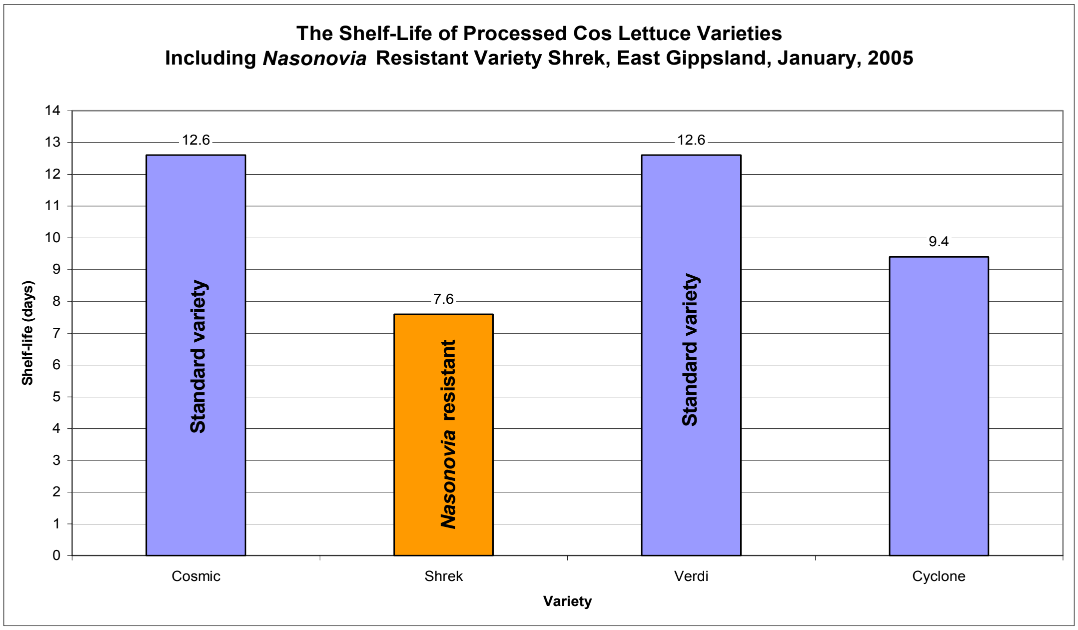

Yields for Iceberg Lettuce Varieties with *Nasonovia* Resistance
Harvested April 2005, East Gippsland
Trimmed weight (g)
1000
900
800
700
600
500
400
300
200
100
0
*Nasonovia* resistant
*Nasonovia* resistant
Standard variety
*Nasonovia* resistant
El Dorado
Barcelona
Patagonia
Cartagenas
Variety


Core Lengths for Iceberg Lettuce Varieties with *Nasonovia* Resistance
Harvested April 2005, East Gippsland
Core length (mm)
80
70
60
50
40
30
20
10
0
*Nasonovia* resistant
*Nasonovia* resistant
Standard variety
*Nasonovia* resistant
El Dorado
Barcelona
Patagonia
Cartagenas
Variety

## Nasonovia Resistance - Cos





The Shelf-Life of Processed Cos Lettuce Varieties
Including *Nasonovia* Resistant Variety Shrek, East Gippsland, January, 2005
Shelf-life (days)
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
12.6
7.6
12.6
9.4
Standard variety
*Nasonovia* resistant
Standard variety
Cosmic
Shrek
Verdi
Cyclone
Variety