Know-how for Horticulture™

Breeding disease and insect resistant supersweet corn

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VG 00073

Final Report of the Project

"Breeding for Disease and Insect Resistance in Super-sweet Corn"

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This report is intended to summarise results of the project research to this point in time. Experiments in progress at this time will be reported in a Final Report to be submitted at a later date.

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Friday, 22 July 2005

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1. Media Summary

The Australian sweetcorn industry is undergoing a phase of significant expansion. From 1997 to 2001 production increased by 70% from 70,000 tonnes to 120,000 tonnes and has probably exceeded that in more recent years.

To supply this burgeoning market the area under production has expanded. As well the advent of the virus resistant hybrid, Hybrix 5, has lengthened the planting window from 4 months to 7 months per year in the Lockyer district. These more intensive production practices have the potential to increase the intensity of diseases and insect problems because of the inoculum build-up factor.

With this in mind, the current project was conceived to develop and select super-sweet corn populations with improved insect and disease resistance. The project also aimed to extract elite inbreds from the populations and to identify hybrids with the potential for commercial use.

The breeding strategy devised was to transfer the insect and disease resistances inherent in tropical germplasm to temperate germplasm. Temperate germplasm lacks adequate resistance but has superior quality for such traits as flavour and tenderness.

In the special case of resistance to the major insect pest of sweetcorn, Heliothis corn ear worm, we investigated the value of a gene, P1. This gene produces a chemical called maysin that, when ingested by the larvae of Heliothis, disrupts protein synthesis and thus causes the larvae to die. The process utilises a naturally-occurring gene in maize and is therefore does not involve transgenics, with the adverse marketing aspects that are associated with inter-specific DNA transfers.

The project has succeeded in achieving its main objectives. For example we are now in a position to supply industry with tropically-adapted super-sweet corn cultivars with much-improved tenderness, yet which retain the high yield potential that makes them suitable for processing (canned or frozen kernels).

A consumer survey, conducted as part of the project, produced a wide range of illuminating results. For example consumers were remarkably conscious of the health values of sweetcorn. Forty-nine percent of those surveyed nominated health considerations as a motivation for purchase. 83% preferred the tip of the cob to be free of Heliothis damage although they were willing to accept some corn ear worm damage in return for absence of pesticide residues. A surprising 71% of consumers preferred organically-grown product if it was available. Interestingly only 33% insisted on “no transgenics” when it was pitted against pesticide-free corn (61%). This seems to infer that a majority of those surveyed would accept transgenic sweetcorn if it can obviate the use of pesticides.

When consumers considered loose corn ears visual features were considered to be important. A majority of those surveyed (53%) looked at the husk colour as a guide to the freshness of the cob and 30% inspected the kernels. Medium green husk colour was preferred to light green or dark green husks and most importantly 72% of consumers preferred ears without flag leaf. Golden kernels were preferred to lighter yellow kernels.

2. Technical Summary.

The suite of super-sweet cultivars available to the Australian sweetcorn industry is adequate for growing situations where the pressure of plant diseases such as rusts, blights and viral diseases is not severe. However, as demand for sweetcorn grows in Australia there will be more sequential plantings with consequent increases in the levels of disease. There is therefore a need to develop breeding populations and commercial cultivars that have superior resistances to disease than are currently available in the current suite of varieties.

A similar situation pertains to the main insect pest, Heliothis corn ear worm. (***Helicoverpa armigera***).The development of biological controls such as NPV (Nuclear Polyhedrosis Virus) and the use of naturally- occurring toxins such as "Dipel" (Bacillus thuringiensis) represent a significant advance. However there are situations where these agents are not effective (for example where weather conditions are not favourable to reproduction of the virus). Growers are then forced to resort to traditional insecticides. It would clearly be preferable to have superior plant resistance which is effective regardless of environmental conditions. Such resistance is not found in the temperate-adapted cultivars that are used widely in the Australian industry.

The super-sweet corn breeding program based at Kairi in north Queensland generated two ***sugary-1*** tropically-adapted gene pools (AS1 and AS2) based on ***sugary 1*** synthetics and composites obtained from Prof. James L. Brewbaker of the University of Hawaii. The resistances to leaf diseases and corn earworm inherent in the ***sugary 1*** populations were improved over twelve generations of selection at Kairi. As the industry moved from sweet corn to super-sweet corn the populations were converted from ***sugary 1*** to the ***shrunken 2*** gene by a backcrossing process. The gene commonly used in the Australian super-sweet corn industry is ***shrunken 2***.

At the outset of the current project a breeding strategy was implemented which involved crossing and backcrossing these tropical populations with temperate super-sweet corn gene pools to create new gene pools with temperate content of 50% and 75% as a means of transferring resistances to the temperate material. This provided us with breeding populations having 0, 50%, 75% and 100% temperate germplasm from which to investigate the optimal dosages for various growing environments.

These new populations were then selected as S0-selfed plants for eating quality traits (flavour and tenderness), kernel depth and for minimal Heliothis ear worm damage. Recombination of the elite S1 inbreds permitted one cycle of improvement per year. Selection cycles were compared in trials to monitor improvement from selection.

Using these empirical selection methods in a recurrent selection breeding format we were able to improve resistance to diseases and earworm quite markedly particularly in the 75% temperate pools. This was our major objective. The final resistance to fungal and viral diseases and Heliothis in these populations is adequate for most situations likely to be encountered in commercial production.

We also investigated whether physical traits provided resistance to Heliothis. Correlations of husk extension and tip cover were thought to be two traits worth examining. We found that both the **length of husk extension** and the **visual rating of tip cover** were negatively correlated with Heliothis damage. Of these selection for tip cover appears to offer the better option for improving Heliothis resistance.

Although these results suggest that selection for longer husk extension and better tip cover are effective in reducing Heliothis damage other physical traits are almost certainly involved. For example in Hawaii research has indicated that the number of husk leaves has a significant role. This trait was not investigated in the current study.

The project also commenced introgression of the Pl gene. This gene is associated with the production of maysin, a chemical present in the silks of maize or sweetcorn. In supersweet corn the presence of the ***shrunken 2*** allele has the effect of causing maysin to be amplified because of the close linkage of the gene with the recessive allele of a locus “A1”. The presence of recessive ***a1*** allele prevents the production of red pigment in the pericarp of maize causing the precursor to be directed to increased maysin production.

This aspect of the project is still in progress. An effective DNA marker for the P1 gene has been located that has enabled us to identify plants bearing that gene. We are now embarking on the second backcross to super-sweet populations. Bearing in mind that the original sources of the high maysin material were in maize background there is a need for backcrossing to super-sweet corn to recover eating quality traits such as tenderness and flavour. A trial is in progress comparing genotypes with the heterozygous P1- genotype and homozygous recessive genotypes to assess whether maysin has a useful effect on Heliothis.

The project also investigated Zapalote Chico, a primitive Mexican maize race recognized for its resistance to Heliothis. Initial crosses to Z. Chico persuaded us that a large number of backcrosses to super-sweet corn would be needed to recover anything of commercial value so this approach was abandoned.

The project generated a large number of experimental hybrids. They were evaluated in numerous trials at three locations, Gatton, Kairi and Bowen. Two of these hybrids appear to be particularly promising and are now undergoing commercial evaluation, including testing for suitability for canning.

3. General Introduction

The Australian sweetcorn industry is estimated to have an annual value in excess of $60 million at the farm gate. Retail value is approximately five times that estimate. In 2001 consumption in Australia was estimated to be 6 kg per head of population (up from 3.5 kg per head in 1997). Improved presentation in supermarkets through the use of pre-packs rather than loose cobs and the adoption of "everyday low prices" by a major supermarket chain are helping to establish sweet corn as a popular item in the household shopping basket.

Domestic production has increased from 70,000 tonnes in 1997 to 120,000 tonnes in 2001 (71% increase) in order to meet this demand. This has been achieved by increasing the planting window and by expanding the area under production. In the Lockyer District growing region in south-east Queensland the planting window has been increased significantly by the introduction of Hybrix 5, a hybrid with resistance to **Johnson grass mosaic virus**. Sweet corn can now be planted from September to March, some three months later than prior to the introduction of Hybrix 5. This development means that the number of successive plantings has been substantially increased. At Bowen in north Queensland, there has been a large expansion in the area planted to sweetcorn, with the likelihood of more sequential plantings.

As a result of this more intensive industry there is greater opportunity for leaf diseases, particularly **Turcicum leaf blight** (*Exserohilum turcicum)* and Common rust (*Puccinia sorghi*), to occur with greater severity on susceptible cultivars, because of the greater number of cycles of inoculum increase. As well, the suite of hybrids with effective resistance to Johnson Grass Mosaic Virus disease has been restricted to one hybrid, Hybrix 5. This has limited the range of choice for growers in the Lockyer District, one of the main sources of sweetcorn for eastern Australia. Since Hybrix 5 is considered to have deficiencies in eating quality there is an obvious advantage in transferring the single gene for JGMV resistance to other genotypes .

The current project has sought to counter these disease problems by transferring the excellent resistance to these diseases found in tropical germplasm to the temperate-adapted germplasm (which constitutes a significant proportion of the Australian industry) whilst maintaining or improving the eating quality characteristics of temperate hybrids.

In recent times biological methods of controlling the major insect scourge of sweet corn in Australia, Heliothis (Helicoverpa armigera), have been used with success. Deuter (2004) estimates that crop losses from Heliothis have been reduced to 20% or less as a result of these practices. However, on occasions the biological controls are not wholly successful. In such situations, growers are forced to resort to the use of chemical insecticides. Therefore an aim of the project was to find ways of improving plant resistance to Heliothis. This objective was pursued through empirical means (once again using tropical sweetcorn germplasm as the source of resistance), and through the use of a gene, P1, that is associated with the production of a natural chemical in the silks of the sweet corn.

4. Development and effectiveness of gene pools with varying dosage of tropical germplasm and their influence on resistance to Heliothis corn ear worm.

4.1 Introduction.

The tropical super-sweet gene pools held at Kairi Research Station were composited from synthetics introduced from University of Hawaii in 1969. To facilitate the eventual production of hybrids, two pools were created from divergent germplasm. **Population 1(SHPOP1)** included some mainland US sweetcorn germplasm, **Population 2 (SHPOP2)** was constituted from long-term tropically-adapted material.
Tropical environments tend to be more favourable for the production of fungal diseases. Contrastingly, the main sweetcorn breeding areas of USA (Washington, Idaho and Oregon) have very low rainfall and humidity and hence disease pressure is low. Consequently there is little opportunity to select for resistance. The value of transferring disease resistances from tropical populations to temperate germplasm is readily apparent.
Additionally the tropical sweetcorn synthetics developed by Professor Jim Brewbaker in Hawaii (which formed the basis of our tropical populations) were selected stringently for resistance to corn ear worm (Helicoverpa spp). This selection is reflected in tighter husk cover, longer husk extensions and greater numbers of husk leaves than is seen in germplasm adapted to temperate environments.

4.2 Materials and Methods.

As a first step in this breeding project it was necessary to ascertain whether the resistances developed in tropical germplasm could be successfully transferred to temperate populations.Our starting materials were the two tropical composites SHPOP 1 and SHPOP 2 and two temperate composites SHTEMP 1 and SHTEMP 2. The temperate populations were synthesized from temperate inbreds and hybrids.
Crosses were made between SHPOP 1 and SHTEMP 1 and between SHPOP 2 and SHTEMP 2. Approximately two hundred full sib families were made in each of these two inter-population matings. This produced new populations SHM1 and SHM2 with 50% tropical and 50% temperate genetic constitution. (The “M” prefix indicates “mid” or intermediate maturity status). These new populations were then backcrossed to SHTEMP 1 and SHTEMP 2 respectively to create further new populations SHF1 and SHF2 with nominal 75% temperate germplasm. (The F prefix indicates that these populations were seen as having commercial application in the”fresh” (i.e. loose cob and pre-pack) market).

These manipulations resulted in three sets of populations with 0%, 25% and 50% introgressions of tropical germplasm needed to investigate the necessary dosage level to provide effective resistance to disease and Heliothis. The populations also provided the basis of a program to improve resistance and eating qualities. The populations together with temperate check hybrids and crosses of the temperate populations crossed with a source of the P1 gene were grown in a replicated field trial in the 2003-4 season to gain an insight into the relative values of these approaches to attaining resistance to Heliothis. The replicated trial was grown completely free of insecticides and without any attempt to infest the plants artificially with ear worm.

4. 3 Results

Genotypes containing 75% or more temperate germplasm had significantly more damage caused by Heliothis corn ear worm (Table 1). Ratings are expressed as means for the two populations in each germplasm group.

Table 1. Influence of the dosage level of temperate sweetcorn germplasm on resistance to Heliothis corn ear worm damage.

Genotype	Temperate germplasm (%)	Visual rating for Heliothis damage (1)
TEMP HYBRID	100	2.9
SHTEMP 1 and 2	100	2.1
SHF1 and 2	75	2.4
SHM1 and 2	50	1.5
SHPOP 1 and 2	0	1.6
SHTEMP 1 and 2 x P1	50	1.6
Sig Diff (P=0.05)		0.3

1) Ear worm rating scale: 1=Damage to silks only, 2 = Ear worm tunnel less than 1 cm in length, 3 = ear worm tunnel up to 1.5 cm in length

4.4 Discussion.

The temperate hybrid used as a check is perhaps the most popular cultivar used in the Australian sweetcorn industry. It suffered significantly greater damage from Heliothis than all other entries. Somewhat surprisingly there appeared to be no substantial advantage for Heliothis resistance gained by infusion of 25% tropical germplasm. Populations SHF1 and SHF2 recorded significantly more damage than the fully temperate populations SHTEMP 1 and 2. Populations SHM1 and SHM2 were just as resistant as the fully tropical populations from which they were developed (SHPOP1 and SHPOP 2 respectively), suggesting a high degree of dominance for resistance to Heliothis.

When the temperate populations were crossed with SIM 6, a source of the Pl gene, the resulting hybrids possessed as much resistance to Heliothis as full tropical germplasm. Since SIM 6 originated from the southern states of USA it possibly has some tropical content and is likely to have other traits which contribute to Heliothis resistance. These confounding factors mean it is not possible to maintain that its contribution to resistance is solely from the Pl gene.

The conclusions from this experiment are that tropical germplasm does indeed have greater resistance to Heliothis armigera than temperate germplasm of US origin and that if one is to transfer that resistance it is necessary to have tropical germplasm at a dosage level of 50% or greater to obtain satisfactory levels of resistance. Such an operation might bring with it undesirable side effects such as the need for more heat units to reach maturity or of a requirement for shorter daylength to induce flowering. Both of these would limit adaptation to higher latitude environments.

5. The influence of tropical super-sweet germplasm on resistance to Turcicum leaf blight (Exserohilum turcicum).

5.1 Introduction.

Turcicum leaf blight *(Exserohilum turcicum)* is probably the most damaging disease of sweetcorn in Australia, rivalled only by Common Rust *(Puccinia sorghi*). Most US-bred supersweet corn hybrids used in Australia are at least moderately susceptible. Single gene resistances to leaf blight such as ***Ht1*** are available but have proved to be susceptible to newer physiologic races of the pathogen. The Atherton Tableland experiences severe epidemics due to its humid climate in summer and autumn. This has enabled selection for particularly strong resistance in tropical supersweet populations.

5.2 Materials and Methods

The same populations that were used in the experiment on resistance to Heliothis were exposed to a severe epidemic of Turcicum leaf blight generated by prior plantings of susceptible cultivars. Visual ratings were carried out some 30 days after silking. This is somewhat later than the normal time of harvest (21 days post silking) and was intended to amplify the differences amongst entries.

5.3 Results

The high degree of susceptibility to Turcicum leaf blight in US temperate material is evident in the results presented in Table 2.

Table 2. Effect of tropical germplasm on resistance to Turcicum leaf blight.

Genotype	Tropical germplasm content (%)	Visual rating for Turcicum leaf blight*
Temperate Hybrid	0	7.2
SHTEMP 1 and 2	0	7.0
SHF 1 and 2	25	5.4
SHM 1 and 2	50	3.4
SHPOP 1 and 2	100	1.8
SHTEMP 1 and 2 x P1	NA	2.3
Sig. Diff (P=0.05)		0.4

- **Visual rating scale for leaf blight**: 1=10% of leaf infected, 10= 100% of leaf infected.

5.4 Discussion.

The pattern of resistance seen here suggests that resistance is inherited in a manner approximating additive effect. It does not resemble the mode of inheritance conveyed by single gene resistance that, as in the case of Ht1, is dominant. There are however indications of partial dominance for resistance in the ratings achieved for the SHM1 and SHM2 populations.
The extreme susceptibility of the commercial hybrid widely used in Australia demonstrates why growers as far south as Bathurst resort to using a tropical hybrid when there is a disease build-up towards the end of the growing season. In practical breeding terms it would seem that a 50% infusion of tropical germplasm would be needed to provide useful resistance to Turcicum leaf blight.

6. The effect of physical traits of the sweet corn ear on resistance to Heliothis corn ear worm (*Helicoverpa armigera*).

6.1 Introduction.

Heliothis larvae most commonly enter the sweet corn ear through the silk channel (i.e. through the tip of the ear). Less commonly they drill through the husk leaves and enter the ear through the side. This is a more economically-damaging method of ingress because the tip of the ear can be removed and still yield a saleable product.

Temperate sweetcorns have a much more open tip cover than tropically-adapted material. They also have fewer husk leaves and a shorter husk extension. Brewbaker found that varieties with a greater number of husk leaves tended to have less Heliothis damage, provided the husk leaves covered the cob tip. In this experiment we chose to study the effect of ear tip cover and husk extension (length of husks beyond the ear tip) on Heliothis damage. It seemed obvious that these traits had the potential to provide physical barriers to Heliothis larvae. If they were found to be closely correlated with Heliothis resistance they would provide easy traits to select.

6.2 Materials and methods

Since the manifestation of both these traits varied depending on the degree of tropical germplasm in the genotypes it was decided to measure correlation in a set of hybrids representing a broad range of germplasm types including temperate, tropical and intermediate genotypes. Sixty hybrids of varying germplasm constitution were tested in the winter of 2004. Rating of tip cover and Heliothis larval damage were made and husk extension measured.

6.3 Results

The correlation between tip cover and Heliothis damage was –0.67 and that between husk extension and Heliothis damage –0.57. These correlations were of greater magnitude than expected. They suggest a greater role for the traits under examination for Heliothis control than previously considered.

6.4 Discussion

Husk length and tightness have long been thought to contribute to reduced insect damage to sweet corn ears (Kaukis and Davis, 1986). Brewbaker and Kim (1979) identified greater number of husk leaves as an important factor in controlling ear worm damage, provided husk leaves covered the tip. They suggested that husk leaf number is less influenced by environment than husk extension and tip cover and tends to be more independent of ear length, cob taper and tip fill. However in this study husk extension and tip cover were strongly correlated with reduced Heliothis damage. Also tip cover, in particular, is more easily measured than husk leaf number.

7. Recurrent selection for improvement of resistance to Heliothis (Helicoverpa armigera) corn ear worm

7.1 Introduction.

An aim of the project was to evaluate the efficacy of improving resistance to Heliothis by the use of recurrent selection in genetically broad-based breeding populations. For this experiment Populations SHF1 and SHF2, with 75% temperate germplasm were chosen. They have the greatest susceptibility to Heliothis corn ear worm and therefore offer the best opportunity to demonstrate the effectiveness of selection.

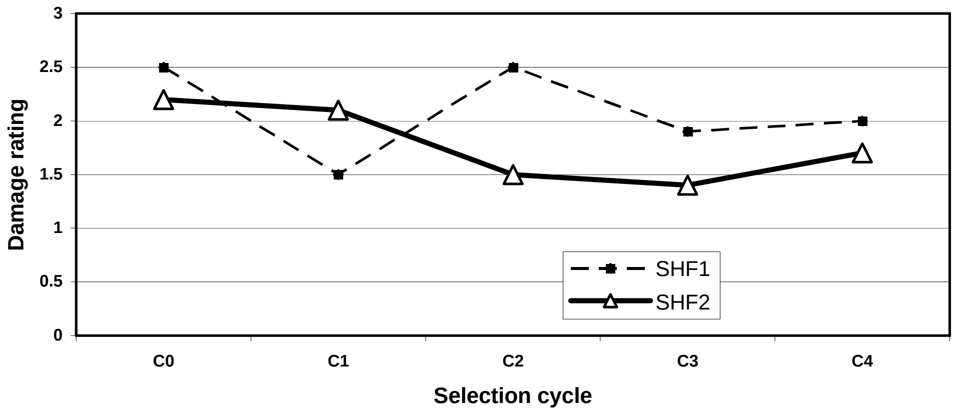
7.2 Materials and methods.

In four cycles of selection over four years from 400 to 600 plants in each of the populations SHF1 and SHF2 were self- pollinated and the dates of pollination recorded on the covering bag. Twenty-two to twenty-four days later covering bags were removed, half the cob snapped off and rated for Heliothis damage and for eating quality traits. The data were recorded and a selection intensity of approximately 10% applied. Seed was collected from the remnant cobs on the selected plants and the resulting forty or fifty S1 families genetically recombined through inter-crossing to produce half sib families for the next selection cycle.

7.3 Results

Good progress was made in Population SHF2 (Fig 1). Heliothis damage was reduced from an approximately 1.5cm tunnel to minor damage. Progress in SHF1 was more erratic but Cycles 3 and 4 appeared to be stabilising at a rating of 2.

Figure 1. Effect of recurrent selection for Heliothis resistance on two sweetcorn populations



7.4 Discussion

Progress toward reducing damage by Heliothis appears to have stopped at the 1.5 rating for SHF2 and at the level of 2 for SHF1. This can probably be explained by the fact that a rating of 1 indicates zero damage and a rating of 2 indicates less than 1 cm of tunnelling in the ear. Selection has produced a very high level of resistance in populations that had relatively high resistance even in C0.
For population SHF1 selection differentials for Heliothis damage were at the low level of 3% to 5 %. This contrasted with selection differentials ranging from 2% to 12% for SHF2. Such low differentials do not promise genetic progress, particularly when heritability of Heliothis resistance is reportedly low (Widstrom et al, 1970 and 1973). The linear regression for SHF1 produced a coefficient of -0.06 and an R squared value of 0.0495, the latter reflecting the lack of discernible trend in the data.

This type of result accords with the experience of Butron et al in Georgia, USA, who found minimal reduction in ear damage per cycle (0.06 cm tunnelling) in a recurrent selection program in three maize populations that extended over 10 cycles of S1 progeny selection and 7 cycles of reciprocal recurrent selection. However in their case the level of resistance was not considered to be adequate and they concluded that the use of marker-assisted selection to select maysin producing plants was necessary.

In SHF2 progress was good in the early generations but not unexpectedly slowed as resistance improved to the stage where damage was minimal. Regression calculated a reduction of 0.17 units of rating per year. The level of resistance expressed in this population is now as good as that found in full tropical material.

This indicates we have developed germplasm possessing 75% temperate parentage which suffers virtually no Heliothis damage even in the complete absence of insecticides, thus attaining one of the major objectives of the project. It would appear that the key to achieving this result has been transference of the resistance inherent in the tropical populations SHPOP1 and SHPOP2 to create 75% temperate populations followed by cycles of selection on S0-selfed plants. It would now be feasible to undertake further backcrossing to the temperate populations if this was thought to be advantageous (eg to regain the photoperiod adaptation to longer daylengths for adaptation to higher latitudes such as are experienced in the southern states of Australia.)

8. Recurrent selection for improvement of resistance to Turcicum leaf blight (*Exserohilum turcicum*) in two super-sweet breeding populations.

8.1 Introduction

Turcicum leaf blight is probably the most commonly encountered disease of sweetcorn in Australia. It is especially damaging when a series of plantings are made at close intervals. At least three monogenic resistances to the disease have been identified and used in maize and sweetcorn. However the pathogen rapidly developed a physiologic race with pathogenicity to genotypes containing the original resistance gene, Ht1. By introducing the resistance from our tropical populations into temperate material we hoped to be able to select for increased resistance using one-year cycles of recurrent selection.

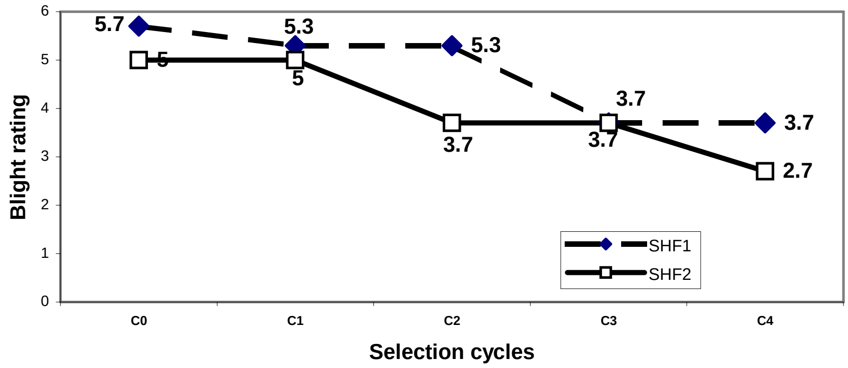
8.2 Materials and methods.

The populations SHF1 and SHF2, having nominal 75% temperate germplasm were selected over four cycles for resistance to Turcicum leaf blight. Selection was not based on a systematic rating of individual plants or progenies but rather it occurred as part of the pollination process where resistant plants tend to be selected for pollination. Five selection cycles for each population (including the original populations) were rated for Turcicum leaf blight in a trial in the 2003-4 season along with two100% temperate populations and two commercially-popular temperate hybrids.

8.3 Results

Figure 2 illustrates the marked reduction in leaf blight achieved through selection in two 75% temperate gene pools.

Figure 2. Recurrent selection for resistance to Turcicum leaf blight in two super-sweet populations



NB:Rating scale: 1= 10% of leaf area affected, 10 = 100% of leaf area affected.

8.4 Discussion

Single dominant gene resistances to Turcicum leaf blight were first identified by A.L. Hooker, and widely used in America in the nineteen sixties. However such resistances have had an unfortunate record of breakdown in the face of evolving new physiologic races of the pathogen. Accordingly breeders have tended to select for generalized resistance. Recent studies by Hakiza et al (Maydica 49(2004) suggest that as many as 4 or 5 genes are involved in controlling the percent of leaf area affected by the disease and 2 or 3 genes in determining the number of lesions. Heritability estimates were quite high (0.73 to 0.75 for affected leaf area), indicating that selection procedures for resistance were likely to be effective. Studies by Moon et al, 1999, found good generalized resistance in the tropical maize inbred Ki14. Distribution of recombinant inbred lines from the cross of Ki14 and susceptible inbred Hi31 closely fitted that expected from a single major QTL.

Selection for resistance to leaf blight in this experiment has been very successful. The importance of selecting in an environment with severe blight, such as exists on Kairi Research Station, has been amply demonstrated by the data. The first cycle of selection was done at Gatton in the Lockyer district where disease pressure was not high. Virtually no improvement was made. Later cycles were carried out at Kairi, a site where the disease is consistently severe on susceptible genotypes. Progess toward resistance was markedly more rapid in the Kairi environment.

Regressions fitted to the data showed a reduction in leaf blight of 0.56 and 0.59 units of rating score per cycle for SHF1 and SHF2 respectively. As the ratings for cycle 4 in both populations were 3.7 and 2.7 respectively, further improvement can probably be achieved. These ultimate ratings contrast with scores of 7.0 and 7.3 for the full temperate populations, SHTEMP 1 and SHTEMP 2 respectively and similar scores for the two widely used cultivars included in the trial. Quite clearly selection for leaf blight resistance is effective in material with 25% tropical infusion.

9. Common rust *(Puccinia sorghi*) resistance in super-sweet corn germplasm

9.1 Introduction

Common rust is a significant disease of sweetcorn in subtropical and temperate regions of Australia. As has been the case with Turcicum leaf blight, single gene resistances have been developed, notably a series at the Rp1 locus, but most have become ineffective in a short period of exposure to the pathogen. We have adopted a strategy of selection for resistance regardless of the manner of genetic control. In the tropics Common rust is seen mainly in the drier spring months or in the cooler autumn period. In summer in the tropics it is a minor disease. This has made screening more difficult so it has not been possible to carry out systematic selection in our breeding populations. Nevertheless one trial of mid maturing hybrids was rated and it provides a comparison of this material with temperate cultivars.

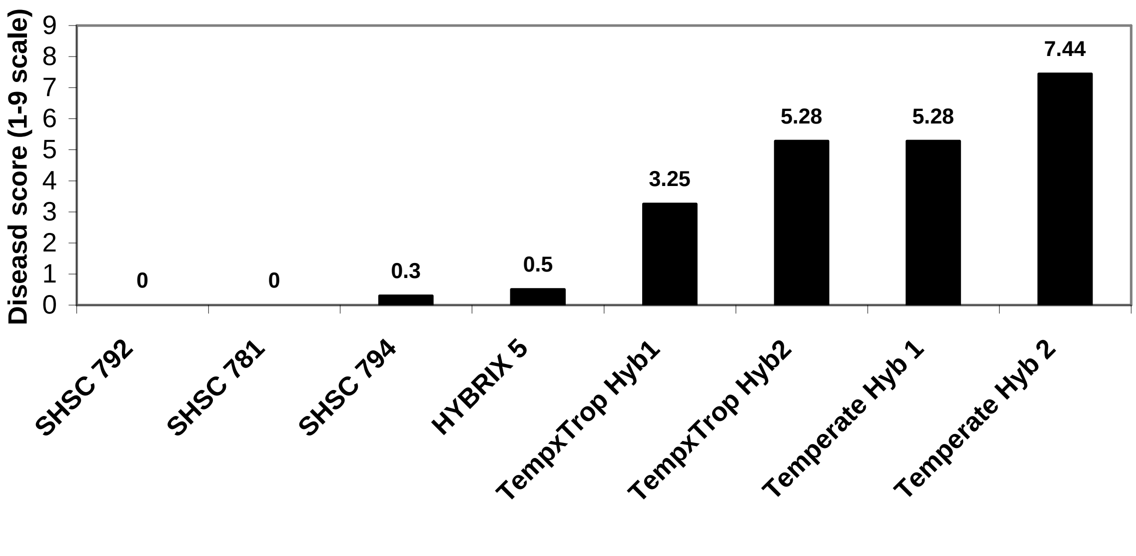
9.2 Materials and methods

In 2002 we compared a set of commonly-used commercial hybrids with a series of hybrids generated from inbreds derived from SHM1 and SHM2 populations. (These populations have a 50% tropical / 50% temperate genetic constitution). Environmental conditions produced quite severe symptoms in susceptible hybrids.

9.3 Results

Figure 3 illustrates the impressive resistance to Common rust present in tropical sweetcorn germplasm at Kairi. The SHSC series of hybrids have equal contributions of temperate and tropical germplasm yet recorded nil infection. The group of four commercial hybrids with temperate content received high ratings for rust infection. Full tropical hybrid, Hybrix 5, widely used because of its comprehensive disease resistance, recorded a low score of 0.5 on a 1 to 9 scale.

Figure 3. Common Rust ratings on various sweetcorn hybrids, Kairi, 2001-2.



Rating scale: 0 = nil infection, 10 = total infection.

9.4 Discussion

Single gene resistances to Common rust exist in the form of multiple alleles at the Rp1, 3 and 4 loci and have been used in sweet corn in USA. However Puccinia sorghi has multiple physiologic races and appears to be quite mutable. For this reason it was not thought advisable to attempt to incorporate any of these single gene resistances. Also there is no guarantee that these resistances will be effective against the race(s) of rust we have in Australia. Moon et al, 1999 found generalized resistance to the disease in the maize inbred Ki14. They found that this resistance fitted closely a model based on a single major QTL.

The nature of the resistance we have in tropical sweetcorn (illustrated in Fig.3) is unknown to us but it is probably oligogenic. In any event it is much more effective than any we have observed in temperate sweetcorn. It also appears to be dominant meaning this resistance should be relatively easy to use in breeding programs.

10. Polysora rust (*Puccinia polysora*) resistance in super-sweet corn germplasm.

10.1 Introduction

Polysora rust is a serious disease of maize in north Queensland but it has not been identified in sweetcorn any further south than the Atherton Tableland. Even the Burdekin and Bowen growing areas are apparently free of it. It has a requirement for persistent high humidity and free water on leaves for infection to occur. These conditions do not exist in any other sweetcorn growing areas in Queensland. Nevertheless there is some value in having a good source of Polysora resistance. If the Atherton Tableland region were to develop a sweetcorn industry (as has been recently mooted) resistance to Polysora rust would be necessary.

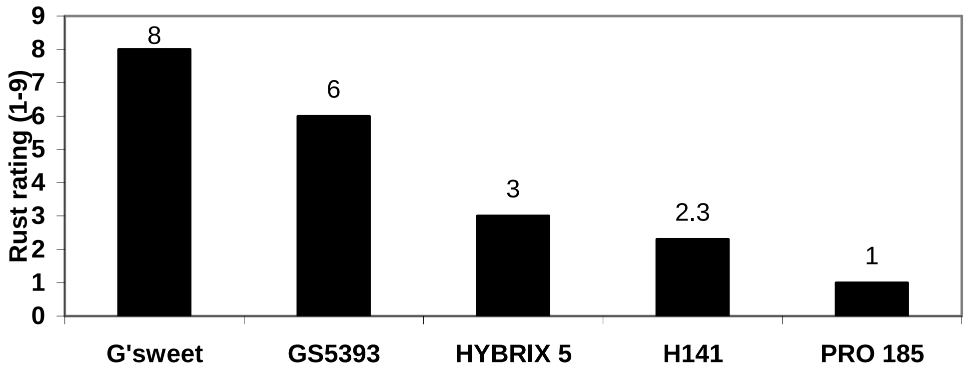
10.2 Materials and methods

Fifty-six hybrids, mainly of tropical adaptation, (but including a temperate check hybrid), were tested in the summer of 2004 for resistance to Polysora rust. Rust infection was promoted by the prior planting of susceptible hosts in the vicinity of the trial and supplementary overhead irrigation.

10.3 Results

Rust ratings ranged from 8.0 for the temperate hybrid Goldensweet to 1.0 for the tropical processing-type hybrid PRO 185. GSS 5393, a proprietary hybrid with some tropical adaptation proved to have a low degree of resistance and the QDPI/Pacific Seeds commercial hybrids Hybrix 5 and H141 had moderate resistance. The very high level of resistance exhibited by PRO185, is encouraging as it is one of a new series of hybrids emerging from work in the current project.

Figure 4. Polysora rust ratings on supersweet corn hybrids, Kairi, 2004.



Rating scale: 1= Nil infection, 9= Leaves totally browned off.

10.4 Discussion

Single gene dominant resistances to Polysora rust exist and have been used successfully in maize hybrids on the Atherton Tableland. The nature of the resistance evident in PRO185 has not yet been investigated but obviously has significance for any future development of a sweetcorn industry on the Tableland.

11 Maydis leaf blight *(Bipolaris maydis*) resistance in super-sweet corn germplasm.

11.1 Introduction

Maydis leaf blight is a relatively minor disease of sweetcorn. It is largely restricted to wet tropics regions such as the Atherton Tableland. Single gene resistance exists to the race of the pathogen believed to be active in Australia but the resistance gene is recessive. This would make it necessary to incorporate it in both parents of a hybrid, an onerous task. If male sterile cytoplasm is used in the production of seed, physiologic races of the pathogen are capable of inflicting massive damage, even in temperate areas.

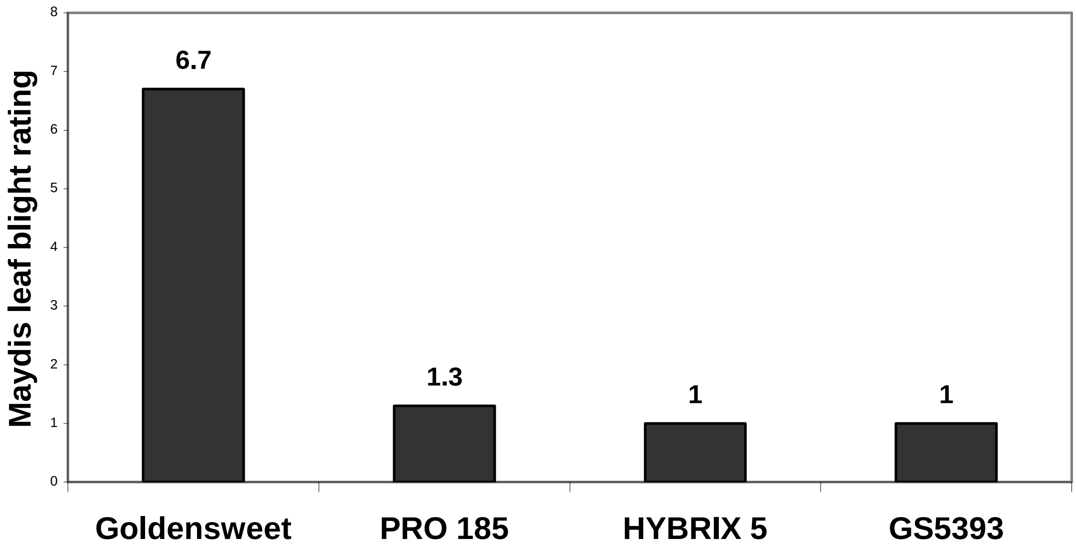
11.2 Materials and methods

Fifty-six supersweet corn hybrids were tested in a replicated field trial in 2002 season. Blight infection occurred naturally affording the opportunity for ratings to be recorded.

11.3 Results

The superiority of tropical germplasm is apparent in the selected results shown in Figure 5. The temperate hybrid Goldensweet proved to be highly susceptible, the three tropical hybrids had good resistance.

Figure 5. Maydis leaf blight ratings for supersweet corn hybrids, Kairi, 2002.



Rating scale: 1= nil damage, 9=very high damage

11.4 Discussion

There is no requirement for breeding resistance to this disease. In the tropical regions where the disease is a potential problem we have existing resistance. In subtropical and temperate areas the disease is not a problem provided male sterile cytoplasm is not used in seed production.

12. Purple sheath rot resistance in super-sweet corn germplasm

12.1 Introduction

Purple sheath rot is a recognised condition in sweetcorn in USA. It is thought to be caused by fungal organisms colonising detritus inside the leaf sheath. The implication appears to be that a parasitic relationship is not involved. However the condition appears to be associated with a pronounced reduction in the length of stalk internodes where the symptoms are observed. In extreme cases the stem is bent. This in turn leads to poor ear development.

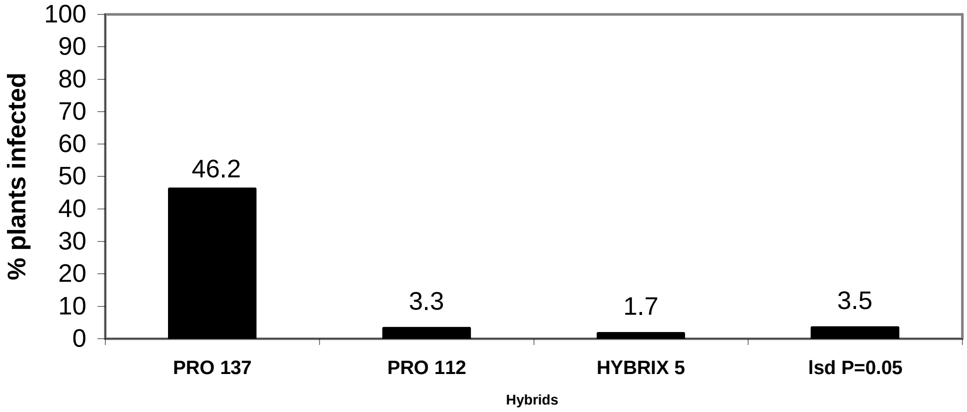
12.2 Materials and methods

A group of 54 testcross hybrids and two check hybrids were tested in a replicated field trial in 2002 season. The incidence of **Purple sheath rot** was sufficiently high to warrant recording of the percentage of plants affected.

12.3 Results

The range of infection rates was extremely large as seen in Figure 6. The standard commercial hybrid Hybrix 5 was the most resistant in the trial. However the experimental processing hybrid PRO112 was not significantly more susceptible than Hybrix 5. Hybrid PRO137 illustrates the degree of susceptibility that exists in the processing (canning) germplasm.

Figure 6. Purple sheath rot in supersweet corn hybrids, Kairi, 2002



12.4 Discussion

Purple sheath rot is unlikely to become a serious disease of sweetcorn. In this particular case it seems the tester inbred common to all hybrids(except Hybrix 5) is susceptible to the disease. Performance of the testcrosses would therefore be dependent on the degree of resistance in the other parent. Fortuitous use of a susceptible tester inbred has enabled us to identify good sources of resistance in the breeding population SHPRO1. Again tropical germplasm proved to be a good source of resistance.

13. Johnson grass mosaic virus (JGMV) resistance in super-sweet corn

13.1 Introduction

JGMV is a debilitating viral disease of sweet corn that is especially devastating in late-planted crops in the areas around the towns of Gatton and Laidley in south-east Queensland. Crops planted for harvest from January to April are particularly prone to infection. Johnson grass (Sorghum halepense) is an alternative host for the virus, so that areas where this grass is prevalent tend to experience problems.

Research by this program in conjunction with virologist Denis Persley of DPI, Indooroopilly, was successful in identifying a single dominant gene for resistance. This gene is effective in artificial inoculation situations as well as in the field. However there are indications that with natural inoculation in field situations, where the vectors are maize aphids, other genes are able to modify the result in a positive manner possibly through providing resistance to aphids.

This major gene and other modifying genes were progressively incorporated into the tropical super-sweet populations SHPOP 1 and SHPOP2 through a process of recurrent selection with subsequent screening at Gatton Research Station. During the course of the current project we have attempted to introduce resistance genes into the populations SHM1 and 2, and SHF1 and 2.

13.2 Materials and methods

S1 families from the four populations SHF1, SHF2, SHM1 and SHM2 are planted at Gatton, subjected to inoculum pressure by prior planting of a susceptible host, for example forage sorghum, then rated for percentage of infected plants and severity of disease symptoms. Those progenies with nil infection and appropriate other characteristics are recombined to generate the next cycle for selection.

13.3 Results

In 2001-2002 we found that of 332 S1 progenies from 75% temperate population SHF2, 158 (47.5%) had nil infection. Others had minor infection only.
In the 2004-5 season we tested 26 S1 progenies from the SHM1 population at Gatton. Only six of these lines recorded any JGMV-infected plants and at very low frequencies.

13.4 Discussion

We have managed to transfer the resistance of tropical populations to 50% and 75% temperate sweet corn pools . On the basis of these results SHF2 and SHM1 were re-combined from resistant progenies. Since most of this resistance is imparted by a single dominant gene this should result in pools of near -temperate supersweet germplasm with very high frequencies of resistant plants, from which resistant inbreds and hybrids can be derived. Currently we are discussing the possibility of attempting to locate the position of the major resistance QTL in conjunction with the biotechnologist at Mareeba.

14. Marker-assisted breeding for Heliothis corn ear worm resistance in super-sweet corn germplasm

14.1 Introduction

The ***P1*** gene on Chromosome 1 of maize leads to the production of a chemical compound called maysin. Maysin is produced in the silks of the maize (or sweetcorn) ear and has the effect, when ingested by Heliothis larvae, of preventing the synthesis of proteins from constituent amino acids. Eventually the larvae die. Widstrom and Snook, 2001, have recurrently selected maize populations for six cycles to produce levels of maysin more than eight times the level needed to prevent completion of the life cycle of Heliothis in the corn ear. We have been able to access one of these populations, SIM6, for use in our breeding work.

Originally researched for use in maize cultivars in the southern states of USA where Heliothis is a significant problem, interest has developed in its use in sweetcorn. There could be a problem in sweetcorn in that maysin causes the internal silks to be brown in colour; this would detract from the marketability of sweetcorn but it might be possible to select against this without reducing the maysin level in the silks.

14.2 Materials and methods

We introduced three sources of the P1 gene from Tifton, Georgia and made F1 families of these with six breeding populations. These F1 families were inbred to the S2 stage and samples of ear kernels sent to Dr Stephen Garland, Biotechnologist at Bowen Horticultural Research Station, for identification of progenies having the P1- gentoype.

Using the microsatellite marker phi095 as a primer it was possible to distinguish high maysin lines from low maysin lines. The former produce 5 or 6 products (depending on the source of P1) while the low maysin lines produced a single product of 165bp. (Dr Garland has previously submitted a full report on this work to Horticulture Australia.)

14.3 Results

14.3.1 Successful identification of the plants bearing the P1 allele.

Of the 143 S2 lines submitted for identification of the P1 allele, 16 failed to amplify. The remaining 127 segregated in a manner that agreed with a 3: 1 ratio. (It was not possible to distinguish between homozygotes for P1 and heterozygotes) .The 102 P1- genotypes have subsequently been crossed to the recurrent parents (low maysin lines) to initiate the first backcross operation.

Interestingly the primitive maize race, Zapalote chico, which has long been recognised for its resistance to Heliothis, produced 5 of the six products associated with the high maysin source SC 102.

14.4 Discussion

At the 2003 meeting of the International Sweetcorn Development Association in Hawaii it was revealed that recent research had shown much higher levels of maysin when the ***P1*** gene was in germplasm with a ***shrunken 2*** (supersweet) background. ***P1*** in association with the ***A*** gene on Chromosome 3 produces red pericarp in maize. The recessive allele at the A locus is linked closely with ***sh2*** **(**both are on Chromosome 3L**)**, which means that in a supersweet background the pigment for red pericarp is not produced. Instead the precursor is directed into the metabolic pathway producing maysin. Consequently higher levels of maysin result. Guo et al, (2001) have described a multi-locus model which includes involving a number of QTL, a1, P1 and epistatic interactions of some of these loci that accounted for 76.3% of the total silk maysin variance. In practical terms, selection for P1 and a1 (linked with sh2) is the simplest method of using a marker for high maysin. This combination accounted for approximately 41% or the variance for maysin in the cross examined by Guo et al.

This work is proceeding well and the intention is to persevere. We have been encouraged to find that hybrids of SIM 6, (one of the sources of P1), with a susceptible parent have exhibited good resistance to Heliothis (see Section 4.3, Table 1). It would be nice also to validate the presence of high maysin levels in P1 material.

15. Effectiveness of P1 gene in combating Heliothis corn ear worm (Helicoverpa armigera) in supersweet corn.

15.1 Introduction.

The research work conducted by Widstrom et al in Georgia, USA, that established the value of maysin and related antibiotic compounds (api-maysin and iso-orientin) in controlling Heliothis was conducted with a different species of Helicoverpa to that which is prevalent in Australian sweetcorn crops. The American species is H.zea; the Australian species H. armiger.

Although we thought it highly likely that maysin would be effective against all species of Helicoverpa, considering it affects a fundamental metabolic procedure (namely synthesis of protein), we thought it necessary to undertake some evaluation of the gene under Australian conditions before committing to the onerous task of incorporating the P1 gene in Australian germplasm.

The only materials at our disposal for the purposes of comparison were a group of first backcross progenies containing the P1 gene and the original broad genetic base populations that we assumed did not have the gene. It would have been more satisfactory to use near isogenic lines but the project has not advanced to that stage.

US research has demonstrated that for antibiotic compounds such as maysin to be effective it is necessary to have good husk cover, in particular a tight husk cover. Tight husk cover forces the ear worm to consume the silks in order to be able to access the corn kernels. In consuming the silks, the larva ingests a large quantity of maysin.

15.2 Materials and Methods.

The two tropical populations, PRO1 and PRO2 were crossed to two sources of high maysin, the inbred line SC102 and a synthetic SIM6 respectively. Inbreds developed from the full sib F1 progenies were screened for the P1 gene. Those possessing the P1- genotype were backcrossed to the original populations on a full sib (plant to plant cross) basis. These bc1 progenies were then compared with the original populations. Data for earworm damage, and influencing traits such as husk tightness rating, husk extension (length of husk protruding beyond ear tip) were recorded. A total of 10 ears were measured in each plot of in a four-replicated trial. Similar procedures were followed with the 75% temperate population, SHF2, and the 50% temperate population, SHM1, except that these populations were crossed with SC102 and SIM 6 respectively.

The tropical hybrid, Hybrix 5, renowned for its resistance to Heliothis, was used as a standard check variety for evaluating levels of resistance and the temperate hybrid Rising Sun was used as a check variety to signal the presence of an adequate Heliothis presence in the trial. The original populations were also used as check varieties. Unfortunately all had undergone some cycles of selection for improvement of ear worm resistance.

15.3 Results.

15.3.1 Effect of the P1 gene on ear damage

Table 3 data tends to support the idea that the P1 gene has some demonstrated ability to reduce the amount of damage caused by the larvae of Helicoverpa armigera to sweetcorn ears. Given that other feeding protective traits may have been contributed by the donor lines to the progeny containing the P1 gene there is a need to treat the data as indicative rather than conclusive. However in 16 of the 17 comparisons of the converted P1- genotypes with the parental germplasm the P1 lines have suffered less damage or equal damage to the parental population. In 7 of the 17 comparisons the damage was significantly less in the P1 material. That length of husk extension and more particularly tightness of husk cover at the ear tip appear to have a negative correlation with the amount of ear damage supports the data provided in Section 6. This is most clearly demonstrated in the comparison of the two check hybrids, Rising Sun and Hybrix5.

Table 3. Effect of the P1 gene and husk traits on damage to sweetcorn ears by Helicoverpa armigera. Kairi, 2005.

Table . Influence of P1 gene and husk physical characters on Heliothis damage. 2004-5 season.

Genotype	Husk Ext	Husk Tight	Damage	Sig diff
(SC102 x sh2POP12-C3 FS5-1-1) x sh2POP12-C5 FS1	10.73	4.83	1.58	
(SC102 x sh2POP12-C3 FS3-3-1) x sh2POP12-C5 FS1	11.33	5.40	1.38	
(SC102 x sh2POP12-C3 FS1-5-1) x sh2POP12-C5 FS1	11.85	5.58	1.33	
POP12-C3	10.30	4.75	1.58	
(SC102 x sh2PRO2-C1 FS7-3-1) x sh2PRO2-C3 FS1	9.16	6.29	1.47	*
(SIM6 x sh2PRO2-C1 FS1-1-1) x sh2PRO2-C3 FS1	9.08	6.43	1.55	
(SIM6 x sh2PRO2-C1 FS2-1-1) x sh2PRO2-C3 FS1	9.40	6.05	1.58	
(SC102 x sh2PRO2-C1 FS6-1-1) x sh2PRO2-C3 FS1	8.93	6.50	1.38	*
(SIM6 x sh2PRO2-C1 FS5-2-1) x sh2PRO2-C3 FS1	12.03	6.33	1.43	*
PRO2-C1	8.83	5.35	1.75	
(SIM6 x sh2POP21-C0 FS1-2-1) x sh2POP21-C2 FS1	5.60	4.78	1.85	
POP21-C0	6.63	4.33	1.75	
(SIM6 x sh2POP15-C3 FS9-3-1) x sh2POP15-C5 FS1	9.73	6.28	1.38	
(SIM6 x sh2POP15-C3 FS1-3-1) x sh2POP15-C5 FS1	11.58	6.15	1.18	*
POP15-C3	8.33	4.73	1.63	
(SC102 x sh2PRO1-C1 FS4-1-2) x sh2PRO1-C3 FS1	6.40	5.85	1.48	*
(SIM6 x sh2PRO1-C1 FS3-1-2) x sh2PRO1-C3 FS1	8.83	5.78	1.60	*
(SC102 x sh2PRO1-C1 FS6-3-1) x sh2PRO1-C3 FS1	4.83	4.70	1.68	*
(SC102 x sh2PRO1-C1 FS6-4-1) x sh2PRO1-C3 FS1	4.30	4.45	1.88	
(SIM6 x sh2PRO1-C1 FS1-1-2) x sh2PRO1-C3 FS1	11.38	**6.53**	1.45	*
(SIM6 x sh2PRO1-C1 FS12-3-1) x sh2PRO1-C3 FS1	9.43	5.90	1.25	*
PRO1-C1	6.35	4.48	1.88	
RISING SUN	9.78	3.40	2.23	
Hybrix 5	5.98	6.70	1.3	
Significant Difference (P=0.05)			0.28	
		1= loose, 9=tight	1=low, 9=high	

15.3.2 Relative efficacies of the two sources of P1 gene for controlling Heliothis corn ear worm.

An additional objective of this trial was to determine whether there was any significant difference in the effectiveness of the two sources of the P1 gene. Table 4 examines the results from crossing the inbred SC102 and the purpose-developed synthetic SIM6 to Australian tropical populations PRO1 and PRO2 for their effects on Heliothis damage. Five first backcross progenies were used for the comparison using PRO 2 and six for the comparison for PRO1. SC102 was slightly more effective in reducing damage in PRO2, but for PRO 1 the reverse was the case. The reduction in damage achieved by using SC102 with PRO2 was significant, as was that achieved by using SIM6 in a PRO1 background.

Table 4. Comparison of two sources of the P1 gene.

Genotype	Husk Ext.	Husk Tight	Ear Damage
(SC102 x sh2PRO2-C1 FS7-3-1) x sh2PRO2-C3 FS1	9.16	6.29	**1.47**
(SC102 x sh2PRO2-C1 FS6-1-1) x sh2PRO2-C3 FS1	8.93	6.50	**1.38**
SC102 x PRO2 mean	**9.04**	**6.39**	**1.42**
(SIM6 x sh2PRO2-C1 FS1-1-1) x sh2PRO2-C3 FS1	9.08	6.43	**1.55**
(SIM6 x sh2PRO2-C1 FS2-1-1) x sh2PRO2-C3 FS1	9.40	6.05	**1.58**
(SIM6 x sh2PRO2-C1 FS5-2-1) x sh2PRO2-C3 FS1	**12.03**	6.33	**1.43**
SIM6 x PRO2 mean	**10.17**	**6.27**	**1.52**
PRO2-C1 Average	**8.83**	**5.35**	**1.75**
(SC102 x sh2PRO1-C1 FS4-1-2) x sh2PRO1-C3 FS1	6.40	5.85	**1.48**
(SC102 x sh2PRO1-C1 FS6-4-1) x sh2PRO1-C3 FS1	4.30	4.45	**1.88**
(SC102 x sh2PRO1-C1 FS6-3-1) x sh2PRO1-C3 FS1	4.83	4.70	**1.68**
SC102 x PRO1 mean	**5.18**	**5.00**	**1.68**
(SIM6 x sh2PRO1-C1 FS1-1-2) x sh2PRO1-C3 FS1	11.38	6.53	**1.45**
(SIM6 x sh2PRO1-C1 FS12-3-1) x sh2PRO1-C3 FS1	9.43	5.90	**1.25**
(SIM6 x sh2PRO1-C1 FS3-1-2) x sh2PRO1-C3 FS1	8.83	5.78	**1.60**
SIM6 x PRO1 mean	**9.88**	**6.07**	**1.43**
PRO1-C1 Average	**6.35**	**4.48**	**1.88**
SC102 MEAN	**7.11**	**5.70**	**1.55**
SIM6 MEAN	**10.02**	**6.17**	**1.48**

15.4 Discussion

On the basis of the results detailed in this report it appears likely that the P1 gene has a beneficial effect in reducing damage caused to sweetcorn by the species of corn ear worm prevalent in Australia (Helicoverpa armigera). However the question has to be asked whether it is any more effective than recurrent selection for ear worm resistance in broad genetic base populations. Butron et al (Maydica 45(2000): 295-300, were in little doubt that recurrent selection based on 10 cycles of recurrent S1 progeny selection and 7 cycles of reciprocal recurrent selection for husk tightness and reduced ear damage was not sufficient and that marker selection for increased maysin was required.

The parental populations in Table 3 have undergone such selection for at least 3 cycles and have reached a degree of resistance where only minimal ear worm damage is experienced in the environment of the Atherton Tableland. As such these populations did not provide much opportunity for the P1 gene to demonstrate its potency in controlling Heliothis damage. As well we made the assumption that our populations did not possess the P1 gene.

If we had used an unselected temperate population or temperate inbreds the gains would have been more substantial and this is the area where P1 gene and related genes will likely have most useful application.

The results presented here appear to support the contention of US researchers that the gene needs to be combined with tight husk cover and preferably a long husk extension for maximum effectiveness. However more detailed examination of the results needs to be carried out to resolve the relative importance of each of these traits in controlling the problem.

More recent research by Butron et al (Maydica, 46 (2001): 117-124, has found a new QTL on Chromosome 2 that produces antibiotic compounds and, importantly, a QTL for husk tightness near the p1 locus. Unfortunately it appears the favourable alleles for these traits are in repulsion linkage meaning markers for both loci would need to be used in a selection program.

More work is needed on this issue. Ideally we should produce a series of recombinant inbred lines in a shrunken 2 background to determine more precisely the value of P1. In the meantime we plan to continue backcrossing the gene to important supersweet populations.

16. Other disease and insect problems

During the course of the project we have become aware of other disease and insect problems that we were not able to address at the time. They were not as important as the major problems we treated but some have the potential to become serious.

- **Thrips**

  Sequential plantings of sweetcorn tend to cause a buildup of this insect problem. It is somewhat insidious in that the problem tends to go un-noticed. Plants look unthrifty and make slow growth. The remedy is usually to spray an insecticide but a resistant variety would save costs and ensure that the condition did not inflict damage before it was diagnosed. We have noted marked differences in the degree of damage caused by Thrips on different progenies so it is highly likely that genetic resistance exists.

- **Monolepta beetle**

  This beetle feeds on the silks protruding from the tip of the ear and can thus have a disastrous effect on kernel production. Insecticides are normally used for control but infestations occur remarkably quickly and the damage may not be noticed in time. We have not discerned any differences in resistance among progenies but as the beetle is a silk-feeder there is a possibility that high maysin (or some similar naturally occurring compound) may have a controlling effect and be amenable to genetic manipulation.

- **Green vegetable bug**

  These insects puncture the husk leaves and suck out juices from the developing ear. They are not a common problem on the wetter parts of the Atherton Tableland but have been noted in drier areas such as Mareeba. Limited observation suggests there are varietal differences in the degree of inflicted damage.

- **Fusarium ear and kernel rots**

  The destructive potential of these diseases caused by Fusarium graminearum and F. verticillioides on susceptible sweetcorn hybrids has been demonstrated in the MIA in recent seasons. Both fungi are capable of producing toxins (eg zearalenone and fumonisin) which are injurious to human health when consumed. Some of the toxins are carcinogenic.

  Most commercial hybrids appear to have effective resistance but we have noted Fusarium disease in temperate varieties with poor husk cover, particularly after periods of constant rain.

  From a health viewpoint the industry needs to take stringent measures to identify cultivars that are susceptible to these diseases.

17. Selection for tenderness in sweet corn populations

17.1 Introduction

Tenderness in sweetcorn is a highly valued trait in sweetcorn. It is largely determined by the thickness of the pericarp (skin layer of the kernel). Pericarp thickness ranges from 40 microns for elite sweetcorn hybrids to 130 microns for some maize hybrids. Both the number of cell layers and the thickness of cell walls have been found tohave a role. It is true that the internal tissues of the kernel have some influence on the perception of tenderness but the pericarp provides the initial impression. Brewbaker (1991) reviewed the literature on tenderness and stated that most studies concluded that thin pericarp was a partially dominant trait and that it was highly heritable with relatively few genes involved (from two to five genes). Later studies by Wang and Brewbaker located 3 QTL involved in pericarp thickness. In any case the high heritability of the trait means selection should be successful. In the current study we employed recurrent selection for tenderness based on the "bite" test of a taste panel as the means of improving the trait.

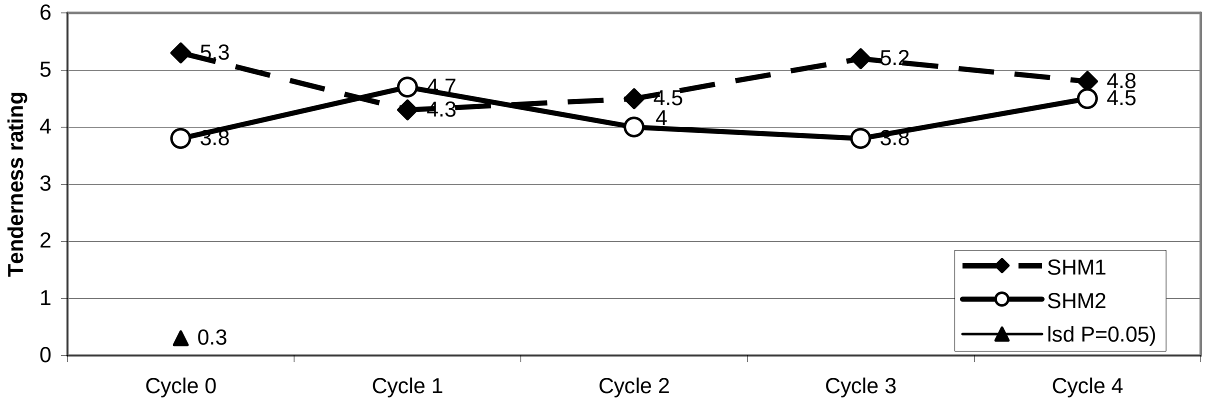
17.2 Materials and methods

Two breeding populations (SHM1 and SHM2) were selected for tenderness (using the bite test) for four cycles. From 200 to 500 S0 plants were self-pollinated then taste tested at the optimal eating time (22 to 24 days after 50% of the plants had commenced silking). Remnant seed of the most tender plants (approximately 10%) were harvested and their S1 families inter-crossed to constitute the next generation of selection. After four generations of selection were completed the selection cycles were planted in a replicated field trial and ratings for tenderness carried out. In this trial a panel of four taste testers was used with each panel member evaluating one cob per plot.

17.3 Results

Population SHM2 improved 37% from a rating of 3.8 in Cycle 0 to 4.5 in Cycle 4 but SHM1 was significantly lower for tenderness in Cycle 4 than C0 (Fig.7).

Figure 7. Recurrent selection for tenderness in two supersweet corn populations



Rating scale: 1 = tough, 9 = tender

17.4 Discussion

The results for SHM1 are disappointing. In view of the high heritability and apparent partial dominance of pericarp thinness noted in previous studies it is difficult to explain why better progress was not achieved. The fact that elite plants tended to cluster in specific half sib progeny supported the theory that heritability was high.

Other traits such as sweetness, Heliothis resistance and kernel depth were selected concurrently with tenderness but there was usually a selection differential of 15% to 20% for tenderness in the selected group and this should have been enough to ensure progress.

Since Brewbaker made good progress with the use of the bite test technique in mass selection procedures there was a degree of confidence that the method would be successful, particularly since we had control over both male and female parents. The alternatives of measuring pericarp thickness or using a penetrometer to replace the bite test are more time consuming and therefore not appealing. Brewbaker used a selection index of 5% compared with the index of approximately 10% used in the current study so perhaps we need to impose more intense selection. It is also possible also that the genes for further improvement of tenderness are not present in the two populations under consideration. Brewbaker selected within F2 populations from crosses between thin pericarp inbreds with thick pericarp inbreds.
These results are for broad genetic base populations. Individual plants within later cycles of the populations achieved tenderness ratings as high as 7. (This was similar to the rating for control hybrid Dominion, which is regarded as the benchmark hybrid for flavour and tenderness). Once advantage is taken of the variability that exists in the populations to select and inbreed elite plants and utilise them to produce hybrids, we can expect to produce cultivars with superior tenderness.

18. Selection for flavour in supersweet corn populations

18.1 Introduction

Flavour in sweetcorn is a very subjective characteristic. As such it does not lend itself readily to scientific study. The most significant advance in sweetcorn in the last few decades has come through the introduction of the supersweet genes, the most prominent of which are ***shrunken 2(sh2)*** and ***brittle 1(bt1).*** The first of these is much more commonly used. Its use results in much higher content of sucrose in the corn kernel than the ***sugary 1(su1)*** gene used in ordinary sweet corn. ***Sugary 1*** produces a higher content of water-soluble polysaccharides which, while not producing the same degree of sweetness, have the effect of giving the kernel a creamy texture not found with ***sh2.*** There are other flavours in the kernels. Much selection consists of eliminating progenies with various “off-flavours” and rejecting”starchy” and “gritty” textures.

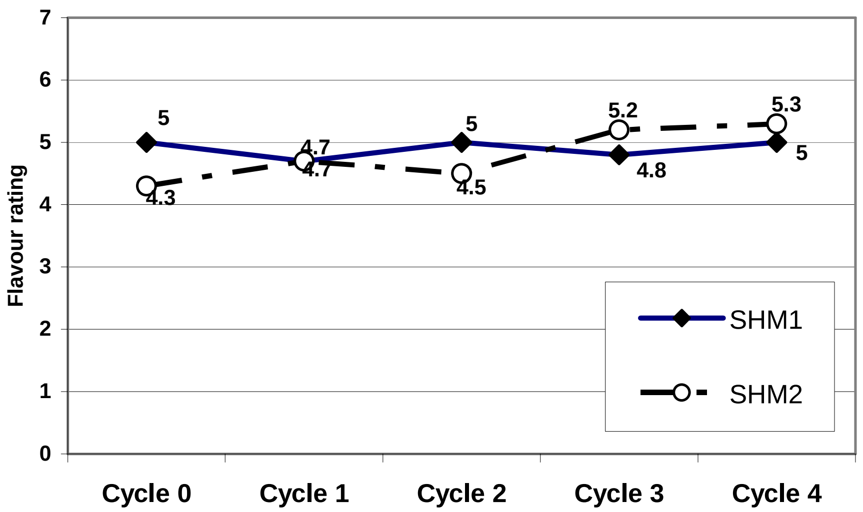
18.2 Materials and methods

Each of two broad genetic base populations SHM1 and SHM2 were selected for four cycles of improvement. From 200 to 500 individual S0 plants were self-pollinated, then at the optimal time, rated for flavour. Remnant seed from the highest rating plants was harvested. The S1 families from these elite S0 plants were inter-crossed to provide half sib families of S0 plants to commence the next cycle of selection. A selection index in the vicinity of 10% was used for most cycles.

18.3 Results

There was a similarity to the results for selection for tenderness in that SHM1 failed to respond to selection whereas SHM2 improved from an initial rating of 4.3 to a rating of 5.3 in Cycle 4 with a pattern of fairly constant improvement (Figure 8).

Figure 8. Recurrent selection for flavour in two supersweet corn populations



18.4 Discussion

Although sweetness and tenderness are not objectives described in the project title they are obviously vital to the commercial utilisation of project outputs. Improvement in SHM2 has been quite satisfactory (23% gain in four years) but there has been no improvement in SHM1 for reasons that are not clear.

. The two control hybrids rated 5.0 and 5.8 for Golden sweet and Dominion respectively. By comparison the scores for the final cycles of the populations are acceptable. With further selection for progeny of outstanding individuals and the heterosis from specific combinations, ratings of 6 should be attainable in hybrids. Ratings as high as 7 were measured in individual plants within the populations.

The main component of flavour is probably sweetness, despite individuals maintaining their dislike of too much sweetness. At the International Sweetcorn Development Association meeting in 2003, it was apparent that private breeding companies were moving towards using combinations of carbohydrate mutants to produce sweeter-tasting hybrids. There are at least nine mutant genes that affect carbohydrate synthesis. Of these, sh2, su1, bt1, ae and wx are all being used in various combinations, usually two genes but sometimes three. One of the most commonly used combinations is that of su1 and sh2. This particular“bi-sweet” (as such combinations are termed), has problems in that seed of the double mutant produces very weak plants. This complicates seed production and the final hybrid. We have embarked on a program to combine the two genes and perhaps we will need to use a sh2 parent as the seed parent to get adequate vigour with the pollen parent being the double mutant. This will give additional sweetness in the final hybrid due to the presence of a proportion of double mutant kernels.

One assumes that the type of progress shown for SHM2 is caused by selection for modifier genes acting in concert with sh2. As such it is unlikely that such progress can continue for many more selection cycles.

19. Genetic outputs of the breeding project

A primary concern of the project was that as well as investigating the potential for improving individual traits the development of genetic entities that would be useful to the sweetcorn industry in the near and long term. To this end the project has produced six gene pools that have the potential to act as selection vehicles for long- term genetic improvement of sweet corn in temperate, subtropical and tropical areas of Australia. It has also identified elite super-sweet inbreds and hybrids that appear to have application in commercial sweetcorn production.

It can be justifiably said that we have carried out only limited testing in New South Wales and that the feedback indicates that the materials developed for the higher latitudes such as Victoria have lacked adaptation to the day-length conditions pertaining there in mid summer. More breeding and testing needs to be done in these regions to exploit the disease and insect resistance inherent in our breeding populations. However inbreds from the project are finding their way into experimental hybrids and they will hopefully be tested in the southern states in the near future under the supervision of the commercial entity involved in the project.

19. 1 Gene pools

The breeding populations are grouped according to genetic makeup and maturity. They have been developed as heterotic-paired populations from which it can be expected that the best hybrids will be crosses of inbreds between the reciprocal populations.

Table 5. Target adaptation areas and prominent traits of the gene pools.

Gene Pools	Genetic Constitution	Target area of use	Main traits	Intended Market use
SHF 1 SHF 2	75% temperate 25% tropical	1.Temperate regions (southern NSW and Victoria) 2.Bowen (winter)	1.Early maturity 2.Intermediate blight resistance 3.Moderate Heliothis resistance	Fresh
SHM 1 SHM 2	50% temperate 50% tropical	1.Lockyer District 2.Bowen (winter)	1.Mid maturity 2.Good blight resistance 3.Good JGMV resistance 4.Good Heliothis resistance	Fresh
PRO 1 PRO 2	Mainly tropical	1.Lockyer District 2. Bowen 3.Atherton. Tableland	1. Late maturity 2. Good blight resistance 3.Resistance Heliothis, JGMV 4. High yield	1.Fresh 2.Canning

19.2 Hybrid performance

To this point we have dealt with individual traits. A commercially-successful hybrid must integrate the most important of these traits in one genotype. This important aspect of the project is examined below.

- **Quick maturing hybrids (SHF series)**

The project has generated 150 quick maturing hybrid combinations. These have been tested at Kairi, Gatton and Bowen. An impression of the worth of these hybrids can be gleaned from a comparison of SHF 12 with commercial hybrids.

Table 6. Comparison of a quick maturing project hybrid with commercial hybrids in a trial at Pacific Seeds Research Farm, Gatton in 2003.

Hybrid	Taste	Turcicum Leaf blight	Tip Fill	Kernel colour	Cob length (mm)	Cob Diameter (mm)
SHF 12	3.5	7	3.5	3	18	44
Punchline	3.5	7	2	2.5	17	44
Dominion	3	2	2	2.5	20	43
Hybrix 5	2.5	5	2.5	3	20	51

NB: Taste, tip-fill and kernel colour are rated on a 1 to 5 scale with 5 being best. Turcicum leaf blight is rated on a 1-9 scale with higher scores superior.

The general comment for SHF 12 was "very good taste and uniform cob appearance". It is superior in all aspects with the exception of cob size. For this trait the tropical hybrid, Hybrix 5, which is a canning-type hybrid, holds sway. When one considers that Dominion is recognised as a one of the best eating quality hybrids in the world the performance of SHF 12 is meritorious. It rated better than Dominion for taste. It also has better resistance to leaf blight than Hybrix 5, a useful advantage.

- **Mid maturing hybrids (SHM series)**

The project has generated 320 mid maturity hybrids of which 175 have been evaluated. The remainder are currently in field trials. As with the SHF series, they have been tested at Gatton, Bowen and Kairi. As a group they have a higher frequency of hybrids resistant to Johnson grass mosaic virus and better resistance to Turcicum leaf blight. They also have better eating quality traits.

Table 7. Comparison of two SHM super-sweet hybrids with commercial hybrids in a trial conducted at Kairi, 2004 spring.

Hybrid	Yield Kg/6cobs	Taste Rating	Tenderness Rating	Blight Rating	Heliothis Rating	Cob Shape	Cob Fill %
SHM 176	1.75	5.5	6.3	2.7	8.4	5.5	96.5
SHM 156	1.8	6	5.5	2.0	8.0	5.7	92.7
Goldensweet	1.25	4.8	5.3	7.0	7.8	3.7	76.0
H141	2.2	5	4.6	3.0	8.2	5.4	85.1

Rating:Taste, Tenderness, Heliothis, Shape(1= poor, 5= average, 9 = excellent) :Blight (1=low, 9=high disease level)

SHM156 and SHM176 are superior for most traits;yield is the exception. Their smaller cobs produce a lower yield compared with H141. Goldensweet, poorly adapted at Kairi is badly affected by Turcicum leaf blight. This is reflected in the yield and poor cob shape. Noteworthy is the good cob fill recorded by SHM 176.

- **Tropical, late maturing, processing hybrids**

These hybrids need to have very good disease resistance because they may be exposed to higher disease pressure but more specifically they need to have high yielding capacity because payment is made by tonnage delivered to the cannery rather than on a "per cob" basis. A further advantage is high kernel recovery, as measured by weight of kernels produced divided by the weight of green corn expressed as a percentage.

It has been difficult to find a processing hybrid to supplant Hybrix 5 which has been in commercial use for about 15 years. This is because it is a robust, widely adaptable hybrid with high yield potential and good resistance to Heliothis. It also has a kernel recovery percentage in the range of 40% to 45% which compares with 35% for most of its canning competitors. This makes it very attractive to canners because of the savings in freight and canning process costs. Hybrix 5 also has a role as a fresh market corn suitable for pre-packs because of its attractive cob and kernel characteristics.

The deficiencies in Hybrix 5 are that the kernels are significantly less tender than cultivars such as Goldensweet and that its resistance to Turcicum leaf blight, though better than many hybrids, needs to be improved to cope with the pressures of serial culture of sweetcorn. In an attempt to overcome the quality problems of Hybrix 5 we have introgressed elite temperate germplasm into the tropical breeding populations to create PRO1 and PRO2 populations, selected them for improvement, extracted inbreds and produced hybrids. Since the commencement of the current project we have made 302 processing hybrid combinations of which 242 have been tested. The remaining sixty hybrids are under test at this time. In the last couple of years the project has, through its commercial participant, Pacific Seeds Ltd, developed a hybrid, SW018, with most of the attractive features of Hybrix 5 but with improved tenderness and cob characteristics. In Table 6 details of its performance at Bowen last winter support the case for its commercial release.

Table 8. Performance of super-sweet hybrid SW 018 and commercial controls at Bowen in 2004 winter season.

Hybrid	Cob size (g)	Tenderness rating	Taste rating	Common Rust rating	Turcicum Leaf blight	Husk colour
SW018	**444**	**5**	**7**	**1**	**1**	**7.5**
Hybrix5	**397**	**3.5**	**6**	**1**	**1**	**5**
Goldensweet	**322**	**8**	**7.5**	**1**	**4**	**7.5**

Tenderness, Taste, Husk colour rating: 1 = poor, 5 = average, 9 = very good
Leaf disease: 1= nil disease, 5 = average, 9 = totally diseased

SW018 rated better than Hybrix 5 for all traits and had equal resistance to leaf diseases. Large cob size and deep kernels (13mm) make it a promising candidate for a processing hybrid. Evaluation at Golden Circle cannery has been arranged. Its tenderness is markedly better than that of Hybrix 5, though a long way short of Goldensweet. a premium quality hybrid for the fresh market.

20. Consumer survey

20.1 Introduction

A critical phase of any plant breeding program is deciding what traits should be breeding objectives. At the outset of this project there was a dearth of knowledge about what consumers really looked for when they purchased sweetcorn. As well the industry had no current knowledge of matters such as the frequency of purchase, the amount of consumption, the preferred form of sweetcorn (canned, frozen cobs, pre-packs or loose fresh cobs).

There were also issues of health. Did consumers prefer organically-grown corn? How averse were they to the use of insecticides? Were they prepared to tolerate some corn ear worm damage to the cobs? What was their reaction to genetically modified sweet corn?For these reasons and others, in 2001 the project commissioned the national survey group NCS Pearson to conduct a survey of consumers. For cost reasons the survey was limited to Brisbane.

20.2 Materials and methods

The survey was conducted on a face to face interview basis on May 17th, 2001 at two major shopping centres in Brisbane, the Westfield Shopping Centre at Indooroopilly and Garden City at Mt Gravatt. A total of 200 consumers responded to the survey; 132 were female and 68 were male. There was a representative balance of age groups, occupational orientation and financial status.

20.3 Results

Key findings

- **Kernels**

65% of consumers preferred a golden (mid) yellow to a pale or dark yellow
Large kernels were preferred over small (54%)

- **Husk characteristics**

Mid green husk leaves were preferred (47%) over pale green or dark green.
Absence of flag leaves was preferred (72%) over presence of flag leaves. (This was a noteworthy response to a contentious issue as most marketers thought flag leaf was preferred as it implied freshness and signalled a sweetcorn identity).

- **Cob size**

Preferred size was 15cm (37%) to 17.5cm in length(34%). Thus length in the range of 15 to 17.5 cm satisfied 71% of consumers.

- **Premium for ideal cob**

32% were prepared to pay additional 5% for ideal cob and 30% were willing to pay an additional 10%. This emphasizes the importance of producing quality cobs.

- **Attractive characteristics**

Fresh moist kernels (94%)
Health benefits (85%)
Tip of cob free from grub damage (83%)
No transgenics (72%)
Organically grown (71%)

- **Conflicting desirables**

When asked to choose between organic production and Heliothis damage 56% opted for organically grown sweetcorn even if it sustained Heliothis damage versus 32% who preferred to have no Heliothis damage even if it entailed insecticide use.

When asked to choose between use of transgenic sweetcorn and insecticides for protection against Heliothis 61% opted for pesticide free transgenics against 33% who wanted no transgenics with the possible need to use insecticides. This is once again a surprising result and perhaps needs to be supported by further surveys.

- **Pre-packs versus loose cobs**

Pre-packs were preferred by 55%.
Reasons for preferring pre-packs were
Can see kernels to check quality (54%)
Easy to prepare, partly processed (29%)
Convenience of packaging (23%)
Ease of handling (18%)
Easy to select (15%)

- **Alternatives to fresh loose cobs or pre-packs**

42% will purchase frozen sweet corn packs
29% will purchase canned sweet corn
29% will purchase other vegetables

- **Recipe cards on packs**

59% found recipe cards on packs appealing because
Provides new ideas (71%)
Provides helpful instructions (16%)

- **Improvements needed in sweetcorn**

Regular eaters of sweetcorn thought that quality of sweetcorn needed improving (70%)
Improvements suggested included
Sweeter (52%)
Fresher (24%)
Juicier (20%)
Fuller flavour (17%)
More corn flavour (13%)
More tender (13%)
The high premium placed on sweetness might suggest that some sweetness is being lost prior to purchase or it may support research into the development of sweeter hybrids through means such as the use of hybrids with more than one

gene for sweetness. In any case it tends to rebut the argument that Australians do not like a high degree of sweetness in sweetcorn.

- **Quality problems in sweetcorn**

Kernels dry and shrivelled (39%)
Too old and not fresh enough (18%)
Grub damage or caterpillar in tip (ear worm) (12%)
Kernels too light in colour (8%)

- **Level of quality concern as a function of shopping outlet**

Respondents were not overly concerned about the problems of quality outlined above with 80% saying they occurred about every 3 to 4 months. 84% of respondents were either not concerned or only slightly concerned.

Those shopping at specialist fruit and vegetable outlets had a greater incidence of concern (40%) than those who shopped at the supermarkets (16%). This might indicate that they are more demanding of quality or it might be that fruit and vegetable shops have a higher proportion of fresh loose cobs which are more prone to quality problems than pre-packs.

NB: A full report of the survey is held at Kairi Research Station. Interested persons can access the Executive Summary of this report if they contact the author of the current report.

21. Technology transfer

21. 1 Field walks and meetings with growers.

Project staff have conducted annual field walks and meetings throughout the life of the project. These have been organized at Gatton and Bowen. The major sweetcorn producers have regularly attended these days, inspected the experimental hybrids, been informed on the latest progress and have offered feedback during presentation and discussion sessions. A comprehensive report has been prepared by Ross Wright on the 2004 field day held at Bowen and would be available if required.

21.2 New hybrids for the industry

As indicated in section 17 we have prospective hybrids with exceptional performance. Three of these SW016, SW017 and SW018 are undergoing commercial evaluation on farms in the Gatton area. SW016 and SW017 are aimed at the fresh market while SW018 is a dual purpose hybrid with perhaps more application in the processing industry. Samples of SW018 have been sent to Golden Circle Ltd cannery at Northgate for evaluation of suitability for canning but results are still forthcoming. If the outcomes of these evaluations are favourable we will move to increase seed of parental inbreds and release seed of the hybrids to the sweetcorn industry. Pacific Seeds Ltd have the expertise to produce quality seed and the sales distribution network to ensure successful promotion of the new hybrids.

21.3 Meetings

The author attended the 2003 meeting of the International Sweetcorn Development Association at Kauai Island, Hawaii and presented a paper on the project results to that point in time. A report on this meeting has been submitted. There have been other less formal meetings with project staff to plan future project work, for example with horticulture and pathology staff, with growers and Pacific Seeds breeding staff.

22. Recommendations

- **Provision of new improved hybrids to industry**

Further testing of new hybrids needs to be carried out to confirm their commercial value. This applies especially to screening for Johnson grass mosaic resistance.

- **Exploitation of recent cycles of selection for eating quality**

Only two cycles of quality improvement in the newly-created gene pools have progressed to hybrids in trial. Further hybrid combinations and testing would permit the full exploitation of this potential improvement.

- **Evaluation of "bi-sweet" hybrids**

We have generated a large number of hybrids containing both shrunken 2 and sugary 1 genes this summer. Given that the consumer survey indicated a desire for greater sweetness, it would be instructive to compare these new hybrids with existing super-sweets. The production of bi-sweets would open up a new area of breeding in Australia, one which is "state of the art" in USA.

- **Tropical bicolours and white super-sweets**

Production of sweetcorn in north Queensland has very large potential because of year round growing ability and large areas of irrigable land. It could eventually support an export industry. The areas around Bowen (eg Gumlu), the Burdekin, the Lakeland district and the Atherton Tableland all have irrigation and production potential. With tropical yellow supersweets reasonably well catered for with cultivars there is a need to develop white and bicolour hybrids adapted to the tropics.

- **Recurrent selection for tenderness, flavour and yield to develop a tropically-adapted variety with export quality**

Development of a variety with greatly improved tenderness than current canning hybrids and with good yield and kernel recovery would place Australia in a position where it could compete for the lucrative export industry to Japan.

- **Variety testing in temperate areas of production**

To obtain value from the SHF1 and SHF2 populations more trials of hybrids from these populations should be carried out in NSW and Victoria.

- **Continuation of P1 breeding for resistance to Heliothis**

If it can be demonstrated that the P1 gene has the ability to control Heliothis corn ear worm the backcrossing program to incorporate the gene should be continued.

- **Baby corn**

Though not technically a sweet corn, baby corn production and marketing has some similarities. Development of male sterile cultivars would assist the industry by cutting labour costs.

- **Continuation of breeding program**

All of the above recommendations would be supported by continuing the sweetcorn breeding program at Kairi.

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