VG409
Queensland fresh market tomato
breeding

Des McGrath
QLD Department of Primary Industries

VG409

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HORTICULTURAL RESEARCH & DEVELOPMENT CORPORATION

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INDUSTRY SUMMARY

The project has successfully developed a range of improved true-breeding lines with early, concentrated maturity, resistance to three races of Fusarium wilt and excellent fruit characteristics. One experimental hybrid developed from these lines has been selected for release to industry and another may be released after further testing in 1998. The new hybrid is adapted to ground cropping in the Dry Tropics of Queensland and produces higher marketable yields than earlier commercial cultivars and similar yields to current cultivars. However, its most significant advantage over commercial varieties is a higher proportion of more attractive marketable fruit.

Genetic resistance to Potato Tuber Moth from a wild species was identified and transferred to a backcross breeding generation of tomato. A procedure for quantifying the degree of resistance in young plants was developed. DNA markers were then found and used to recognise areas of genetic interest in tomato which appear to be linked to genes controlling resistance to the pest. By targeting these genes it is expected that the efficiency and outcomes of further cycles of breeding for resistance will be enhanced.

True-breeding lines with improved levels of sweetness and flavour were developed from a pink Japanese cultivar. The lines showed good agronomic performance, disease resistance and were adapted to ground cropping. An evaluation panel determined that several lines were sweeter and had more acceptable overall quality than a commercial check variety. The solids content of the fruit was associated with both these attributes. Hybrids with pink and red skin are being developed for field and panel evaluation.

TECHNICAL SUMMARY

A range of improved true-breeding lines with superior agronomic performance for early, concentrated maturity, resistance to three races of Fusarium wilt and excellent fruit appearance was developed using multiple sources from America. Several new experimental hybrids were developed from these lines and one was selected for immediate release. Statistical analysis of field trials indicated that while marketable yields for the best of the new hybrids was similar to the best current commercial hybrid, the former produced a significant 3% improvement in the proportion of marketable fruit.

Genetic resistance to Potato Tuber Moth was identified in PI accession LA1777 of *Lycopersicon hirsutum* and transferred to a backcross generation of cultivated tomato. A bioassay for quantifying the resistance of individual plants was developed and used to determine resistance scores for parent, F1 and backcross genotypes derived from an *L. esculentum x L. hirsutum* hybrid population. Bulk segregant analysis applied to these two backcross groups identified DNA marker differences which were linked to resistance genes in the population. The analysis provided the foundation for a conventional segregation analysis which will identify those markers useful for selection.

Three true-breeding lines with significantly improved flavour and eating quality were developed. Soluble solids content of the lines was approximately 5.1% Brix compared with 4.5% Brix for a commercial standard. The higher Brix content of the lines was associated with increased sweetness and improved eating quality when measured by a panel. Pink and red fruited hybrids were made for field testing and panel evaluation.

AGRONOMIC IMPROVEMENT OF COMMERCIAL TOMATO
D.J. McGrath and I.O. Walker

Introduction

A program of tomato cultivar improvement was established to diversify the range of varieties available for cropping in Bowen, primarily because the requirement for Fusarium 3 resistance restricted the number of varieties available commercially. The program has undergone step-wise modifications since its inception, but its broad objective has always included the development of early-maturing, uniform cultivars for ground cropping in the Dry Tropics of Queensland. A particular objective which received early attention was the improvement in fruit quality characteristics such as uniformity of shape and blossom-end defects which continue to reduce the yield of marketable fruit in several commercial varieties.

Three American hybrids were inbred across different stages of this program to provide a series of breeding lines for population development. The cycles of crossing reflect decisions about maximising gain from selection but always considered the goals of early and uniform maturity, fruit quality and marketable yield. A relatively unadapted disease resistant line, Tristar, was hybridised with American sources of early, uniform maturity and improved fruit shape; subsequent hybridisation of derived inbred lines to other American lines with excellent blossom and stem-end features, deep globe shape and uniform green fruit shoulders produced a further series of elite inbred lines. These inbreds were early and more uniform in maturity, and produced fruit with excellent appearance. The American parent lines from which these were obtained were themselves generated by inbreeding from an outstanding hybrid identified in field trials.

A further set of inbred lines was developed from another hybrid with marked early maturity and Fusarium resistance. A series of experimental hybrids was produced between lines of

these two groups. Three years of experimental field trials have identified a number of hybrids with commercial potential and one has been selected in 1997 for release.

The field performance of selected experimental hybrids for 1996 and 1997 is presented below.

Materials & Methods; Results

A series of replicated trials at Bowen Horticultural Research Station in 1996 and 1997 evaluated experimental hybrids from the program and commercial check varieties. In one case (Trial 2) unreplicated data are included as an additional comparison; in this case strict statistical inferences are not possible, but the differences identified are large and contrast with relatively small differences observed with other replicated trial data sets.

Trial 1   Border C12 Bowen HRS June 1996

The trial was designed as a randomised block experiment with 6 F1 varieties and 4 replications. The designation of the parent lines of the hybrids in this and subsequent trials was as follows:

1 - F5 761-3-1-1; 2 - F5 761-3-3-1; 8 - F5 761-1-1-1; 9 - F5 (N91 x 4215141) -1-1-1;

11 - F5 (N91 x 4215141) -1-4-1; 14 - F5 (N91 x 4215141) -4-1-1; 15 - F5 (N91 x 4215141) - 4-3-1.

The commercial variety Tornado was the check. Plots were 10m long in rows 1.5m apart, with plants spaced at 75cm. Plants were transplanted to the field on 28-3-96 and 3 harvests took place on 19-6-96, 27-6-96 and 4-7-96.

Data was obtained for coloured and mature green fruit from 5 plants per plot. Unmarketable fruit were separated on the basis of blossom-end defects, irregular shape, cracks, scarring and

excessive green shoulder pigment and marketable fruit were then graded into 4 categories by size.

Table 1 compares hybrids and the commercial check Tornado for a range of agronomic performance attributes. Data for marketable and total yield is presented as sums over two and three harvests.

Variety	Marketable Fruit No. 3 Harvests	Marketable Yield kg 3 Harvests	Marketable Yield kg 2 Harvests	Total Yield kg 3 Harvests	Total Yield kg 2 Harvests	Average Marketable Fruit Size g
8 x 1	179	33	22	37	26	181
9 x 1	160	30	20	35	23	184
9 x 2	194	37	31	43	36	191
14 x 1	100	16	11	18	12	162
15 x 1	144	25	17	28	20	171
15 x 2	150	27	20	31	23	180
Tornado	129	25	13	31	17	190
LSD p<.05	38	7	5	7	6	12

Table 1 Yield and yield components for experimental hybrids Bowen HRS June 1996

Hybrid 9 x 2 produced a substantially larger number of marketable fruit than Tornado over three harvests. This was associated with a corresponding increase of 48% in marketable yield. The large difference was due to the late maturity of Tornado at this time of the season; the effect was even more pronounced for the yields calculated over two harvests. Although the conditions of this trial produced an abnormally large yield difference, other observations indicated hybrid 9 x 2 generally matured earlier than Tornado and therefore yielded more over three harvests.

The proportion of unmarketable fruit was lower for hybrid 9 x 2 (15%) than for Tornado (24%). This reflected the better shape, size and appearance of its fruit which was due to smaller blossom-end scar, deeper, more uniform globe shape and a smoother shoulder with no green pigment . The better quality of hybrid 9 x 2 fruit relative to Tornado was especially pronounced. Average fruit size was similar for both varieties. Hybrids 8 x 1 and 9 x 1 also performed better than Tornado, although both were inferior to 9 x 2. Under the conditions of this trial the performance of 9 x 2 was outstanding.

Trial 2   Border C14 Bowen HRS June/July 1996

The trial was a comparison of the same hybrids and Tornado as in Trial 1, except that the plots were used for demonstration purposes and therefore unreplicated. Seed was sown 29-3-1996, the trial was transplanted 28-3-1996 and 3 harvests were made in late June and early July. Plots were 10m in length with plants spaced within the row at 75 cm. Data was obtained for a section of 5 plants within the plot. Unmarketable fruit were separated as indicated previously.

Table 2 below compares six hybrids and Tornado for marketable yield and its components.

Variety	Marketable Fruit Number 3 Harvests	Marketable Yield kg 3 Harvests	Average Fruit Size g 3 Harvests
9 x 1	196	37	191
9 x 2	202	37	185
11 x 1	182	38	207
11 x 2	201	35	175
14 x 1	166	28	168
15 x 1	203	36	176
Tornado	143	26	182

Table 2 Marketable yield and components for experimental hybrids Bowen HRS June/July 1996

Table 2 indicates yield differences similar to the replicated data of Trial 1. Although statistical comparisons of genotype means were not possible, similar yield differences in marketable yield were observed between hybrids 9 x 1, 9 x 2 and Tornado. As in Trial 1, the higher yields for 9 x 1 and 9 x 2 relative to Tornado were due to larger numbers of better quality fruit. Hybrids 11 x 1 and 11 x 2 were also higher yielding for the same reason. Average marketable fruit size was similar for most varieties.

Trial 3   Border D7 Bowen HRS August/September 1996

Two hybrids and the check variety Tornado were compared in 4 replications of a randomised block design. Seed was sown 18-4-96, field planting occurred on 23-5-96 and 3 harvests were made on 23-8-96, 29-8-96 and 9-9-96. Plants were spaced at 75 cm. Marketable and unmarketable fruit were separated as indicated previously.

The results of this trial are presented in **Table 3** below.

Variety	Marketable Fruit No. 3 Harvests	Marketable Yield kg 3 Harvests	Marketable Yield kg 2 Harvests	Average Fruit Size g. 3 Harvests
9 x 1	200	37	19	186
15 x 1	229	40	16	175
Tornado	189	35	13	189
LSD(p<.05)	50	9	8	15

Table 3 Yield and components for two experimental hybrids and Tornado, Bowen HRS August/September 1996.

In this later trial, both 9 x 1 and Tornado produced similar numbers of marketable fruit and marketable yield when evaluated over three harvests; however hybrid 9 x 1 produced substantially more yield than Tornado when measured over the first two harvests, reflecting the earlier maturity of hybrid 9 x 1. It was also apparent that most fruit of Tornado were free of major defects at this time, possibly because of favourable conditions at the time of fruit set. The net result was similar yields of marketable fruit for both varieties over three harvests.

Trial 4   Border E7 Bowen HRS August 1997

The trial compared four experimental hybrids with the commercial standards Eagle and Tempest in six replications of a randomised block design. Seed was sown 2-4-97, field planting occurred on 1-5-97 and three harvests were done on 31-7-97, 2-8-97 and 14-8-97. Plots were 10m ,with plant spacings of 75 cm. Data were obtained for five plants from the plot. Results are presented in Table 4.

Variety	Marketable Fruit No. 3 Harvests	Market Yield kg 3 Harvests	% Flat/ Scarred Fruit	%Reject Fruit	Average Fruit Size g
9 x 1	254	41	2.4	6.4	161
9 x 2	245	42	5.3	9.1	171
11 x 1	245	38	4.7	9.2	157
11 x 2	244	42	6.6	12.7	172
Eagle	234	40	5.2	11.2	171
Tempest	256	44	6.2	11.7	173
LSD (p<.05)	39	6	3.2	4.1	8

Table 4 Marketable yield, yield components and percentage reject fruit for experimental hybrids and commercial checks, Bowen HRS August 1997

The data demonstrate no differences between varieties for fruit numbers and marketable yields obtained from this trial harvested in August. The commercial check hybrids Eagle and Tempest are more recent introductions than Tornado and performed better relative to the experimental hybrids. The percentage of reject fruit however was lower for 9 x 1 (6.4%) and 9 x 2 (9.1%) than for Tempest (11.7%); this difference was small in absolute terms but statistically significant at a level slightly above p<.05. Fruit size of most experimental hybrids was similar to that for the check with the exception of 9 x 1 and 11 x 1 which were slightly smaller.

Post Harvest Evaluation Of Hybrid 9 X 2

Several varieties were evaluated by a panel of 15 tasters who tasted fruit on five separate occasions over two days. The testing was carried out using four replicate sensory tests comparing the standard Tornado with other hybrids including hybrid 9 x 2. Tasters identified and rated appearance, odour, flavour and texture characteristics in a standard rating test (AS

2542.2.3 1988). Data was subjected to an analysis of variance and results are expressed as means over the four replicates and 15 tasters.

Table 5 presents mean scores for flavour profile and overall acceptability for hybrid 9 x 2 and Tornado.

	Flavour of Tomato				
	Tomato Flavour	**Acid**	**Sweet**	**Other**	**Acceptability**
Hybrid 9x2	56.7	25.2	33.0	4.3	59.8
Tornado	56.9	28.4	31.2	5.8	59.4

Scale 0 = none to 100 = high level of attribute

Table 5 Mean scores for tomato flavour attributes of hybrid 9 x 2 and Tornado

No significant differences were identified by tasters for the flavour characteristics measured. The data indicated that hybrid 9 x 2 was of similar flavour to Tornado which is to be expected, given that no sources of superior flavour were introduced into the breeding populations which generated the parents of the hybrid. The panel data provided evidence that the new hybrid is not inferior to standard commercial varieties and should therefore be as acceptable as Tornado to the consumer.

Description of Hybrid 9 x 2

Hybrid 9 x 2 is a determinate, small bush variety with concentrated maturity suitable for ground cropping. It is resistant to Fusarium wilt races 1, 2, and 3.

Fruit are an even, deep globe shape with very small blossom-end scar, smooth, uniform green shoulders and moderate stem-end scar. Compared with several commercial determinate varieties, Hybrid 9 x 2 may produce a higher proportion of globe-shaped fruit, thereby

increasing the percentage of marketable yield. In certain circumstances related to cool-setting conditions, it may produce up to 10% more marketable fruit. More typically, up to 5% more marketable fruit are produced relative to other commercial varieties. The pedicel is jointless. Average fruit size ranges from approximately 170 to 190 g. For Bowen field plantings in early May, time to first harvest is about 13 weeks.

Discussion

Experimental hybrid performance

The experimental hybrids developed so far were clearly superior to older established cultivars such as Tornado in terms of marketable yield and fruit appearance. Although the trial data indicated very large yield increases for several hybrids relative to Tornado, most observations in the last few years have suggested more moderate increases. The advantage of these hybrids was their ability to set more fruit than Tornado under most conditions and the lower incidence of fruit quality defects such as cracking, scarring and blossom-end blemishes; they also produced light green instead of heavily pigmented shoulders which are favoured by domestic markets.

The marketable yields of hybrids 9 x 1 and 9 x 2 were similar to the current commercial checks Eagle and Tempest. Their particular advantage, in addition to their improved appearance, was the lower incidence of unmarketable fruit. Only small improvements were obtained in the trial data of Table 4, although large advantages have been noted at other times. Hybrid 9 x 2 was judged the best genotype in terms of production attributes and stability of performance across seasonal planting times in several years and a decision has been taken to release this hybrid to industry.

Extension/Adoption by Industry

Assessments of many breeding lines were made during their development by a group of producers who regularly inspected breeding plots and provided advice for selection. From a small number of parent lines developed in this way, a range of elite hybrids was generated for evaluation. The hybrids were also assessed by the panel of producers and by a larger group at several field days during 1996 and 1997. The consensus which emerged from this process identified two hybrids as candidates for release. During 1997, seed companies were offered small quantities of seed for testing on growers' properties and as a result it was decided to submit one hybrid, 9 x 2, for release by DPI.

Directions for future research and funding by HRDC

The improved parent lines developed in this component of the project should serve as the foundation for further cycles of improvement in the pest resistance and flavour improvement work which is addressed in other areas of the project. It is anticipated that these lines will be recurrent parents for additional backcrosses so that newly generated material will be both well-adapted and improved for the specific characters under development.

Commercial benefits of adoption of research findings

It is expected that the new hybrid will be released under an exclusive licence determined by tender. Royalties will be paid based on seed sales and distributed to the stake-holders, QDPI, HRDC and QFVG according to a royalty-sharing agreement. Although the new variety is intended for Dry Tropics ground cropping it could be used elsewhere with a wider potential market. Until recently the market for Fusarium 3 resistant hybrids was confined to Bowen but since 1996 there has been a rapid increase in affected crops in the United States. This could lead to a much larger demand for suitable hybrids.

GENETIC RESISTANCE TO POTATO TUBER MOTH
D.J. McGrath, M. Kelly and J. Bezant

Introduction

Although Potato Tuber Moth (PTM), *Pthorimaea operculella*, is predominantly a pest of potato, it is responsible for losses in other solanaceous crops such as eggplant, tobacco and tomato (Trived and Rajagopal, 1992). In recent years there has been extensive damage to Queensland tomato crops in the major production areas, usually as a result of unsound production practices. Kay(1994) demonstrated that in severe field infestations no commercial or experimental insecticides provided adequate control. Integrated pest management practices have moderated the severe levels of crop damage sustained some years ago, although periodic infestations are still common.

Genetic resistance to Lepidopteran pests of tomato has been identified in many different accessions of Lycopersicon hirsutum. For example, Eigenbrode and Trumble (1994) identified five compounds in L. hirsutum associated with resistance to Spodoptera exigua (beet army worm). Accession LA1777 of L.hirsutum was reported to exhibit high levels of genetic resistance to PTM in Israel (Juvik et al., 1992), and was the foundation for this breeding project to incorporate genetic resistance into tomato breeding populations.

The initial objectives were to confirm resistance of LA1777 to PTM in planthouse bioassays and to study gene action in hybrid and backcross populations. A further objective was to identify genetic differences between LA1777 and a susceptible line using DNA markers, and to determine markers which could ultimately assist in selection for resistant genotypes in backcross breeding populations. Marker-assisted selection is a desirable means of improving selection efficiency since it can provide an opportunity to avoid difficult or unreliable

bioassays. Where resistance is conferred by multiple genes, as is likely for PTM, markers may also identify several genes, all of which are necessary for full expression of resistance.

The work reported here is the development of a suitable planthouse bioassay, the confirmation of genetic resistance in an accession of L. hirsutum and the identification of DNA markers for resistance.

Materials and Methods

Genetic Material for Bioassay

Seedlings of accession LA1777 of L. hirsutum were grown in the planthouse and three plants designated LA1777-1, LA1777-2 and LA1777-3 provided open -pollinated progeny for experimental work. Each of the three parent LA1777 genotypes was hybridised as a male parent with a susceptible inbred line of L. esculentum, N91, to provide six hybrid individuals, two from each of the three crosses. The hybrids were then grown in order to produce selfed and backcross(BC) progeny for evaluation of genetic resistance. None of the hybrids produced selfed progeny because of sterility although BC progeny were readily obtained when the hybrids served as pollen parents. Only two BC populations, N91 x [N91 x LA1777-1] and N91 x [N91 x LA1777-2], were tested because of resource limitations and these were designated as N91 x Hybrid 2 and N91 x Hybrid 4 respectively.

Bioassay Procedure

Bioassays were performed without temperature control in the plant house with daytime ambient temperatures up to 27C. Plants of N91 and susceptible cultivar Floradade were four-week old seedlings when the bioasssay commenced, whereas LA1777-1, LA1777-2, LA1777-3, N91 x Hybrid 2 and N91 x Hybrid 4 were all obtained as four to six week-old

rooted cuttings from original plants. Plants were grown in a peat/sand medium with applied fertiliser.

Resistances of N91, LA1777-1, LA1777-2, LA1777-3, Hybrid 2, Hybrid 4 and genotypes from two BC populations were determined by placing two neonate larvae of PTM on young fully expanded leaves and scoring for mine damage seven days later. The procedure was repeated six times on different leaves of the same plant. Scores were determined by the extent of leaf area mined as follows: 1 - no damage, 2 - minute point of damage, 3 - < 5% damage, 4 - 5 to 10% damage, 5 - 10 to 20% damage, 6 - 20 to 50% damage, 7 - > 50% damage. Because backcross and L.hirsutum parent genotypes were available as rooted cutttings rather than seedlings, replication of data was possible only in time and conventional randomisation of plants was not possible. Means of damage scores over time were calculated for each genotype.

DNA Markers

Marker Applications and Genetic Material

Randomly Amplified Polymorphic DNA(RAPD) markers were used to first characterise genetic differences between N91, LA1777 selections and hybrids of the two lines. Variation among backcross lines was also determined. The results of the backcross screening were then applied to form resistant and susceptible groups of lines from each of the two backcross populations. For N91 x Hybrid 2, five susceptible and three resistant lines were selected and for N91 x Hybrid 4, six susceptible and eight resistant lines were selected. DNA from each member of a group was pooled for bulked segregant analysis(BSA) (Michelmore et al., 1991). The polymorphisms identified between the resistant and susceptible groups provided evidence of RAPD markers linked to one or more resistance genes.

RAPD Procedures

DNA extraction was undertaken using a modified form of Edwards (Kang Fu Yu et al., 1993). Briefly, the procedure used SDS extraction buffer of 200mM Tris-HCl at pH 7.5, 250mM NaCl, 25mM EDTA, 0.5% sodium dodecyl sulphate, into which young tissue was homogenised, centrifuged and re-extracted; iso-propyl alcohol was added to precipitate DNA which was then air-dried and re-dissolved in TE/Rnase buffer. The DNA was analysed with a spectrophotometer for concentration and purity checks.

The Polymerase Chain Reaction (PCR) was performed to amplify DNA sequences, using random decamer primers from kits supplied by Operon Technologies. The PCR reaction occurred in 20ul volumes using 200mM PCR buffer, 50mM MgCL, 2.5mM dNTPs, 10mM primer, 10ng DNA and 0.8U Taq polymerase enzyme. Some reactions were also performed with the Stoffel enzyme as a minor variation. The cycling profile adopted was : 1 cycle of 5 min/94 C; 35 cycles of 30 sec/94 C, 1 min/57 C, 1 min/56 C, 1 min/55 C, 1 min/54 C, 1 min/53 C; 1 cycle of 5 min/72 C; 1 cycle of 16 hrs/25 C.

Amplified DNA fragments were visualised on both agarose gels stained with ethidium bromide and polyacrylamide gels stained with silver.

Results

Bioassay

The range of PTM resistance scores for the N91 x Hybrid 2 population and mean scores for each backcross line in the resistant and susceptible groups selected for further analysis are presented in Table 1. Equivalent data for the N91 x Hybrid 4 population are presented in

Table 2. The scores in both tables range from 0 (no damage) to 7 (>50% damage) and indicate the degree of resistance expressed in each genotype.

Line	Group	PTM Resistance Score
N91 x Hybrid 2	Backcross Population	1.0 - 6.8 Range
88	Bulk 3 susceptible	3.6 ± 0.7
90	Bulk 3 susceptible	2.8 ± 1.0
159	Bulk 3 susceptible	4.6 ± 1.2
167	Bulk 3 susceptible	6.8 ± 0.2
72	Bulk 4 resistant	1.1 ± 0.4
107	Bulk 4 resistant	1.0 ± 0.2
171	Bulk 4 resistant	1.2 ± 0.3
N91	Susceptible parent line	5.7 ± 0.6
LA1777-1	Resistant parent line	1.6 ± 0.3
N91 x LA1777-1	Hybrid	1.8 ± 0.4

Table 1. PTM resistance scores for selected lines in N91 x Hybrid 2 Backcross population.

Line	Group	PTM Resistance Score
N91 x Hybrid 4	Backcross population	0.6 - 4.8 Range
112	Bulk 5 susceptible	4.2 ± 0.5
113	Bulk 5 susceptible	3.4 ± 1.0
135	Bulk 5 susceptible	2.8 ± 0.9
145	Bulk 5 susceptible	3.3 ± 0.7

193	Bulk 5 susceptible	3.5 ± 0.8
195	Bulk 5 susceptible	4.8 ± 0.1
48	Bulk 6 resistant	1.0 ± 0.2
50	Bulk 6 resistant	1.2 ± 0.2
60	Bulk 6 resistant	1.2 ± 0.2
96	Bulk 6 resistant	1.0 ± 0
97	Bulk 6 resistant	0.6 ± 0.2
99	Bulk 6 resistant	1.0 ± 0.2
100	Bulk 6 resistant	1.0 ± 0
121	Bulk 6 resistant	0.9 ± 0.2
N91	Susceptible parent line	5.1 ± 0.6
LA1777-2	Resistant parent line	1.8 ± 0.2
N91 x LA1777-2	Hybrid	2.0 ± 0.6

Table 2. PTM resistant scores for selected lines in N91 x Hybrid 4 backcross population.

Both selections of LA1777 showed minor leaf damage from PTM larvae amounting to small points where feeding was attempted and then abandoned. No mines were established in leaves. The susceptible line N91 was extensively mined with more than 50% leaf area damaged in most instances. Larvae were observed to be well established in many of the mines. There were significant differences between N91 and LA1777 for damage score. The hybrids N91 x LA1777-1 and N91 x LA1777-2 were also highly resistant to larvae; scores for the hybrids were similar to those for the LA1777 parent genotypes.

Each backcross population was selected for extreme susceptible and resistant phenotypes. Although there were large and significant differences between these classes, the most susceptible backcross genotypes were seldom as susceptible as N91. The most resistant lines in each population were as resistant as LA1777.

DNA Markers

A series of RAPD banding patterns for a range of primers was developed initially to characterise genotypic differences between N91, LA1777 and their hybrids. The following polymorphisms were visualised on agarose gels.

Figure 1 illustrates the profile obtained for LA1777-1, LA1777-2, LA1777-3 and N91 amplified with Operon primers A1 (lanes 1-4), A3 (lanes 5-8), A4 (lanes 9-12) and A5 (lanes 13-16). A ladder of known molecular weights was present in the un-numbered lane at the left of the gel. Significant differences in patterns were apparent for N91 relative to the LA1777 genotypes for primers A1 and A4. The LA1777 selections were more uniform, although a polymorphism could be seen between LA1777-1 and 2 (absent in lanes 1 and 2) and LA1777-3 (present in lane 3); a second polymorphism separated LA1777-1 (absent in lane 9) from the other two LA1777 genotypes (present in lanes 10 and 11).

Figure 2 presents LA1777-1, LA1777-2, LA1777-3 and N91 amplified by Operon primers B10 (lanes 1-4), B11 (lanes 5-8) and C6 (lanes 9-12). A molecular weight ladder was present in the left lane of the gel. N91 was clearly distinguished from the LA1777 genotypes in each case (lanes 4, 8 and 12), and sometimes by multiple polymorphisms (lanes 4 and 12). The LA1777 selections were mostly monomorphic, but a major difference was evident between LA1777-1 (lane 9) and LA1777-2 and LA1777-3 (lanes 10 and 11).

The profiles were useful in discriminating between parent and hybrid genotypes. In Figure 3

LA1777-1, LA1777-2 and LA1777-3 (lanes 1-3) were compared with a number of their

hybrids to N91 (lanes 4 to 7) for primer C2; the same sequence was repeated in lanes 11 -17

for primer B3. Both primers indicated extra bands present uniformly in the hybrid genotypes

and it was inferred that they were derived from the N91 parent. In this gel, the reactions failed

in lanes 4 and 14, producing blank lanes.

Differences between backcross lines are presented in Figures 4 and 5. The primer used in both

cases was B10. The lines were obtained randomly from both N91 x H2 and N91 x H4

backcross populations. Several bands were polymorphic among the lines and provided

evidence of genetic variation in the backcross population.

Backcross lines from each breeding population were assigned to resistant and susceptible

groups based on their extreme phenotype for PTM resistance score (Tables 1 and 2). For N91

x H2, susceptible lines 88, 90, 105, 159 and 167 were designated group 3 and resistant lines

72, 107 and 171 were placed in group 4. Similarly for N91 x H4, group 5 comprised

susceptible lines 112, 113, 135, 145, 193 and 195 and group 6 contained resistant lines 48,

50, 60, 96, 97, 99, 100 and 121. Comparisons of the two samples from each population

revealed polymorphisms which indicated the presence of markers linked to gene(s)

differentiating the bulked samples.

The following figures present polyacrylamide gels containing an extensive survey of

polymorphisms between bulked DNA samples from groups 3 and 4 and groups 5 and 6. A

molecular weight ladder is present in the right lane and the appropriate base pair size is

inserted as a reference. DNA sample number and Operon primers are indicated at the top of the gels and an arrow indicates the approximate position of the difference in the lane. Although the differences identified may lack clarity in the printed reproductions here and are subject to later revision, the discrimination between bands under magnification was compelling in most cases.

In Figure 6, differences were observed as follows: Primer AN3, groups 3(absent) / 4(present) at 350 base pairs (bp); Primer AN15, groups 3(present) / 4(absent) at 430bp; Primer AN16, groups 5(absent) / 6(present) at 676bp. The last polymorphism was strongly marked.

Figure 7 presents one difference for Primer AI1 between groups 5(present)/ 6(absent) at 350bp.

Figure 8 identifies three possible differences: Primer AL13, groups 5(absent) / 6(present) at 300bp; Primer AL13 , groups 5(absent) / 6(present) at 396bp; Primer AL13, groups 5(absent) / 6(present) at 620bp.

Figure 9 indicates a probable difference for Primer AH13, groups 5(present) / 6(absent) at 460bp.

In Figure 10, there was one distinct difference for Primer AK6, groups 3(absent) / 4(present) at 396bp.

Figure 11 indicates a likely difference for Primer AH20, groups 3(present) / 4(absent) at 396bp. The resolution here is poor, however, and subject to revision.

In Figure 12 a fine difference was observed for Primer AI18, groups 3(present) / 4(absent) at approximately 400bp. This is also subject to clarification.

Two polymorphisms were identified in Figure 13; Primer AJ7, groups 3(absent) / 4(present) at 676 bp; Primer AJ14, groups 5(present) / 6(absent) at 517 bp.

There were two strong differences evident in Figure 14; Primer AK4, groups 5(absent) / 6(present) at 1605 and 1198 bp. A magnification of the lanes for this primer is presented in Figure 20.
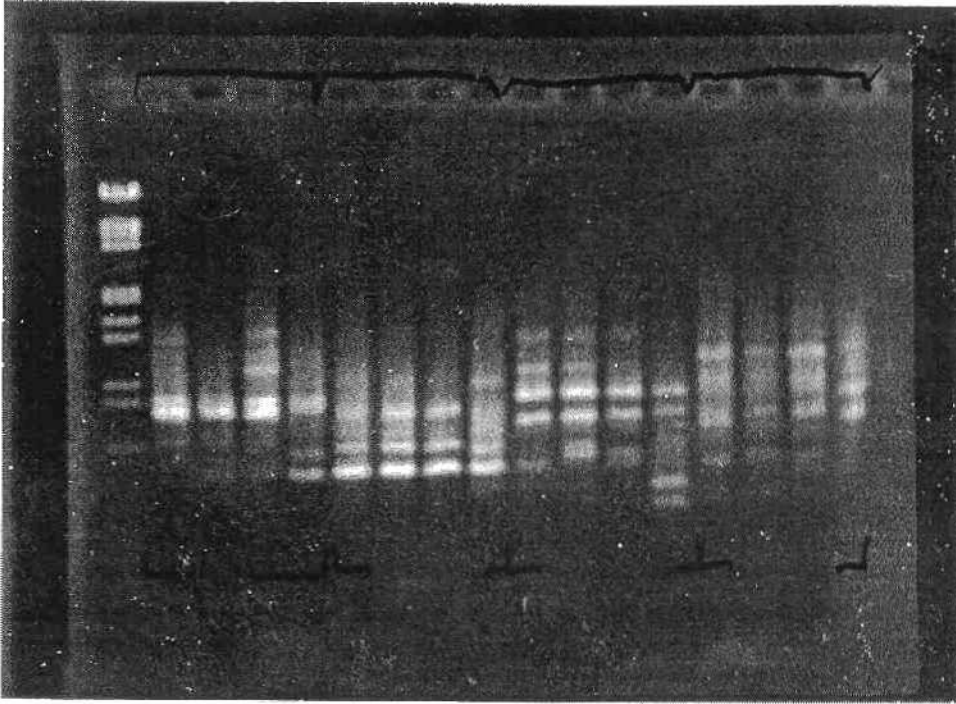
Figure 15 indicates two possible markers; Primer AH15, groups 3(present) / 4(absent) at 650 bp; Primer AL11, groups 5(absent) / 6(present) at 517 bp. Both were fine differences not readily visible without magnification.

There were three polymorphisms present in Figure 16; Primer AH7, groups 3(present) / 4(absent) at 517 and 676 bp; a third occurred in the same lanes for groups 3(absent) / 4(present) at approximately 1000 bp.

A strong difference was identified in Figure 17 for Primer AN4, groups 3(absent) / 4(present) at 676 bp.
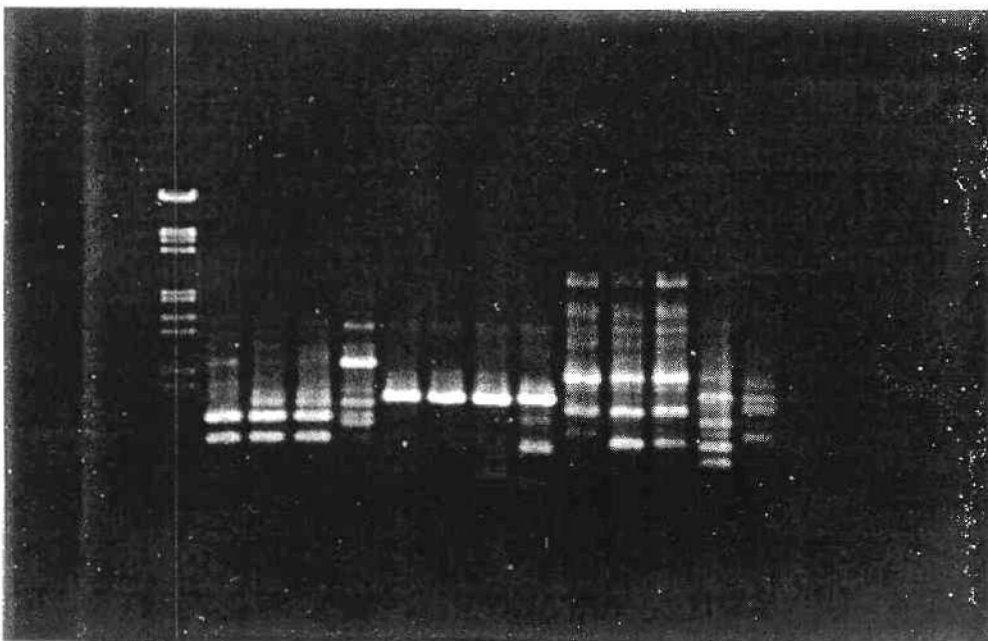
Figure 18 presents one difference for Primer Ak18, groups 3(present) / 4(absent) at 676 bp.

Figure 19 presents a magnification of lanes for Primer AD2, with a polymorphism at about 676 bp. The relevant band was absent in group 5 and present in group 6.
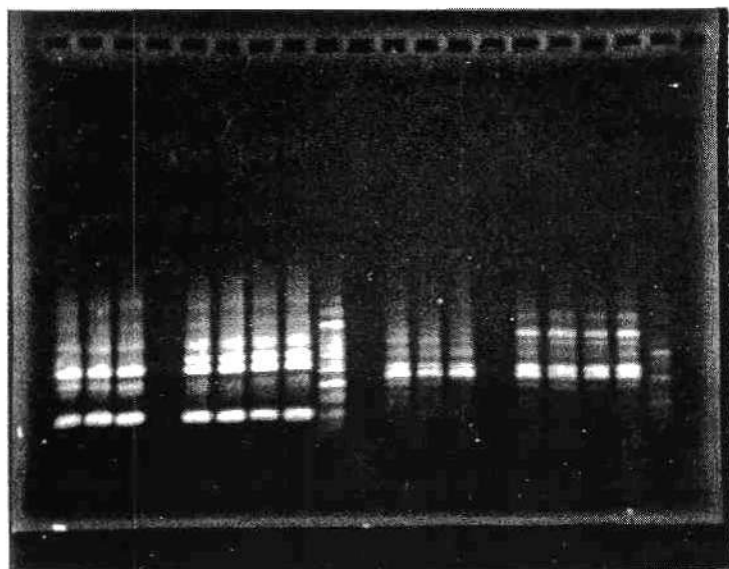
Figure 1: PCR profile for LA1777-1,2,3 and N91 amplified with primer A1
(lanes 1-4), A3 (lanes 5-8), A4 (lanes 9-12) and A5 (lanes 13-16).

Figure 2: LA1777-1, 2, 3 and N91 amplified with primer B10 (lanes 1-4), B11 (lanes 5-8) and
C6 (lanes 9-12).

1 ————————————————————————→ 19

Figure 3: LA1777-1, 2, 3 and N91 (lanes 1-3) and hybrids to N91 (lanes 4-7) amplified by primer C2; the same sequence was repeated for primer B3 in lanes 11-17.
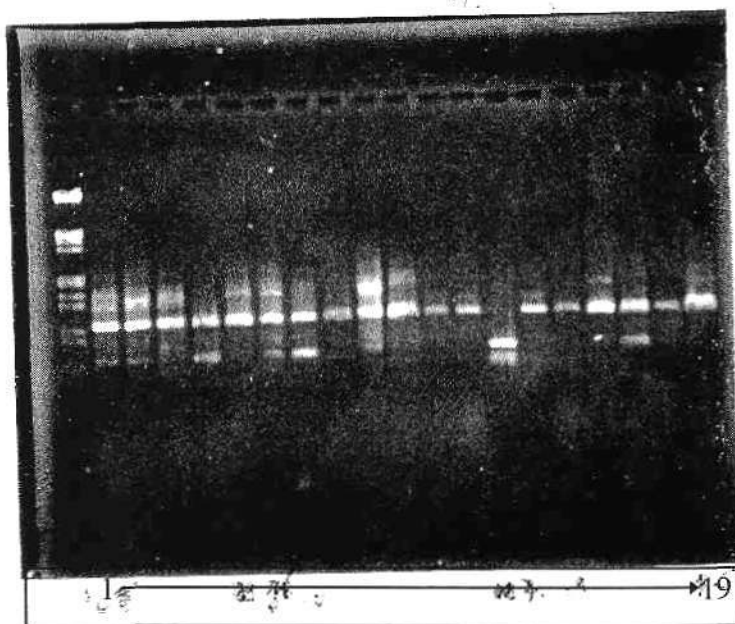

1 ————————————————————————→ 19

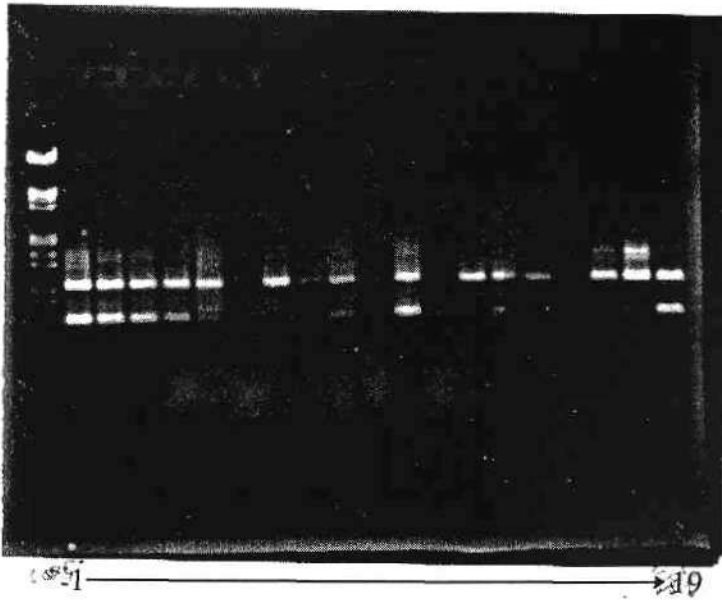Figure 4: Backcross lines 65-69,71-78 and 81-86 amplified by primer B10.

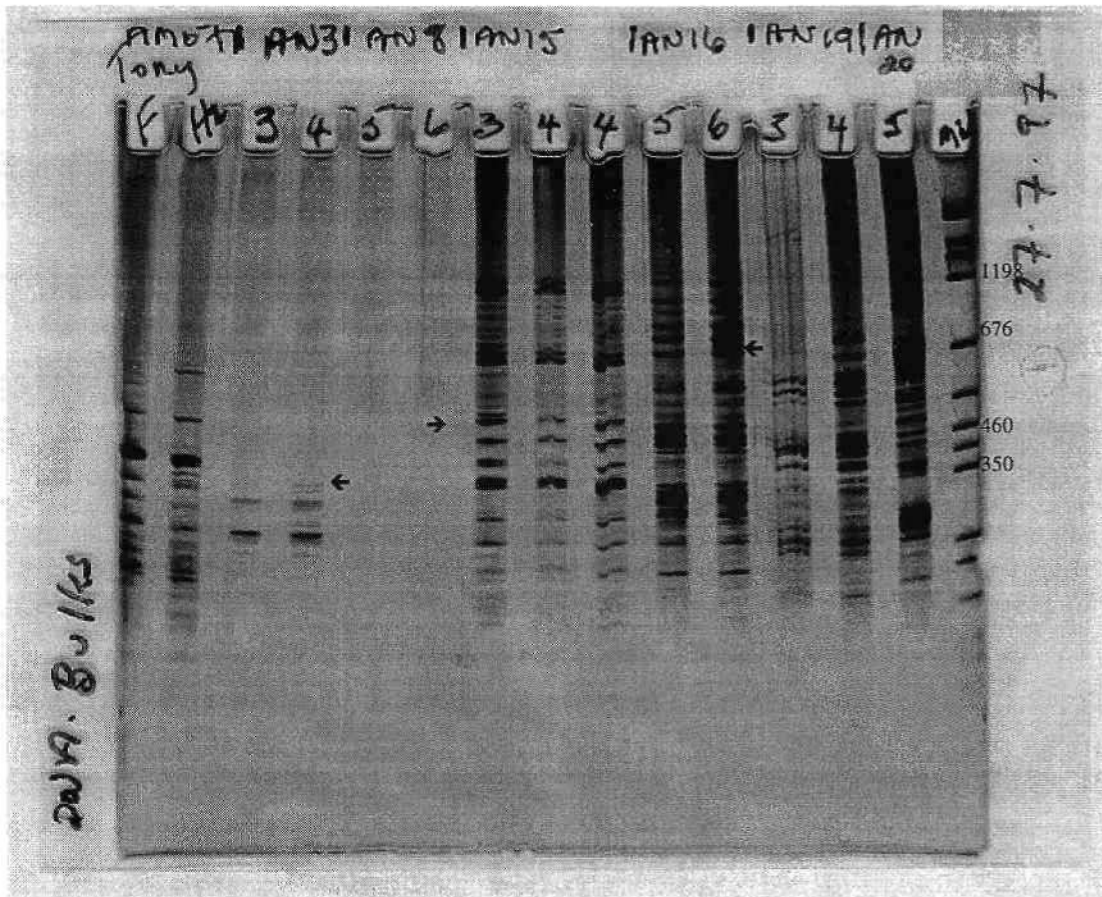Figure 5: Backcross lines 87-105 amplified with primer B10.

Figure 6: Bulk segregant analysis for backcross groups 3 and 4, 5 and 6.
Polymorphisms indicated for primers AN3, AN15 and AN16.

Figure 7: Bulk segregant analysis for backcross groups 5 and 6; polymorphism indicated for
primer AI1.

Figure 8: Bulk segregant analysis for backcross groups 5 and 6; three polymorphisms indicated for primer AL13.

Figure 9: Bulk segregant analysis for groups 5 and 6; polymorphism indicated for primer AH13.

Figure 10: Bulk segregant analysis for backcross groups 3 and 4; polymorphism indicated for primer AK6.

Figure 11: Bulk segregant analysis for backcross groups 3 and 4; polymorphism indicated for primer AH20.
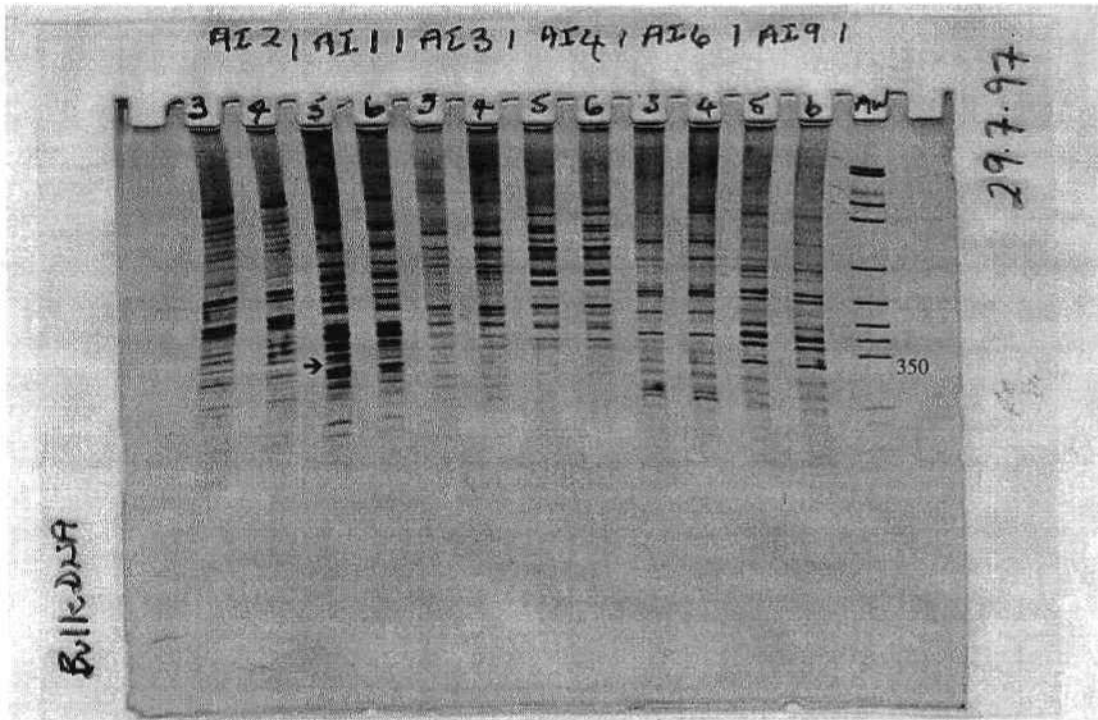
Figure 12: Bulk segregant analysis for backcross groups 3 and 4; polymorphism indicated for primer AI18.
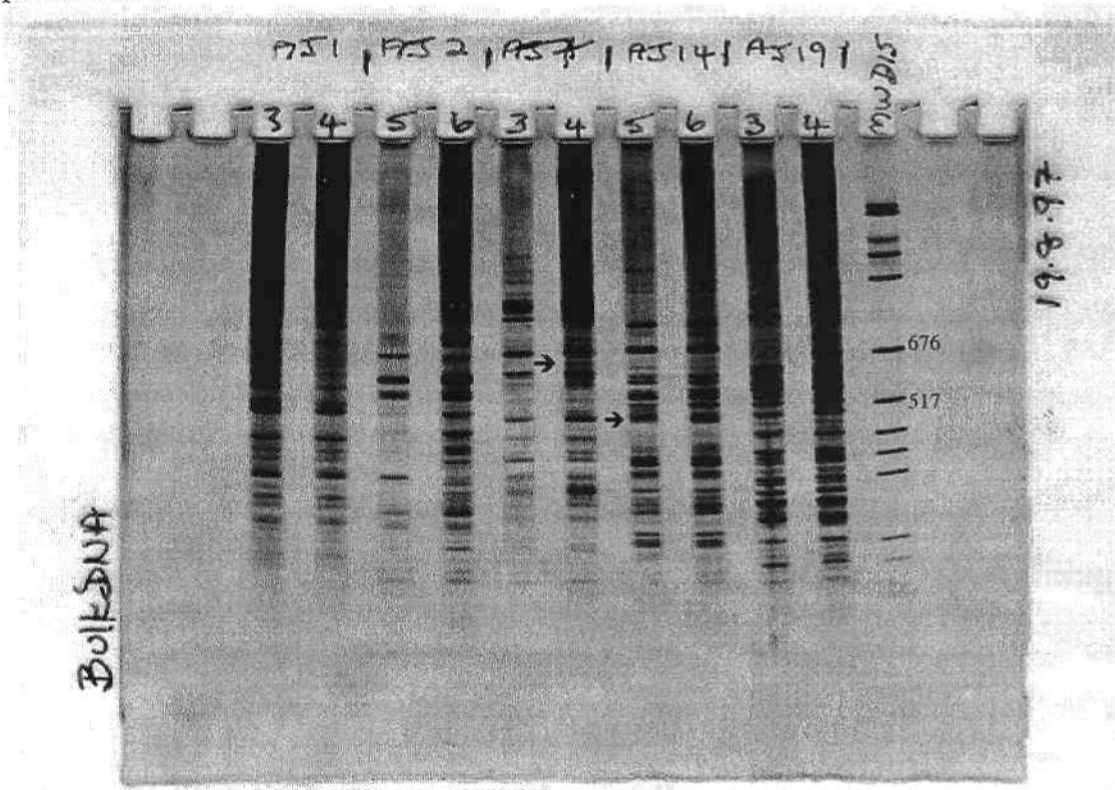
Figure 13: Bulk segregant analysis for backcross groups 3 and 4, 5 and 6; two polymorphisms indicated for primer AJ7 and AJ14.
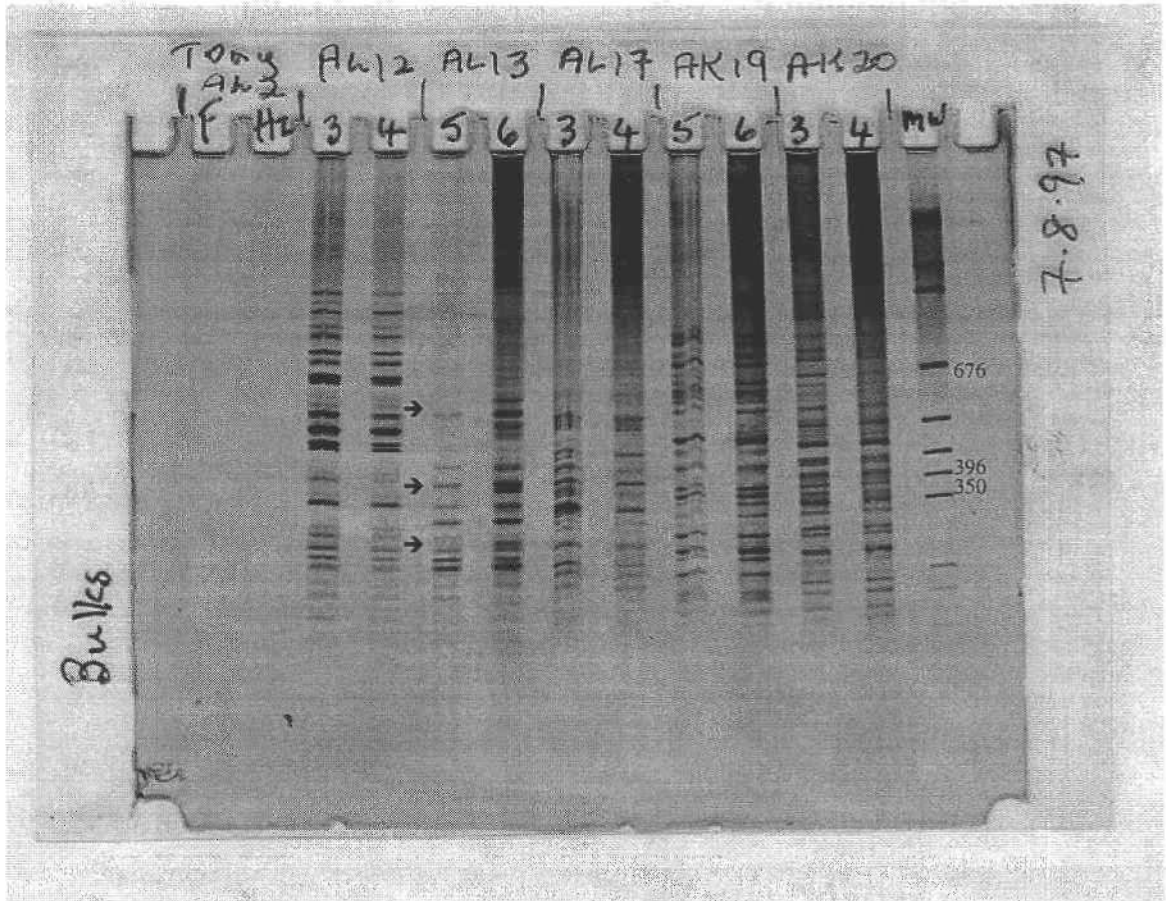
Figure 14: Bulk segregant analysis for backcross groups 5 and 6; two polymorphisms indicated for primer AK4.
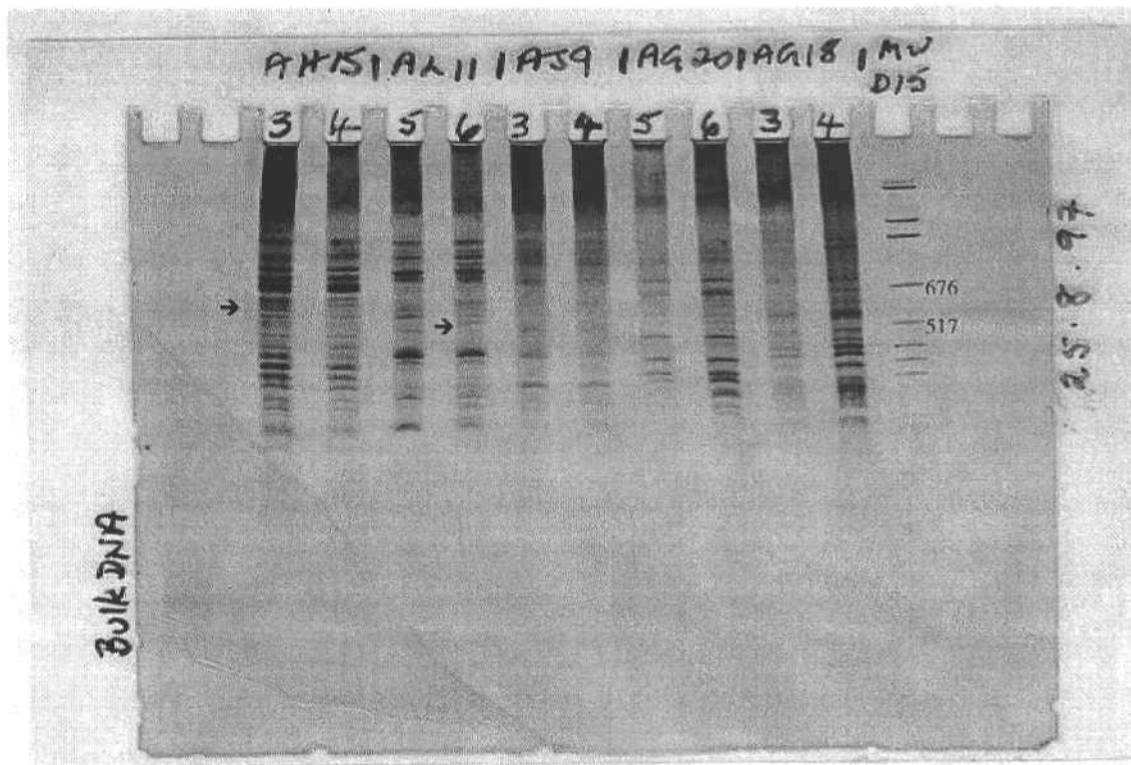
Figure 15: Bulk segregant analysis for backcross groups 3 and 4, 5 and 6; two polymorphisms present for primers AH15 and AL11.

Figure 16: Bulk segregant analysis for groups 3 and 4; three polymorphisms present for primer AH7.
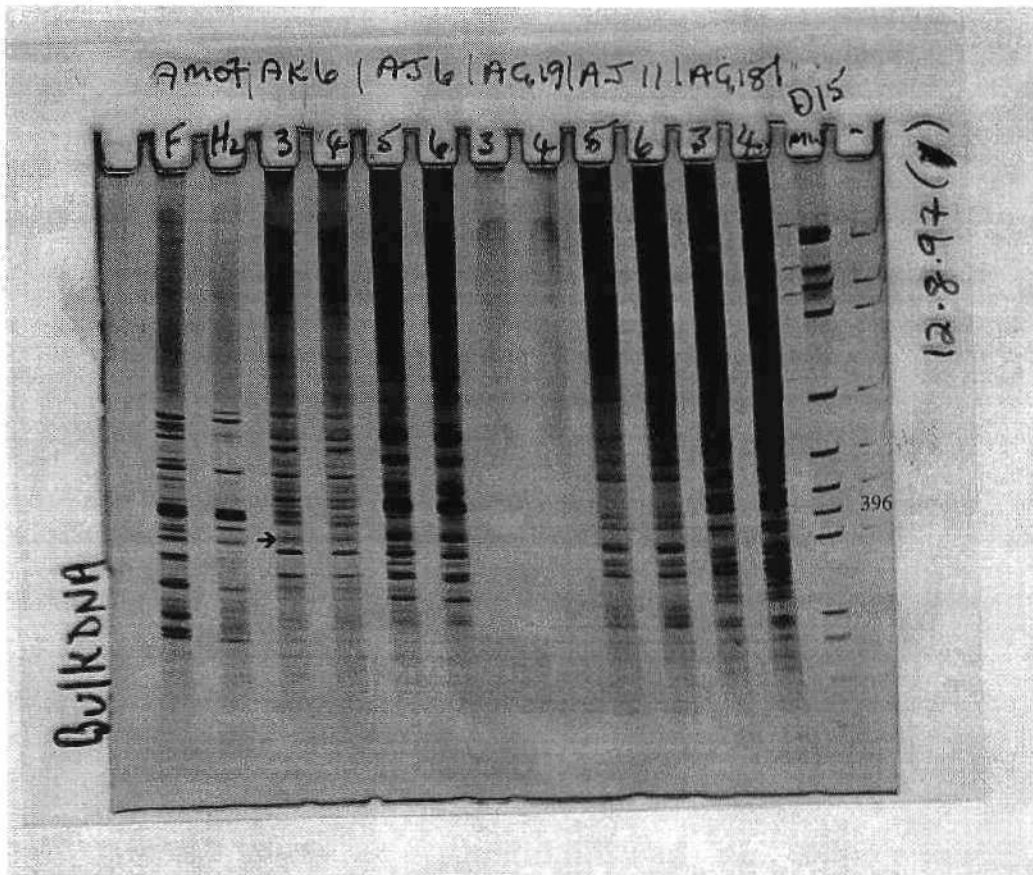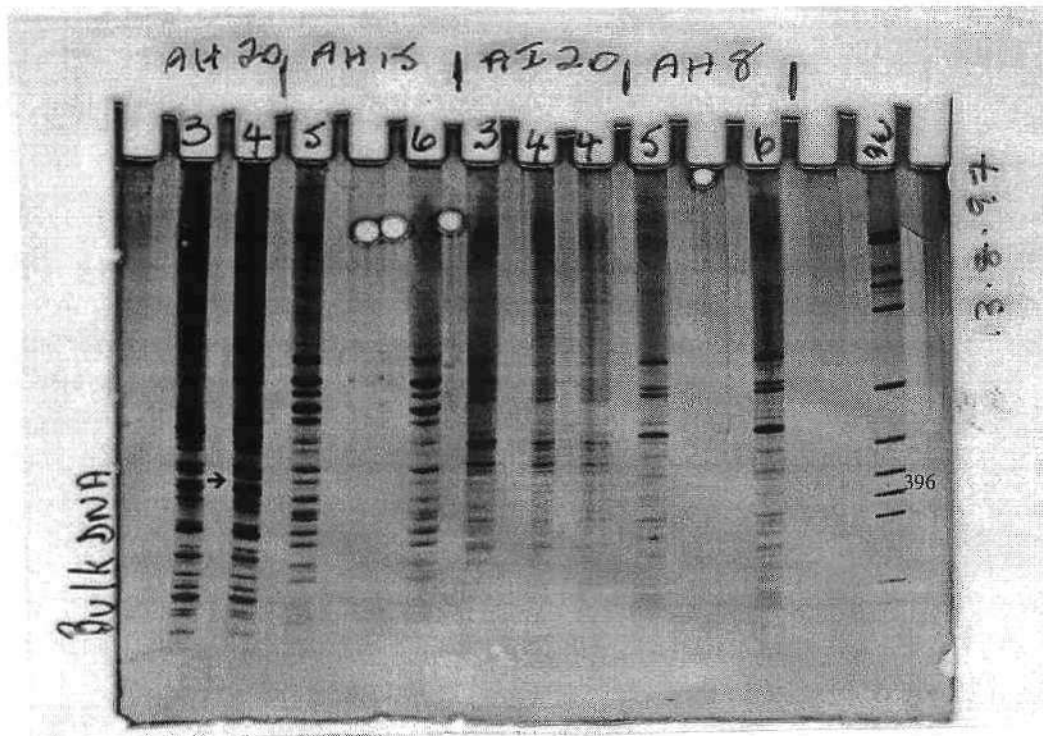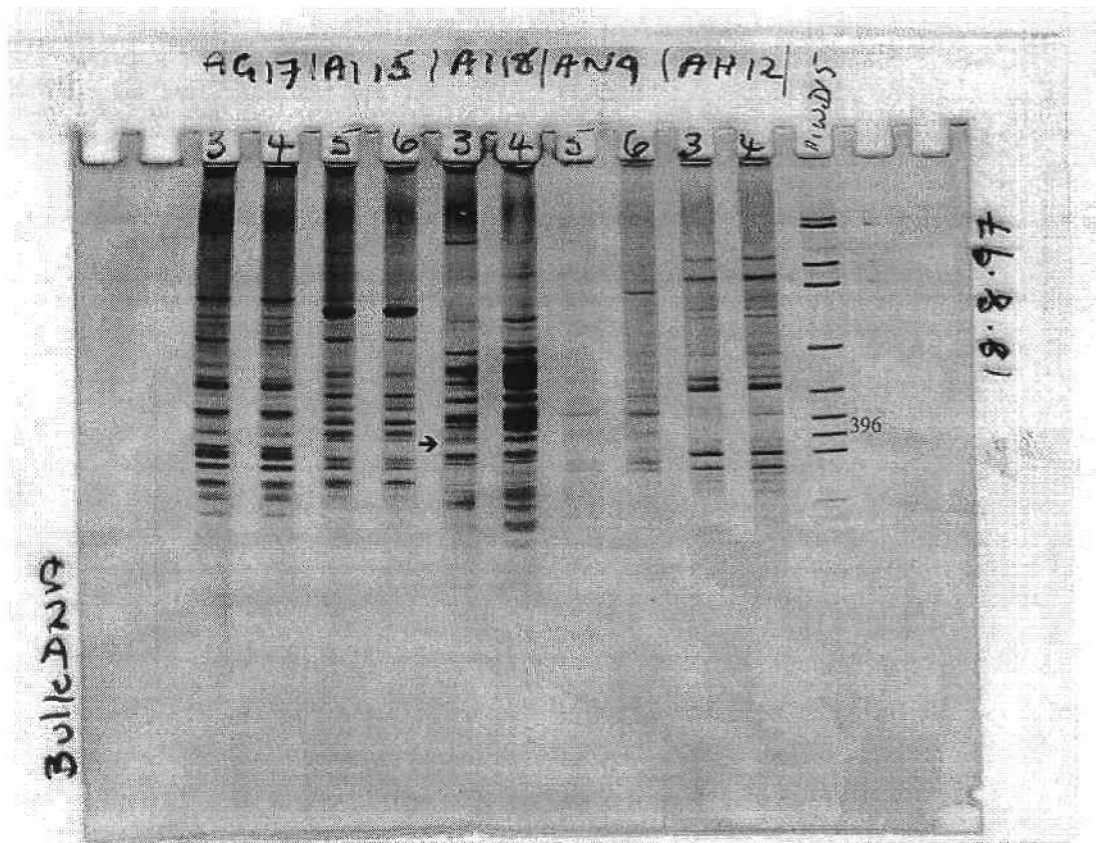

Figure 17: Bulk segregant analysis for groups 3 and 4; polymorphism present for primer AN4

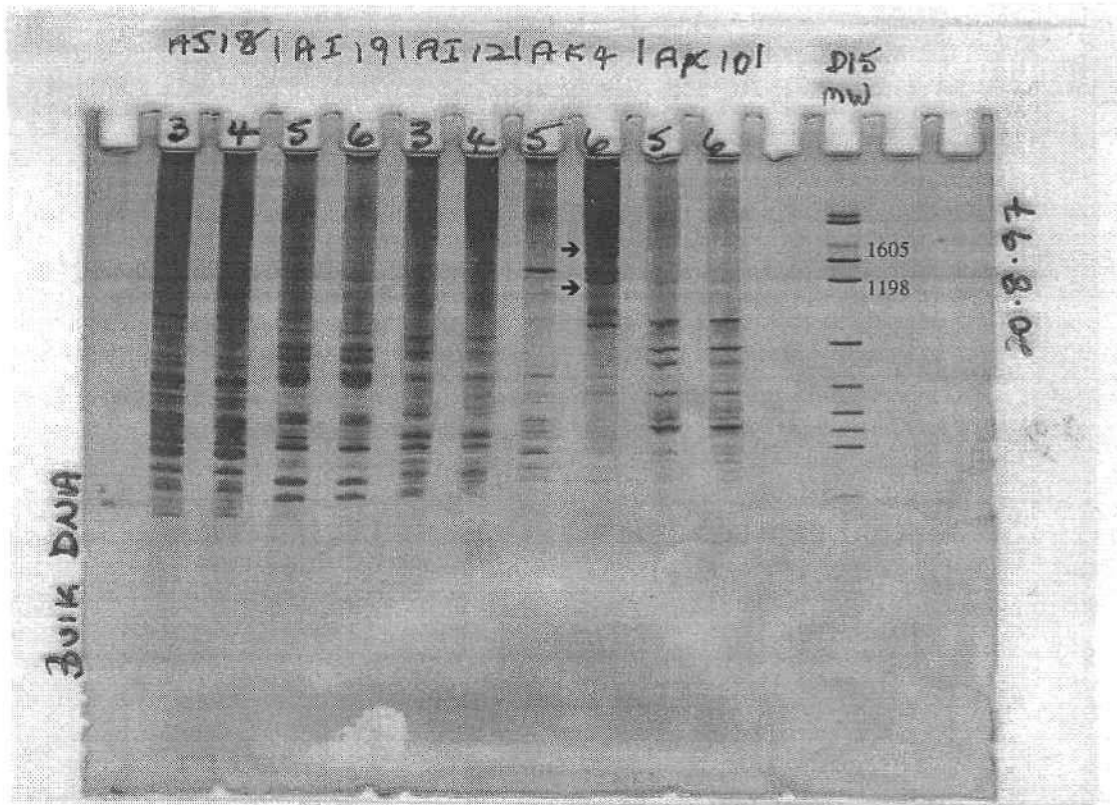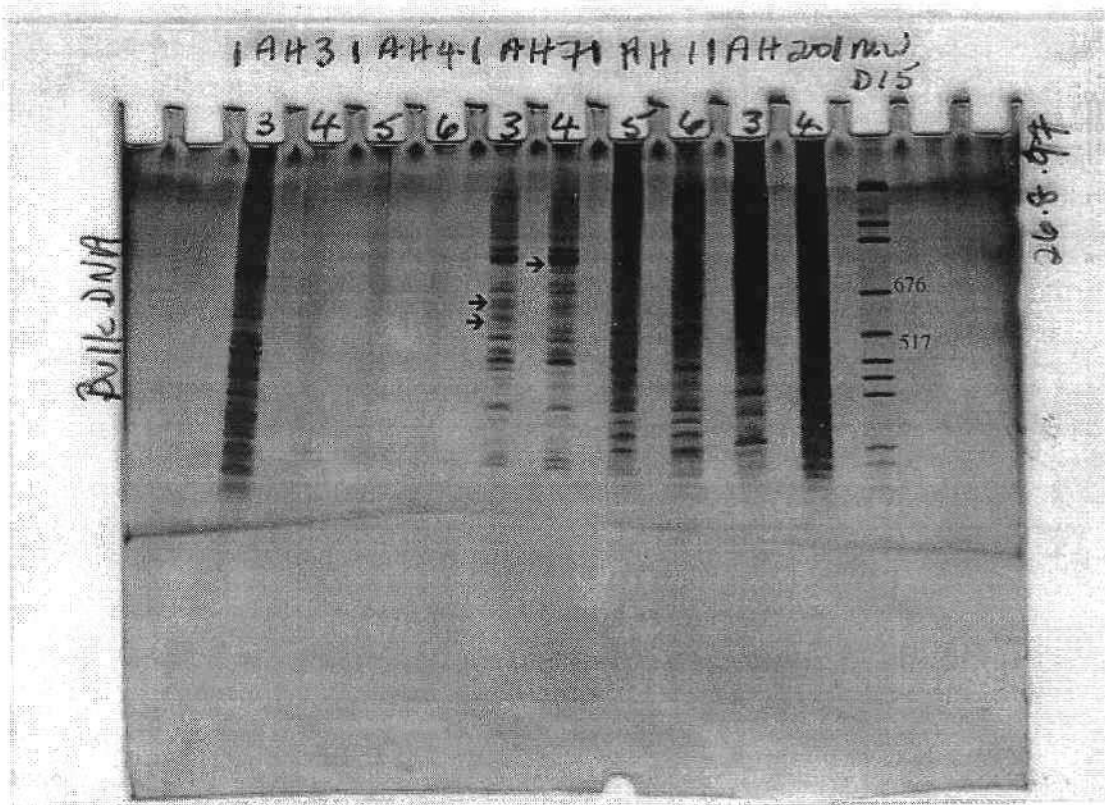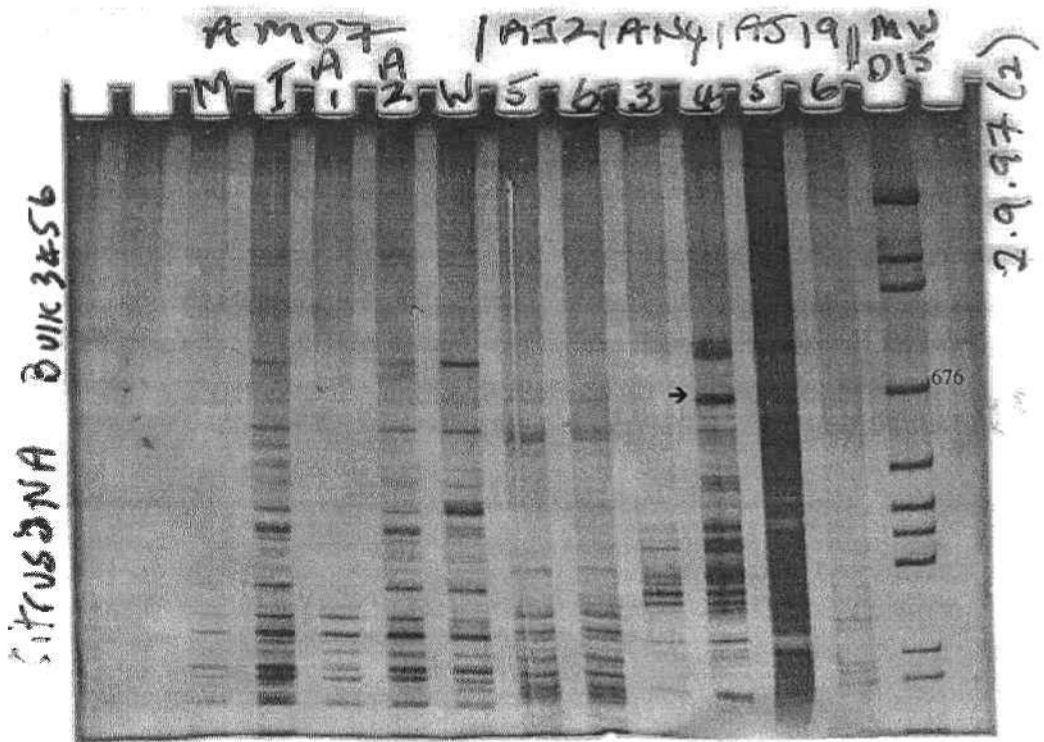Figure 18: Bulk segregant analysis for groups 3 and 4; one polymorphism present for primer AK8.
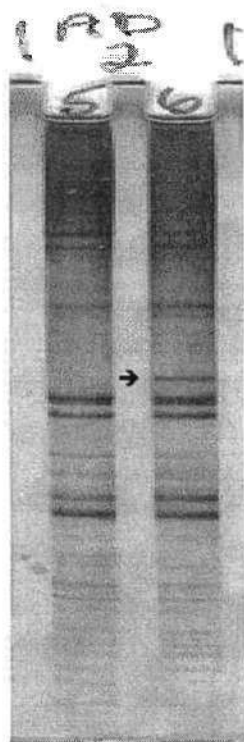
Figure 19:Backcross groups
5 and 6 for primer AD2.
One polymorphism present
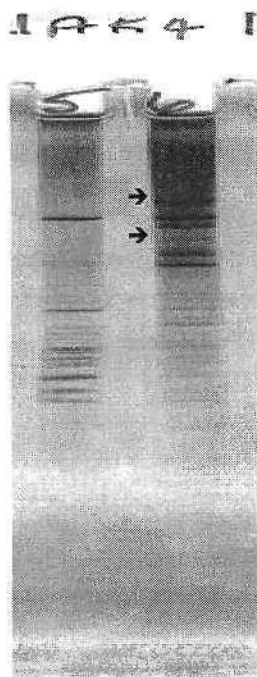
Figure 20: Backcross groups
5 and 6 for primer AK4.
Two polymorphisms present

Discussion

The development of the PTM bioassay procedure for resistance score was difficult for several reasons. Larvae were highly mobile and sometimes reluctant to mine leaves of susceptible genotypes, leading to difficulties in scoring in some instances. Feeding was also erratic on leaves of LA1777 and derived resistant lines so that these scores were often variable. Because LA1777 is genetically heterogeneous, its selections and their hybrids to N91 and backcross genotypes could not be represented by genetically uniform progeny grown from seed. These genotypes were replicated as rooted cuttings and data was obtained from a sequence of scores on different leaves of one or more individuals of a given genotype over time. Although this precluded conventional statistical analysis of means, it was possible to calculate standard errors for each genotype mean.

Plants were originally established in a constant temperature room at 27C to standardise environmental conditions for PTM larvae between trials. However, LA1777 and its hybrids were adversely affected by intumescence resulting from changed light conditions; the disorder was not rectified by the addition of artificial lighting and plants were later transferred to a plant-house with natural light and ambient daytime temperatures up to 27C.

Despite the relative lack of environmental controls in the plant-house, the bioassay data confirmed marked phenotypic differences between *L. esculentum* and *L. hirsutum* for PTM resistance. This reflected earlier observations made in fields subject to severe pest pressure. The strongest evidence for antibiosis in LA1777 of L. hirsutum arose from small points of leaf damage inflicted by larvae which then failed to establish a mine and continue feeding and development. By contrast, the susceptible line of L. esculentum usually displayed extensive mining and larval development at the end of the trial.

Both F1 hybrids were as resistant as their L. hirsutum parents, indicating that resistance was highly heritable and conferred through strongly dominant gene action. The continuous distribution of backcross line mean scores in both populations suggested multigenic control of resistance, although inferences drawn from phenotypic distributions such as this can be biased by large environmental effects influencing a few major genes. The segregation of several lines in both populations with levels of resistance similar to or better than LA1777 indicated that testing of selfed progeny could provide further understanding of genetic control. Several resistant segregants could be heterozygous and selfs of these lines would then segregate further. In any event, the highly resistant lines will produce selections for further backcross breeding cycles.

The RAPD profiles obtained for parent, F1 and backcross breeding lines(Figures 16-20) indicated their usefulness for differentiation of genotypes in breeding programs. Marked differences between L. esculentum and L. hirsutum were evident and it was possible to distinguish F1 hybrids from their L. hirsutum parents by the pattern of relevant bands. There were also more subtle differences between accessions of L. hirsutum which made it possible to differentiate these lines. Similarly, there were a number of polymorphisms apparent for backcross breeding lines. However, the patterns obtained were not necessarily related to PTM resistance but may have reflected the broad genetic divergence between species.

DNA markers are valuable as a means of locating sources of favourable alleles for developing superior cultivars or hybrids and of implementing marker-assisted selection. Tanksley et al. (1989) indicated how marker-assisted backcrossing could be used to minimise linkage drag and enhance the production of near-isogenic lines. Where markers have not been identified in

any region of the genome the use of bulked segregant analysis is a rapid method of adding markers to a genetic map (Michelmore et al. 1991). The technique relies on the use of two DNA samples formed by bulking individuals with extreme phenotypes and identifies markers which are linked to a gene or genomic region on which the bulks are based. In the most straight-forward cases, the analysis typically determines markers linked to a major gene whose phenotype is easily classified. When markers are identified they are then shown to be linked to the gene by conventional segregation analysis in the population. In this way markers can be readily added to an existing map.

In the N91 x LA1777 backcross there was no prior information on markers for PTM. The formation of resistant and susceptible bulks was the easiest way to quickly identify potential markers for genes of interest in the breeding population and many polymorphisms between bulks were recognised. Although these differences were not unequivocal evidence of markers for PTM resistance, they strongly suggested the presence of several regions of the genome with resistance and indicated markers which should be targeted for greatest expression of resistance. Without a gene map it is difficult to estimate the number of genes or Quantitative Trait Loci (QTL) responsible for an attribute and to determine which contribute significantly to its expression. Marker genotypes now need to be confirmed for all entries in the bulks, and an analysis of the entire backcross population to ensure co-segregation of resistance with markers would be valuable. A further check on the validity of markers would be to confirm their presence in both, rather than one, of the populations. At this point those markers associated with resistance could be scored in conjunction with others to implement an interval mapping exercise, allowing map positions and linkage groups to be established. Such a project is costly and is not planned.

It is likely that a number of the RAPD differences identified between bulks reflect linkages to a limited number of genes for resistance, perhaps distributed throughout the genome. A survey of linked marker genotypes for resistant backcross breeding lines to ensure an optimum combination of resistant alleles would be desirable prior to undertaking further cycles of hybridisation. Ideally the development of a genetic map of resistance genes will create a picture of the distribution of favourable alleles between parents and progeny, allowing for effective selection of breeding lines. One of the most important problems in disease and pest resistance breeding in tomato is finding new sources of alleles in donor lines for introgression into elite adapted lines. The mapping of QTL provides knowledge about the distribution of alleles, estimates of gene effects without restrictive assumptions about gene action and marker loci linked to the genes to be selected.

A major difficulty in the use of primitive germplasm is that diversity for important genes is distributed among many genotypes which can not be recognised by the traditional reliance of breeders on phenotypic parameters such as means and variances. These statistics alone do not guarantee an appropriate choice of favourable alleles different from those already fixed in adapted breeding lines. This has contributed to the widening gap between exotic and elite germplasm and to the reluctance of breeders to exploit primitive material (Troyer 1990). QTL analysis provides a means of comparing the status of gene loci in different lines so that the most effective combination of donor genes can be incorporated into the most adapted lines. Without this discrimination it becomes harder to accumulate new favourable alleles in elite germplasm since the new sources are usually fixed for unfavourable alleles at most other loci. So far the project has successfully targeted several RAPD sequences which are associated with genetic resistance to PTM. Comparison of these markers for individual backcross genotypes should guide decisions about future hybridisation and assist in the future selection

of breeding lines. The markers will also serve as a rapid means of creating a genetic map if this next progression is justified.

Directions for future research

The PTM breeding lines developed so far are quite undomesticated and it will be some years before commercial material will be generated, even if further cycles of breeding are straight-forward. Continued breeding with this material will incorporate parent lines with better agronomic performance and improved eating quality generated in other parts of the project. It is expected that a broad range of useful lines and hybrids will be developed in this way.

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FLAVOUR AND EATING QUALITY IMPROVEMENT
D.J. McGrath, I.O. Walker, A. Ford and R. Roberts

Introduction

Genetic improvement of eating quality is significant for the Australian fresh-market tomato industry because there is a need to provide fruit of better flavour to the consuming public. Attempts to improve flavour by pre-harvest fertiliser treatments, management of harvest procedures and post-harvest storage conditions have provided mixed success in improving quality although work in these areas is valuable and should be pursued.

Varietal differences between indeterminate and determinate genotypes are well-known. Indeterminate varieties usually have more solids content and are therefore frequently recognised as better-flavoured, although some determinate types may also have pleasant flavour if correct management procedures are followed from harvest to consumption.

Soluble solids content (SSC) is of prime concern due to the important contribution that sugars and acids make to the overall flavour of fruit (Stevens et al., 1977). In their review of tomato fruit quality, Davies and Hobson (1981) estimated that of the water soluble portion of fruit dry matter, about half is in the form of the reducing sugars fructose (25%) and glucose (22%). A further quarter of the dry matter consists of citric (9%), malic (4%) and dicarboxylic amino acids (2%), lipids (2%) and minerals (8%). Because sugars and organic acids account for the major portion of tomato total and soluble solids, most research has centred on these components.

The literature concerning the genetic control of SSC in tomato indicates the trait is quantitatively inherited. In a significant study using an RFLP linkage map, Paterson et al.

(1988) were able to map four loci controlling SSC, indicating that there may be relatively few genes and that some advance in breeding programs may be possible.

The following research reports comparisons of breeding lines bred for higher concentration of SSC and indicates the advances made in flavour perception and eating quality for those lines.

Three breeding lines derived from the high-solids Japanese cultivar Momotaro were assessed in replicated field trials at Bowen HRS during 1996 and 1997. The lines were obtained by crossing Momotaro to an adapted line with disease resistance followed by partial selfing with selection for SSC; two further crosses to adapted lines with selection in segregating generations produced F4 and F5 lines which were replicated in field plots for evaluations in successive years. The fruit were harvested at either 'breaker' stage where a first indication of colour appears at the blossom end, or at a full red stage.

Two sets of evaluations are reported, Set A for F4 lines grown in 1996 which were assessed by the Centre for Food Technology, DPI Hamilton, and Trial B for the same lines in the F5 generation evaluated in 1997 by a panel at Bowen HRS.

TRIAL SET A
A Ford and R Roberts, Centre for Technology, DPI

Materials and Methods

Samples

The tomatoes were received on Tuesday 19 November 1996, in commercial packing boxes and were stored at 20°C until ripe. Most fruit was harvested at the 'breaker' stage, however, some tomatoes were more advanced. The tomato ripeness was monitored regularly. Ripeness was judged visually using the degree of redness and absence of yellow as the ripeness indicator. "Full red" is normally six days past breaker stage. Where tomatoes reached "Full red" before the tasting dates (November 26 - 28 inclusive) they were transferred to storage at 10°C in order that all tomatoes were similar in degree of ripeness on the days testing took place.

The varieties received were
- Tornado (commercial check variety)
- breeding line 6
- breeding line 8
- F1 Tristar x 11-11-20

Approx 50 fruit were received for F1 Tristar x 11-11-20 and about 100 fruit were received for each of the other tomato varieties.

Preparation of Tomatoes

Tomatoes were weighed, washed (by floating them to prevent damage) in cold tap water (approx 21°C), and towel dried .

Sensory Evaluation

Tomatoes were presented to panellists, whole, at room temperature (20 - 22.5°C) on white styrofoam trays with a fork and a small sharp knife. Each tomato was identified by a random three digit code.
A panel of 13 tasters (7 male, 6 female), who were experienced in sensory procedures and had previously assessed tomatoes in September 1996, tasted the tomatoes on three separate occasions on three days, November 26-28 inclusive. The order of tasting was balanced across the panel. Samples were served to tasters in individual booths illuminated with white light (daylight equivalent). Purified water was freely available for palate cleansing prior to and during tasting. A preliminary session was held for training on procedures for assessment, and definitions of terminology used.

The tasting was carried out in two trials. Trial three consisted of duplicate sensory tests comparing Tornado, Line 6 and Line 8.
Trial four compared Tornado, and F1 Tristar x 11-11-20 in one trial.

Tasters identified and rated the appearance (external and internal), odour , flavour, and texture characteristics on unstructured line scales in a standard rating test (AS 2542.2.3 1988). A list of descriptors used on the questionnaire, with end points of scales defined, appears in Appendix 1.1. Tasters selected additional descriptors that they considered applicable to the fruit from a list supplied. Descriptors listed appear in Tables 6 and 9 in the results section. Definitions of descriptors are listed in appendix 1.2. In both trials overall acceptability of the tomatoes was also rated, and tasters were given the opportunity to add any other descriptors or general comments about the samples.

Data was collected directly into computers using an integrated software package CSA 5 (Compusense Inc., Canada).

Results

The tomatoes were transported from Bowen to Brisbane in commercial tomato packing boxes and were received in good condition, but there was some difference in degree of ripeness.

Table 1 Average weights of tomatoes in grams

	Tornado	**Line 6**	**Line 8**	**F1 Tristar 11 - 11 - 20**
Average weight	211.1	181.7	157.0	166.6
Range of weights	121 - 310	113 - 266.	100 - 262	142-218
Number of tomatoes weighed	58	47	44	15

Trial Three - Tornado, Breeding Line 6 And Breeding Line 8 (2 Reps)

Data was subjected to analysis of variance and results are expressed as means over the two replicates and thirteen tasters. Where significant ($p<0.05$) treatment effects occurred, pairwise comparisons of means using Tukey's HSD were made.

Appearance

There was a significant difference ($p<0.05$) between breeds in the number of depressions. Line 6 hybrid showed significantly less depressions than Tornado (Table 2 and Appendix 2 Figure 1). All tomatoes were rated firm with an even tomato colour, and a typical tomato smell

Table 2 Mean Taste Panel Scores - Tomato Appearance

Sample	Appearance of Tomato			
	Typical tomato colour (red)	**Evenness of colour**	**Depressions***	**Degree of ripeness**
Tornado	70.56	55.68	36.24^a	69.60
Line 6	70.88	45.84	19.36^b	69.12
Line 8	72.88	58.16	24.80^{ab}	69.12

Scales 0 to 100 see Appendix 1.1 for end points
* Difference between treatments significant($p<0.05$)

Odour And Texture

Table 3   Mean Taste Panel Scores
          Texture of Whole Tomato and Odour of Whole and Cut Tomato

Sample	Whole Tomato Smell and Texture		Ease of Cutting and Cut Tomato Flesh Smell	
	Tomato smell (typical)	**Whole tomato* firmness**	**Ease of cutting**	**Intensity of smell of cut tomato**
Tornado	44.80	62.08	64.56	52.64
Line 6	36.16	62.40	70.48	47.60
Line 8	41.68	71.12	61.36	45.84

The smell of the three varieties was not significantly different ($p>0.05$) for either whole or cut fruit. (Table 3 and Figure 2). There was a significant difference ($p<0.05$) in whole tomato firmness between varieties, but little difference between them for ease of cutting.

Texture Of Cut Tomato

Table 4 Mean Taste Panel Scores - Texture of Tomato

Sample	Texture of Tomato			
	Skin toughness*	**Graininess**	**Juiciness****	**Other**
Tornado	54.48^a	40.88	65.12^a	8.56
Line 6	55.60^a	33.68	77.68^b	6.88
Line 8	64.80^b	42.72	75.20^b	1.68

* Difference between treatments significant($p<0.05$)
**Difference between treatments significant($p<0.01$)
a,b Samples in the same column with common superscript are not significantly different $p>0.05$

The skin toughness ($p>0.05$) of the three tomato varieties was significantly different ($p<0.05$) and reflected the same pattern as the firmness scores (Table 4, Figure 2). The skin of Line 8

was tougher (p<0.05) then the other two varieties. Tornado was the least juicy variety and was significantly less juicy than either Line 6 or Line 8.

Flavour

Table 5 Mean Taste Panel Scores - Flavour of Tomato and overall acceptability

Sample	Flavour of Tomato				Overall acceptability
	Typical	Acid	Sweet	Other	
Tornado	54.08	30.08	37.60	13.84	56.16
Line 6	53.36	29.36	39.68	5.20	54.56
Line 8	49.92	31.04	35.92	10.72	54.48

No significant differences were identified by tasters for the flavour characteristics measured. Scale 0 = dislike extremely to 100 = like extremely

Comments made by tastes are listed in Appendix 2.

Overall Acceptability

All tomatoes were liked. The overall acceptability scores (Table 5, Figure 3) for the three varieties in trial three were not significantly different. This implies that flavour of the fruit was more important in determining acceptance than texture.

Additional Descriptors

Additional adjectives selected by tasters to describe the tomatoes are tabulated in Table 6 below and shown in Figures 4-7 in Appendix 2. These results are not statistically analysed, but are useful for indicating trends. Tornado appeared to be more susceptible to scarring and "other" defects, receiving comments about blotchy and streaky colouration. The smell of line 8 was considered more acidic than the other varieties.

Table 6 Frequency of selection of extra descriptors for tomatoes

Appearance descriptors	Splits in skin	Grainy skin colouring	Scarred skin	Decayed	Bruised	Discoloured	Other
Tornado	2	9	16	0	7	4	5
Line 6	2	17	9	0	5	8	2
Line 8	4	18	10	2	6	11	1

Whole tomato smell descriptors	Sweet	Acid	Over ripe	Other
Tornado	6	6	3	0
Line 6	9	8	2	0
Line 8	5	10	2	1

Cut tomato smell descriptors	Green	Acid	Sweet	Over ripe	Other
Tornado	9	9	9	1	1
Line 6	7	9	7	2	1
Line 8	11	13	7	2	1

Appearance and texture descriptors	Gaps in flesh	No gaps in flesh	Pale colour	Normal colour	Bright colour	Dark colour	Crunchy	Sloppy	Other
Tornado	7	9	7	10	8	1	12	7	1
Line 6	1	16	2	11	11	5	7	9	3
Line 8	2	16	3	10	13	4	9	3	1

Flavour descriptors	Bitter	Watery	Bland	Green	Other
Tornado	2	12	16	9	2
Line 6	3	16	10	8	0
Line 8	4	12	9	8	2

Tornado was described as pale and gaps in the flesh were noticed. Line 8 was the least "sloppy" in texture, and Tornado the crunchiest. Tornado was also described as bland more frequently than the other varieties.

Trial Four - Tornado And F1 Tristar X 11-11-20

Tornado fruit used in this trial was slightly less ripe than that in trial 3 and than the Tristar variety. Data was subjected to analysis of variance using tasters as replicates. Since there was no replication of sessions, results should be taken as an indication of possible differences only.

Appearance, Odour And Texture Of Whole Tomatoes

F1 Tristar x 11-11-20 was rated significantly riper and more even in colour than the Tornado fruit (Table 8 and Figure 9). The Tornado was firmer ($p<0.01$) and had a more intense smell (Table 9, Figure 9)

Table 8 Mean Taste Panel Scores - Tomato Appearance

Sample	Appearance of Tomato			
	Typical tomato colour (red)	Evenness of colour**	Depressions	Degree of ripeness*
Tornado	70.15	53.69	25.69	68.00
F1 Tristar x11-11-20	75.85	78.62	38.15	72.00

Table 9 Mean Taste Panel Scores - Texture of Whole Tomato and Odour of Whole and Cut Tomato

Sample	Whole Tomato Smell and Texture		Ease of Cutting and Cut Tomato Flesh Smell	
	Tomato smell (typical)	Whole tomato firmness**	Ease of cutting	Intensity of smell of cut tomato*
Tornado	44.92	73.54	66.77	58.15
F1 Tristar x11-11-20	40.46	56.77	69.38	43.08

Texture And Flavour Of Cut Tomato

Differences in texture were non significant (Table 10) although Tornado appeared to be more grainy. It had a significantly more intense tomato flavour (Table 11, Figure 9).

Both varieties were liked.

Table 10 Mean Taste Panel Scores - Texture of Cut Tomato

Sample	Texture of Tomato			
	Skin toughness	Graininess	Juiciness	Other
Tornado	53.38	38.77	72.62	5.85
F1 Tristar x11-11-20	55.08	32.92	73.08	4.62

Table 11 Mean Taste Panel Scores - Flavour of Tomato

Sample	Flavour of Tomato				Overall acceptability
	Typical tomato flavour*	Acid	Sweet	Other	
Tornado	60.00	26.77	39.23	8.00	60.00
F1 Tristar x 11-11-20	54.92	26.77	36.15	11.23	57.08

Scales 0 to 100 refer to appendix 1.1
Scale 0 = dislike extremely to 100 = like extremely
* Difference between treatments significant ($p < 0.05$)

Additional Descriptors

There were few obvious differences between Tornado and F1 Tristar 11-11-20 in selection of descriptors. The skin of the Tornado fruit was described as grainy (Table 12) and it was more

frequently described as sweet, which supports the difference in sweetness intensity scores. Tasters comments are listed in Appendix 2.

Table 12 Frequency of selection of extra descriptors for tomatoes in trial four.

Appearance descriptors	Splits in skin	Grainy skin colouring	Scarred skin	Decayed	Bruised	Discoloured	Other
Tornado	2	7	6	1	5	2	0
F1 Tristar x 11-11-20	1	2	6	0	5	2	1

Whole tomato smell descriptors	Sweet	Acid	Over ripe	Other
Tornado	3	5	1	0
F1 Tristar x 11-11-20	4	6	1	0

Cut tomato smell descriptors	Green	Acid	Sweet	Over ripe	Other
Tornado	5	4	5	0	0
F1 Tristar x 11-11-20	4	6	2	0	1

Appearance and texture descriptors	Gaps in flesh	No gaps in flesh	Pale colour	Normal colour	Bright colour	Dark colour	Crunchy	Sloppy	Other
Tornado	3	5	3	8	4	0	4	4	1
F1 Tristar x 11-11-20	6	5	3	8	3	1	3	5	0

Flavour descriptors	Bitter	Watery	Bland	Green	Other
Tornado	3	7	5	2	0
F1 Tristar x 11-11-20	2	6	4	2	2

APPENDIX 1

1. DESCRIPTORS AND END POINTS OF SCALES USED FOR PROFILING

Appearance

- Typical tomato colour (red)   Not red to very red
- Evenness of colour   Uneven to even
- Depressions in tomato   None to many
- Degree of ripeness   Not ripe to very ripe

Whole tomato smell and texture

- Tomato smell (typical)   None to very strong
- Whole tomato- firmness   None to very

Ease of cutting and cut tomato flesh smell

- Ease of cutting   None to very
- Intensity of smell of cut tomato   None to very strong

Texture

- Skin toughness   Not tough to very tough
- Graininess   Not grainy to very grainy
- Juiciness   Not juicy to very juicy
- Other   None to very

Flavour

- Tomato flavour (typical)   None to very strong
- Tomato flavour (acid)   None to very strong
- Tomato flavour (sweet)   None to very strong
- Tomato flavour (other)   None to very strong

Overall Acceptability

- Acceptability (dislike extremely to like extremely).

2. TOMATO: DEFINITIONS OF DESCRIPTIVE TERMS

Appearance

- Colour - Evenness: all over colour consistency

- Depressions: where one tomato has been slightly squashed by the one next to it

- Split: fissure developing in the skin some times exposing internal flesh

- Decay: where mould etc maybe starting to invade the fruit

- Grainy: fine spots apparent on skin

- Scarred: marks on skin of tomato, usually dry and brownish in colour

- Discoloured: unusual colouring of skin or flesh other than red pink green or whitish

- Degree of ripeness: over all redness ranges from whitish green to dark (overripe) red

- Full: when the tomato is cut: the absence of cavities between seeds and outer flesh

Odour and Flavour

- Typical tomato: the way you expect a good tomato to taste and smell

- Sweet: the sweetness you would expect in a good tomato

- Acid: sharpness of flavour

- Green underripe, freshly cut green vegetation

Texture:

- Skin toughness: degree of difficulty in cutting, biting and chewing the skin

- Graininess: perceived mouth feel of individual tomato cells

- Juiciness: the degree of moisture within the tomato flesh

- Crunchy create distinct noise when chewing

- Sloppy excessive softness and moistness

APPENDIX 2

TRIAL 3 -TORNADO, LINE 6, AND LINE 8

COMMENTS MADE BY TASTERS
External appearance of tomato

Tornado

- Pale orange/yellow around stalk end. Small indentations in skin.
- Blotchy speckled.
- Streaky colour, paler towards stalk end.
- I chose discoloured because there are some darker areas that look like a typical bruise colour but don't seem to be typical bruising.
- Nice square shape!
- Small spots of rot/decay.

Line 6

- Discoloured patches and scarring near stem.
- Colour good except for graininess around stalk end.
- Grainy round stalk end. Merges to solid pale pink patch.
- Colour is a dirty mute red not true tomato red.
- Stem rot puffy, blotchy artificial.

Line 8

- Slight artificial appearance.
- Perfect looking tomato and good size (not too big).
- Grainy blotches round stem end.
- Not true tomato red.

Whole Tomato Smell Descriptors - Comments on 'Other'

Line 8

- It has a chemical smell and not much of tomato.

Cut Flesh Smells Other Then Typical - Comments on 'Other'

Tornado

- Slightly salty.
- Faint tomato smell with acidic overtones.
- This was difficult to cut because of a woody stem and It has a very intense (under ripe) type of green smell.

Line 6

- Slightly salty.

Line 8

- Slightly salty.

Texture and Appearance of Cut Flesh

Tornado

- Lot of internal 'core' and white colour inside.
- Severe darkening in one of the vacuoles. Has a mushy non structured texture, grainy gritty and coarse, lacks body.

Line 6

- Very high level of moisture - but quite firm flesh.
- Lots of immature seeds - hardly any formed mature seeds.
- Texture too soft.

Line 8

- Green segments.

Tomato Flavour

Tornado

- Slightly salty some depth of flavour.
- Has a very under ripe type of green flavour.
- Sort of green but without acid.

Line 6

- Lacked flavour although it smelled as though it would.

Line 8

- Slightly salty, more depth of flavour.
- Weedy flavour.
- Sort of green or metallic flavour.

TRIAL 4 - TORNADO AND TRISTAR X 11-11-20

External Appearance of Tomato

Tornado

- Variation in colour. Perfect appearance for a tomato.

F1 Tristar X 11-11-20

- Only some slight imperfections/pale patches.
- Looks perfect.
- Couple of very small discoloured spots/depressions.

Cut Flesh Smells Other Then Typical - Comments on 'Other'

F1 Tristar X 11-11-20

- Slightly salty.

Texture and Appearance of Cut Flesh Comments

Tornado

- Bruised brown.

Tomato Flavour

Tornado

- Sweet but bland.

F1 Tristar X 11-11-20

- Slightly salty.
- Starting to taste a little off.
- Weedy flavour.

Trial B

Materials and Methods

Three high-solids breeding lines designated 6-46, 6-51, 8-13 and the commercial standard variety Tempest were grown in six replications of a randomised block design at Bowen HRS. The high-solids lines were F5 progeny derived from two backcrosses of adapted lines to a hybrid with the high Brix parent cultivar Momotaro. The progeny had been selected from single plants with high SSC in each generation of inbreeding. The trial was planted in the field on May 1 1997 and fruit were harvested and evaluated on August 12 1997. Plants were grown on black plastic mulch and spaced at 88 cm between plants within the row. Fruit were harvested at a full red stage by sampling randomly from a 10 m plot and immediately evaluated by an experienced panel of six tasters.

Fruit from each plot were presented simultaneously to all tasters who scored the sample for sweetness (1- very low, 4 - average, 7 - very high) and overall acceptability (1 - very poor, 4 - average, 7 - excellent). Panel members were blindfolded while tasting fruit to prevent bias arising from the colour of the sample; this was necessary as the high-solids lines are pink in colour whereas the check is red. A sample of five fruit from the plot was used to obtain the mean Brix content for the plot. Mean scores for each sensory attribute and Brix were compared for the genotypes.

Results

	Sweetness	**Acceptability**	**Brix**
Table 13 presents mean values for panel scores of sweetness and overall acceptability and Brix content.			

Genotype			
6-46	4.0	4.3	5.0
6-51	4.4	4.5	5.1
8-13	4.0	4.4	5.2
Tempest	3.5	3.8	4.5
LSD (p<.05)	0.5	0.4	0.2

Table 13 Mean scores for sweetness, acceptability and Brix content of high-solids breeding lines and cultivar Tempest.

All breeding lines 6-46, 6-51 and 8-13 were judged by the panel to be significantly sweeter and more acceptable than Tempest. Brix content of the breeding lines was also significantly higher than for Tempest and was strongly associated with flavour perception scores.

Discussion

There were mixed results from the different sets of trials. Trials of Set A indicated several differences between lines related to odour and texture, the most important being the better juiciness of F4 line 6 and 8 compared with the standard Tornado. However the key parameters of flavour and acceptability showed no advantage for the high-solids lines. By contrast, the F5 lines derived from the same families were clearly superior to Tempest for sweetness and overall acceptability and this was supported by the strong genetic association between these traits and Brix content (Table 13).

Difficulty in discriminating between fine perceptions of flavour may have contributed to the similar scores for improved and standard lines in the F4 data set. Because panel data is subjective, unspecified variability may have confounded small differences between treatments. Another potential problem was the use of 'breaker' stage fruit for this trial;

experience with other data of the same lines suggests that the range of flavour scores between standard and improved lines was smaller for 'breaker' fruit (2.1 units) than for fruit harvested at full red maturity (7.2 units). This would compound the problems already inherent in the use of panel assessment. A further source of bias was the comparison of F4 and F5 data between years; it is likely that F4 lines contained more genetic variance than F5 lines , thereby contributing to poorer flavour perception in this generation. The advantage of high-solids breeding lines over Tempest in the F5 trial was nonetheless compelling in the Bowen data (Table 13) and suggested that significant genetic gain had been achieved through two backcrosses and inbreeding generations.

Directions for future research

Current work is directed towards incorporation of improved flavour genotypes in other components of the tomato breeding project. An ultimate objective is the production of well-adapted hybrids with at least a 0.5 - 1.0 unit Brix increase associated with measurable flavour improvement. In time it is anticipated that all parent lines used for hybrid production in this program will have enhanced flavour profiles which will broaden the consumer appeal of these cultivars. Several years will be required before improved hybrids will be available for commercial testing.

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