INHERITANCE OF YIELD AND QUALITY CHARACTERISTICS IN PROCESSING TOMATOES

By

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CHAPTER 1
INTRODUCTION

The usage of hybrids has increased dramatically in many crops during the last few years. Most processing cultivars sold in South Africa are F_1-hybrids. The success of hybrids is mainly attributed to heterosis.

Processing tomato production has increased globally from 15.2 million tons in 1976 to 26.1 million tons in 1989 (Bieche and Covis, 1992). This is an 84 percent increase over a period of 13 years, and corresponds to a 4.2 percent annual growth. During the same period, world population grew from four billion in 1976 to 5.2 billion in 1989, a two percent annual growth. They argue that factors contributing to the immense growth in processing tomato production was the revival of the pasta market as well as advertising efforts on behalf of secondary processing products, especially that of ketchup. The increase in the number of meals eaten outside the home and the increase in microwave cooking as well as children's food and the use of tomato products for red food colouring to replace paprika in some cultures also contributed to the growth of the processing industry world-wide.

Major processing tomato production areas in South Africa includes the Weipe/Pondrif, Duiwelskloof and Baltimore areas in the Northern Province as well as the Robertson, Lutzville and Vredendal areas in the Western Cape. Processing tomato production is estimated at approximately 200 000 tons harvested on 4000 hectares during the 1995 growing season. A production of approximately 260 000 tons are predicted by the major processing companies for the 1996 growing season.

The demand for higher yielding cultivars with better fruit quality could be addressed by using the heterosis effect in the F_1-generation after crossing different inbred lines. Yordanov (1983) points out that heterosis is confirmed more and more as a basic, highly effective breeding method applied in an ever-growing number of agricultural crops. Heterosis as a breeding method which offers numerous benefits ranging from early, high-yielding, uniform cultivars which also combines a number of other valuable economic characteristics. The heterosis effect is manifested to a different extent in the individual F_1 combinations and cannot be predicted beforehand. The choice of the parental pair's for F_1 crosses is made on the basis of preliminary studies of their general and specific combining ability.

Therefore the aim of this study is:

(I) The identification of inbred lines with good general combining ability (GCA) with regard to numerous yield and quality characteristics.

(II) To determine the heritability of the various yield and quality characteristics

(III) To study the amount of heterosis expressed in the F_1 hybrids for the different yield and quality characteristics in local open pollinated breeding lines with the aim to select the best parental lines for use in hybrid combinations.

CHAPTER 2
LITERATURE REVIEW

2.1 The Use of Hybrid Cultivars

According to Boleda (1992) and Tikoo (1987) one of the main reasons that growers choose hybrid cultivars over open pollinated cultivars is the potential increase in yields. From 1985 to 1990 the usage of hybrid cultivars in the California processing industry increased from 26 percent to 52 percent in total tonnage delivered to processors. The increase has been more dramatic in Chile where it is estimated that 70 percent of the total area is planted to hybrid cultivars.

Tigchelaar (1990) explains that the increase in the usage of hybrid cultivars is likely to continue. He states that the heterotic advantages and greater ease of combining desired characteristics in F_1 hybrids will make it increasingly difficult to develop inbred varieties which compete favourably with F_1 hybrids. On the other hand Opeña (1993) points out that the advantages over the open pollinated cultivars have not been as great as in cross-pollinated crops. Furthermore the popularisation of F_1 hybrids among self-fertilised crops owes much to the biological rights they impart to their developer, which in many cases are the seed companies. Nienhuis and Sills (1992) argue that commercial development is limited to those self-pollinating crops in which the added value of heterosis is sufficient to justify the cost of hybrid seed production. They also point out that in many self-pollinated crops F_1 hybrids represent the quickest way available for a plant breeder to accumulate the maximum number of favourable dominant genes in one genotype.

Besides the better yields, hybrid cultivars offer the processing industry other benefits such as better and complex resistance to diseases, early ripeness, uniformity of plants and fruit, improved processing characteristics (solids, colour, and peelability recovery) and strong adaptive ability to different environmental conditions (Stamova, Jordanov and Konstantinova, 1994; Boleda, 1992; Georgiev, 1991).

In addition to all the advantages, F_1 hybrid cultivars are preferred by plant breeders and seed-producing companies for purely commercial consideration. They see in hybrids a sure way to preserve their originators rights on the cultivars developed by them (Yordanov, 1983).

Boleda (1992) also found that the increase in usage of hybrids is a good indication that growers and processors are willing to pay for the added value provided by hybrids. Hybrid cultivars are expensive in comparison to open pollinated cultivars because firstly it takes a major and very costly research effort to introduce new hybrid cultivars. Secondly the leading cultivars have a short market life cycle. Thirdly the cost of hand hybridisation is high. Georgiev (1991) points out that the best possibility to facilitate and cheapen hybrid seed production is presented by the utilisation of female parents with functional sterility such as the *ps-2* gene (non ripening stamens) in combination with *sh st* (short style) genes and a genetic marker (absence of anthocyanine or potato leaf). Male sterility genes in linkage with the genetic maker *aa* (absence of anthocyanine) can also be used.

2.2 Development of F_1 hybrids (Hybridisation)

The inflorescence of the tomato is formed terminally on the shoot and the flowers produced are ebracteate, bright yellow, chasmogamous, pentamerous and hermaphrodite with a pistil envelope in a solid tube formed by the stamens (Kaul, 1991; Atherton and Harris, 1986). The tomato is essentially a self-pollinated crop and self-pollination varies between 94 percent and 99 percent (Kaul, 1991).

2.2.1 Male Sterility in tomato breeding

Stevens and Rick (1986) points out that there has been some use of genetic male sterility, but generally that is still done by hand emasculation and pollination. Israel was the first country to utilise genetic male sterility in tomato breeding, which was found to be highly profitable in terms of time and labour (Lapusher and Frankel, 1967). They, however, point out that the greatest drawback in the commercial use of male sterility in tomato breeding is the lack of a stable gene with cytoplasmic male sterility in it. In all the genetic male steriles that are maintained under heterozygous conditions by backcrossing, 50 percent of the plants that are to be used are fertile. These plants must be removed and causes loss of plant population.

Tanksley and Zamir (1988) proposed the double tagging of a male sterile gene in tomato with a morphological marker (absence of anthocyanin) and an enzymatic marker (presence of peroxidase-2). This enables the selection of male steriles in the seedling stage.

Scott and George (1980) examined the influence of the environment and flower maturity on hybrid seed production of tomatoes with exerted stigmas (*ps-* gene) crossed without emasculation. They found that seed production (fertilisation)

was more efficient in mild, cloudy, relative humid days and inefficient on hot, dry, and possibly windy days. Most commercial seed production takes place in hot, dry environments to avoid problems such as diseases. Seed producers may also consider collecting and storing pollen during favourable weather conditions for use during hot weather (stored pollen resulted in greater pollination success at high temperatures).

Opeña and Chen (1993) highlighted the fact that self-pollinating species do not have the mechanisms of hybridity that are commonly found among cross-pollinated crops. Therefore hybrid seed production has to be done manually.

2.2.2 Artificial Hybridisation

Microsporogenesis starts soon after flower initiation and the first meiosis of pollen mother cells is observed nine days before anthesis at 20°C. Pollen is formed from tetrads seven days before anthesis and reaches maturity within four days. Low pollen production can be caused by low assimilate supply, high temperature (40°C) at the meiosis stage, or low temperature (10°C) after the meiosis stage of microsporogenesis (Ho and Hewitt, 1986).

With artificial hybridisation the corolla androcium fusion cap is gently removed by a fine forceps as described by Kaul (1991), in the "fully developed bud" or "beginning of opening" stages (Georgiev, 1991). Emasculation at an earlier phase of flowering is associated with lower seed yield and in a later phase with the danger of self-pollination (Georgiev, 1991). At dehiscence in the tomato the anthers open to allow the pollen grains to fall to the stigma, either by degradation of the middle lamella of the epidermal cells, by degradation of the

entire epidermal cell walls or by mechanical rupture of the epidermis due to the hygroscopic action in a layer of fibrous cells in the anther walls (Picken, 1984).

Seed is physiologically mature when fruit reaches full ripeness (Tigchelaar and Edward, 1986).

2.3 Manifestations of Heterosis in Tomato

The founder of the heterosis concept defines it as the superiority of the hybrid over its parents in vegetative growth, adaptiveness and productivity (Shull, 1952). Heterosis manifests itself most strongly in the F_1 and decreases progressively in each consecutive segregating generation (Georgiev, 1991). Research on heterosis in the tomato began almost simultaneously with that on maize (Yordanov, 1983). Hayes (1952) pointed out that tomato F_1 crosses have considerable practical value because crossing is relatively easy.

The increased interest towards F_1 hybrid breeding is due to the possibility of combining a complex of valuable attributes in a genotype (Georgiev, 1991). Such attributes are increased yield, early yield, number of fruit, fruit size, acidity, ascorbic acid content, reducing sugar, dry matter content, juice and pulp ratio, β-carotenoids and nutrient utilisation (Yordanov, 1983; Georgiev, 1991; Kalloo, 1988).

Georgiev (1991) explains that male parents are chosen which complement those characteristics that are not transferred through the female parent (see Table. 2.1). He points out that the selection of parents based on the various characteristics to develop a hybrid may differ from place to place, depending upon production problems and consumer demands.

Table 2.1 Selection of male/female plants for best F_1 hybrid (Georgiev, 1991).

No.	Characteristics	Female	Male	F_1 hybrid
1.	Stem	Semideterminate	Semideterminate	Semideterminate
2.	Leaves	Potato type	Normal	Normal
3.	Flower	Sterile	Fertile	Fertile
4.	Fruit			
4.1	Size	150g	60g	100g
4.2	Shape	Flat-round	Oval	Round
4.3	Green shoulder	Without	Without	Without
4.4	Colour	Red	Pink	Red
4.5	Firmness	Good	Very good	Very good
5.	Adaptability			
5.1	To low light	Weak	Very good	Good
5.2	To low temperature	Weak	Very good	Good
5.3	To soil salinity	Very Good	Weak	Very good
6.	Resistance to			
6.1	disease	*Tm2*^{2}	*Tm*	*Tm2*^{2}, *Tm*
6.2	TMV	-	Ve	Ve
6.3	*Verticillium*	-	F	F
6.4	*Fusarium*	C (ABC)	-	C (ABC)
	Leaf mould			
7.				
7.1	Fruit yield	Medium	High	High
7.2	Early	High	Medium	High
	Total			

In addition to the superior performance of hybrids due to heterosis, intermediate states of gene expression in heterozygotes may be of value. This can be illustrated by the potential utilisation of the *nor* (no ripening) gene in hybrids exhibiting normal pigment production but slowing down ripening of the fruit (Tigchelaar, McGlasson and Buescher, 1978; Bruescher, Sistrunk, Tigchelaar and Tomothy, 1976).

2.3.1 Fruit Yield

High yield potential is one of the foremost objectives in many breeding programmes. Unless a new cultivar has a yield potential equal to or exceeding that of current cultivars, it generally cannot be utilised even where the improvement of other characteristics have been achieved, such as improved quality or the ability to be effectively machine harvested (Berry and Uddin, 1991).

Number of fruit and mean fruit mass of the fruits are the main components of total yield with the number of fruits being of greater importance than their mass (Yordanov, 1983). He also points out that no one has recorded a heterosis effect in respect of mean fruit mass.

Opeña (1993) highlights high productivity, as one of the major goals of breeding and that yield is genetically complex and invariably influenced by environmental factors.

Yordanov (1983) explains that the heterosis effect is observed in tomato with respect to yield. According to Powers (1952), who studied this problem in detail, the average yield of F_1 hybrids is better than the average yield of the parental lines and that a lower level of all components of yield is found in F_2 generations.

2.3.2 Solids in tomato fruit

2.3.2.1 Composition of tomato fruit

Total dry matter generally comprises between four percent and 7.5 percent of the fresh weight of the commercial tomato fruit (Berry and Uddin, 1991). Of

this total dry matter, the soluble and insoluble solids account for approximately 75 percent and 25 percent respectively. Major components of soluble solids are the reducing sugars, glucose and fructose, which comprise approximately 50 percent of the total solids and 65 percent of the soluble solids. Sucrose is present in very small quantities (0.1 percent) of the fresh weight. The remaining soluble solids are composed of organic acids, lipids, minerals, pigments and volatiles. Large differences regarding percentage of soluble solids exist within the cultivated tomato with soluble solids ranging between 4.5 percent to 6 percent (Stommel and Haynes, 1993).

Experiments done by Emery and Munger (1970) showed that high solids are associated with large, indeterminate vines, dispersed fruit set, late maturity and small fruit size. A high leaf area to fruit ratio contribute to a higher content of soluble solids, which is not suitable in processing cultivars because this may lead to problems in mechanical harvesting (Hewitt, Dinar, and Stevens, 1982).

2.3.2.2 Sugar accumulation in tomato fruit

Sugars, mainly glucose and fructose, account for about half the dry matter or 50 percent of the total soluble solids of a ripe tomato fruit (Ho and Hewitt, 1986). Once the fruit starts to grow, the content of the reducing sugars increases from 0.1 percent of the ovary fresh weight to 2 percent of the fruit fresh weight within two weeks and then to 3.5 percent at ripening (Marre and Murneek, 1953).

The rate of starch accumulation during the rapid growth period has a great influence on the final content of total soluble solids (Dinar and Stevens, 1981). The soluble solids content of ripe fruit is positively associated with starch

content early in fruit development. Starch and structural materials are the only forms of storage of important carbon.

Starch breakdown starts when the fruit absolute growth of the fruit reaches its maximum and the starch content is about one percent dry matter at the mature green stage or 0.03 percent fruit fresh weight at ripening (Ho and Hewitt, 1986). This breakdown of starch is associated with a rapid accumulation of reducing sugars and there is a high correlation between the starch content in green fruit and the total soluble solids content of ripe fruits (Dinar and Stevens, 1981).

Sucrose may be hydrolysed by apoplastic acid invertase, resynthesized by cytoplasmic SPS, and stored in the vacuole (Miron and Schaffer, 1991). The hydrolysis and resynthesis of sucrose in this later developmental stage would lower the apoplastic concentration of sucrose, thereby increasing the sucrose gradient from the phloem as well as establishing a hexose gradient between the apoplast and cytoplast.

In the fruit, imported sucrose from the phloem is metabolised by a series of biochemical steps to starch in the early stages of development (Brampton, Asquith, Parke, Barraclough, and Hughes, 1994). This allows the fruit to build up carbon stores without an osmotic penalty. The first step is the cytoplasmic cleavage of sucrose by sucrose synthase or alkaline invertase to form UDPG. This is then converted via UDPG-pyrophoshorylase to glucose-1-phosphate which, crosses the plastid membrane where it is a substrate for the enzyme ADP-glucose pyrophosphorylase. This starch is metabolised at a later stage by a phosphorylitic mechanism to hexoses with a concomitant increase in soluble sugars in ripening fruit. The biochemical scheme is outlined in Fig. 2.1.

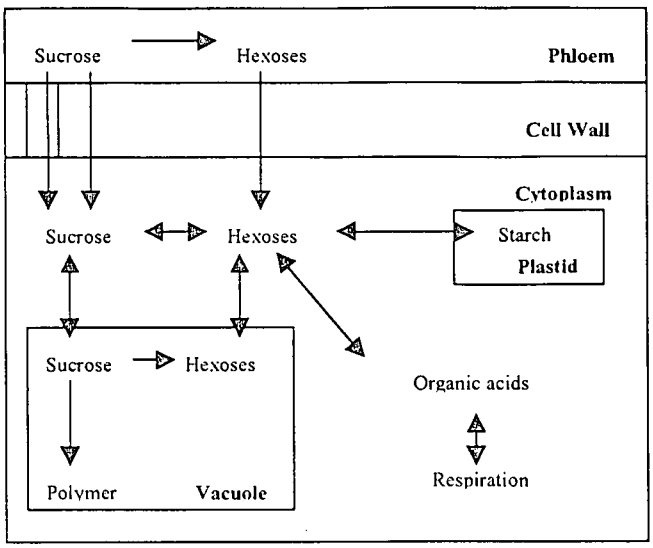

Fig. 2.1 Biochemical scheme for sugar formation in the tomato (Brampton *et al.*, 1994).

It is evident that there are distinct regions within the pericarp and other areas of the fruit that handle their metabolism differently (Brampton *et al.*, 1994). They speculate by saying that the cells have the same competency but receive different stimuli. In this case the sucrose entering the fruit may be split to provide different concentrations throughout the fruit (sieve element distribution) or metabolised in different ways (depending on the symplastic or apoplastic method of entry).

According to Morag and Ho (1993), glucose uptake by pericarp protoplasts increased to a peak in fruit of 20g fresh weight (15 - 20 days after anthesis) and declines as the fruit matured, whereas sucrose uptake continued to increase with time from a lower initial rate.

Sun, Loboda, Sung, and Black (1992) measured sucrose synthase in the fruit pericarp tissues, seeds and in flowers of *L.esculentum*. Sucrose in tomato fruit is broken down by sucrose synthase (SS) in a reversible reaction into UDP-

glucose and fructose. The main pathway of sugar accumulation in very young tomato fruits may be through the plasmodesmata with imported sucrose being cleaved by SS to provide precursors for starch synthesis (Morag and Ho, 1993). In older fruit, sugars may be accumulated across the membrane with sucrose hydrolysis by acid invertase (AI) in both the cell wall and the vacuole. At this point starch is broken down and sugars accumulate in the vacuole.

Klann, Chetelat and Bennet (1993) point out that reduced acid invertase activity was associated with sucrose accumulation and that the absence of acid invertase activity in sucrose accumulating fruit results from the introgression of the *L. chmielewskii* invertase gene and failure of invertase mRNA to accumulate in fruit.

2.3.2.3 Wild tomato species as a source for improved fruit solids

The wild tomato species exhibit a large range of variation in soluble solids. Poysa (1991) suggests that one of the most promising methods for increasing solids levels is transferring so-called "high solids" genes from related species, *Lycopersicon chmielewskii* and *L.cheesmanii* to tomato using a backcross breeding method. Rick, DeVerna, Chetelat and Stevens (1987) points out that it has been possible to increase the soluble solids by 40% using backcrossing and selecting from a *L. chmielewskii* source. A major factor in using this source is the higher effectiveness in carbohydrate movement from the leaf source to the fruit (Hewitt, Dinar and Stevens, 1982).

Genetic analysis of progeny resulting from a cross between *L. chmielewskii* and *L. esculentum* indicated that the sucrose accumulating trait could be transferred

and that the trait is controlled by the action of one or two recessive genes (Yelle, Chetelat, Dorais, DeVerna, and Bennett, 1991).

Stevens (1994) points out that the use of wild germplasm was unsuccessful in creating a high yielding, high solids cultivar. By the time the high solids potential of *L. chmielewskii* and *L. cheesmanii* was introgressed into an acceptable horticultural type, most of the high solids potential disappeared.

The green-fruited *Lycopersicon* species, *L. peruvianum*, differs substantially from the cultivated tomato *L.esculentum* in sugar content and metabolism. In contrast with *L. esculentum*, in which a steady increase in hexose sugars was noted throughout development, *L. peruvianum* fruit accumulated low total sugar levels midway through fruit development followed by a sharp increase in sucrose and solids accumulation during the latter stages of fruit development (Stommel, 1992).

2.3.2.4 Conventional breeding for improved fruit solids

Though there is large genetic variation in soluble solid content of the fruit in wild species, breeders have only limited success in combining increased level of soluble solids with high yield in processing cultivars (Berry and Uddin, 1991; Stevens and Rick, 1986).

Stevens and Rick (1986) explained that successful selection for high solid progeny in segregating populations is difficult because of environmental impact on solid content. They pointed out that the susceptibility to diseases and variation in irrigation and soil texture which effect the water uptake of the plant

can have a much larger effect on soluble solid content than genotypic variation for fruit solid content.

Most Californian grower's use a 30- to 40-day irrigation cut off (before harvesting), which results in higher yields of fruit and tons of solids (May and Gonzales, 1994; May, Peters, Wolcott and Grimes, 1990).

Both size and the total soluble solids content of tomato fruit is strongly influenced by the solar radiation received by the leaves. The influences of direct light on fruit metabolism is CO_2 fixation, protein synthesis and pigment synthesis (Ho and Hewitt, 1986).

Direct selection for increased soluble solid content has proven very difficult and there has been interest in gaining more understanding of the physiological factors which influence fruit solids content (Stevens and Rick, 1986).

From an eight-parent diallel cross with four large and four small-fruited lines, the estimated heritability for soluble solids of 0.54 percent was obtained. Stoner and Thompson (1966) showed that the combination of high soluble solids with larger fruit size is possible, even though the lines with high general combining ability for solids were small-fruited types.

2.3.2.5 Molecular techniques for the improvement of fruit solids

According to Stevens (1994), breeders have spent considerable time and effort trying to breed cultivars with higher solids but with poor results. Higher solids are a difficult goal because it is inversely related to other important

characteristics (e.g. high yield and concentrated ripening). He concluded that the best hope for a drastic improvement in fruit solids is a major gene that will overcome present limitations and several rDNA approaches may help achieve higher soluble solid content.

Ripe tomato fruit contains very little (<1%) or no sucrose (Stommel and Haynes, 1993), but fruit of the green-fruited wild tomato species accumulate significant quantities of sucrose (Davies, 1966). This sucrose is synthesised in the cytosol of the source organs (leaves) and translocated via the phloem to the sink organs (fruit). The flow of sucrose occurs along a concentration gradient and it should be possible to affect the source sink relationship either by increasing sucrose synthesis in the source tissue or by increasing sugar accumulation in sink tissue (Stevens, 1994).

High activities of sucrose-metabolising enzymes, such as acid invertase (EC3.2.1.26), which hydrolyse sucrose into fructose and glucose, or sucrose synthase (EC 2.4.1.13), which converts sucrose into fructose and UDP-glucose, are present in tomato fruit (Wang, Sanz, Brenner and Smith, 1993). A reduction or elimination of invertase activity with antisense RNA would prevent the conversion of sucrose to fructose and glucose (Stevens, 1994). Such a reduction could increase fruit solids as fructose and glucose have a higher osmotic concentrations than sucrose, and the result could be a greater flow and accumulation of sucrose. Experiments done by Wang *et al.* (1993) showed that that sucrose synthase, but not invertase, was positively correlated with starch content on the tomato fruit pericarp tissue. They concluded that during early fruit development, sucrose synthase rather than invertase is the dominant enzyme in metabolising imported sucrose.

Sucrose-phosphate-synthase (SPS) appears to catalise a rate-limiting step in sucrose biosynthesis (Galtier, Foyer, Huber, Voelker and Huber, 1993). They found that SPS was a major determinant of the quantities of starch and sucrose in leaves of tomato. They concluded that SPS has a vital role in carbon partitioning and that high SPS activity may boost photosynthetic rates.

Stark, Timmerman, Barry, Preiss and Kishore (1992) isolated a mutant form of ADP glucose pyrophosphorylase (ADPGPP) in *E.coli* and introduced it into the potato under the control of a tuber specific patatin promotor, the tubers on average contained 35% more starch. Stevens (1994) speculated if it is possible to introduce this gene into the tomato genome so as to increase the starch content.

Bostwick viscosity is greatly increased when the cell wall modifying enzyme, polygalacturonase, is inhibited. Serum viscosity is improved through the inhibition of pectinesterase. The inhibition of both enzymes leads additionally to an increase in Brix (Schuch and Bird, 1994).

Tieman, Harriman, Ramamohan and Handa (1992) introduced antisense and sense chimeric pectin methylesterase (PME, EC 3.1.11) genes into tomato to elucidate the role of PME in fruit development and ripening. PME demethoxylates pectins and is believed to be involved in degradation of pectin in cell wall components by polygalacturonase in ripening tomato fruit. They concluded that the trait segregates in normal Mendelian fashion. Their results indicate that the reduction in PME enzyme activity in ripening tomato fruits had a marked influence on fruit pectin metabolism and increased the soluble solids content of fruits, but did not interfere with the ripening process.

2.3.3 Tomato fruit colour

Fruit colour is an important quality parameter to the grower as it affects grade, and to the processor as it affects product appearance and ultimately consumer acceptance (Porretta, Sandei and Leoni, 1990; Berry and Uddin, 1991). This is particularly true since the consumer notices colour first, and this observation often provides preconceived ideas about other quality factors such as flavour or aroma (Gould, 1974).

Tomato fruit colour is determined by the colour of the skin and flesh (Chalukova and Manuelyan, 1991). The skin is usually colourless or yellow, depending on the content of an unidentified alkali-soluble pigment. The colour of the flesh is determined mainly by the content of the carotenoid pigments.

Colour perception of tomato products by the human eye has its limitations (Gould, 1974). Some of these limitations are the eyes inability to distinguish small colour differences in a non-homogeneous surface; the need for a suitable colour standard for comparison; the quality of colour in the tomato product being graded; and eye fatigue. Although the human eye has some weaknesses when involved in colour evaluation, subjective colour determination can provide meaningful results.

2.3.3.1 Carotenoid biosynthesis

The production of the normal red colour of ripe tomato fruit is due to the destruction of chlorophyll and the extensive accumulation of the carotenoids ß-carotene and lycopene as the chloroplasts are transformed to chromoplasts (Grierson and Kader, 1986).

These carotenoids are C_{40} isoprenoid derivatives and are divided into two groups called carotenes (hydrocarbons) and zantophylls (derivatives of carotenes possessing in their molecule one or more oxygen containing groups: hydroxylic, epoxidic, carbonylic). According to the carbon chain structure, the carotenoids are acyclic and cyclic, with one or two rings (Chalukova and Manuelyan, 1991).

Grierson and Kader (1986) gave a detailed description on the biosynthesis of carotenoids. The precursors for carotenoid biosynthesis are derived from acetal CoA which is converted into a series of reactions to mevalonic acid, which in turn is converted into isopentenyl pyrophosphate (C_5 component) in the plastids. Isomerization of isopentenyl pyrophosphate produces dimethylallyl pyrophosphate and these two molecules are condensed, with the elimination of pyrophosphate, to form geranyl pyrophosphate (C_{10} compound). Further additions of isopentenyl pyrophosphate produce farnesyl pyrophosphate (C_{15}) and geranylgeranyl pyrophosphate (C_{20}). Two molecules of geranylgeranyl pyrophosphate are then combined to form prephytoene pyrophosphate (C_{40}). The above reactions are carried out by enzymes that are either soluble or peripherally associated with the inner plastid membranes. The prephytoene pyrophosphate is converted into 15-*cis*-phytoene, which undergoes dehydration to produce 15-*cis*-phytopfluene. This is followed by a series of dehydration steps, with removal of two hydrogens at a time from alternative sides of the molecule, to generate trans-ζ-carotene, neorosporene and lycopene. This series of dehydration reactions is probably carried out by a multifunctional dehydrogenase enzyme associated with the inner chromoplast envelope membrane. Lycopene is not the end of the biosynthetic pathway and undergoes cyclization to produce either δ-carotene or γ-carotene. A second ring closure

generates α-carotene and β-carotene respectively. An alternative route to γ- and β-carotene via β-zeacarotene probably also operates in tomato.

Characterisation of genes for carotenoid biosynthesis has not proceeded very far yet, mainly as many substrates and enzymes are relatively insoluble in aqueous solutions. The early steps of the pathway are catalysed by soluble enzymes, whereas the later steps of the pathway are catalysed by membrane-bound enzymes (Gutterson, 1993).

2.3.3.2 Breeding for improved colour

Chalukova and Manuelyan (1991) point out that carotenoid biosynthesis in tomato fruit is under direct nuclear control and the existing diversity of fruit pigmentation is controlled by the participation in carotene production of a great number of non-allelic genes distributed on almost all chromosomes.

Berry and Uddin (1991) report that the crimson gene (og^c), and the high pigment gene (*hp*) are responsible for the increase of the red colour in tomato fruit and the simple inheritance of these characters makes incorporation by backcrossing rather easy. They also found that the Crimson (og^c) by itself lowers ß-carotene content of tomato fruit, which reduces the nutritional value by lowering vitamin A. The high pigment (*hp*) gene could be manipulated to enhance both vitamin A and vitamin C in combination with crimson (og^c), but the usefulness of *hp* is limited by the undesirable reduction in seed germination and weak seedling vigour, which are closely associated with *hp*. To date, no successful cultivar containing *hp* has been developed because of adverse pleiotropic effects (Stevens and Rick, 1986).

The dark green (*dg*) mutant was found by Konsler (1973) and contains substantially more chlorophyll than the *hp* mutant. The ripe fruits were darker red both externally and internally. Wann, Jourdain, Pressey and Lyon (1985) have shown that ripe fruit of *dg* contains up to 100 percent more lycopene than normal tomato types. The mean ß-carotene content was about 50 percent greater than that of *hp* lines and 250 percent greater than that of normal genotypes.

Stommel and Haynes (1994) studied the inheritance of ß-carotene content in the wild tomato species *L.cheesmanii* and their results provide evidence for monogenic control of ß-carotene content in *L.cheesmanii*. They point out that total coloured carotenoid concentration (lycopene and ß-carotene) appeared to be under separate genetic control and influenced by additive gene modifiers or other genetic interactions.

2.3.4 Total acidity and pH

There is tremendous variation among tomato genotypes for pH and titratable acidity (Stevens and Rick, 1986). In a study of 250 accessions of *L.esculentum* it was found that the pH varies between 4.26 and 4.82. Gould (1974) points out that the acid in tomato fruit is generally considered to be almost entirely citric acid and free acids are almost always determined as citric monohydrate. Traces of malic, tartaric, succininc, acetic and oxalic acids are also present in tomato fruit.

Acidity influences the storability of processed tomatoes and tomato products (Berry and Uddin, 1991). In the canning of foods, one of the important factors affecting the sterilisation times and temperatures is the actual pH value of the food (Goldoni, Roca, Cavestre, Kurozawa and Bonassi, 1994). The lower the

pH values the lower the degree of heat required for sterilisation. It is usually considered that a pH of 4.5 is the dividing line between acid and non-acid foods. This usually means, that a product with a pH of 4.5 or less has a lesser chance for growth of bacterial spores from organisms such as *Clostridium botulinum*, which will be inhibited after proper sterilisation, as well as from various other potentially dangerous micro-organisms.

Lower and Thompson (1967) concluded that the inheritance of acidity is largely quantitative, but that there was evidence of a single major gene conditioning high acidity in two of their populations. They also found that the major component of genetic variance affecting acidity was additive, and the heritability estimate for pH was 0.38.

Koutsos, Portas, and Paroussis (1994), pointed out that irrigation, from a tomato production side, does not significantly affect the pH value but that the delay of harvesting causes an increase in pH (Hanna, 1961; Yoltas and Carkariz, 1994).

Fruit pH is one of the quality-control checks many food processors have not fully relied upon (Gould, 1974). It is a simple measurement requiring little time to accomplish. Further, little cost is required to provide the adequate equipment.

2.3.4 Viscosity (consistency) of tomato products

Insoluble solids are made up of proteins, pectins, cellulose and polysaccharides and determine the viscosity (Berry and Uddin, 1991; Ho and Hewitt, 1986). Processed product's consistency and the amount of raw product required to achieve a desired consistency are influenced by the viscosity potential of the raw fruit.

Viscosity can be defined as the degree of solidity and degree of density (Gould, 1974). It can also be defined as the measure of a fluid's internal friction, or the measurable resistance when one layer of fluid is made to move in relation to another. More precisely, it is the ratio of resistance to shear to rate of shear.

There is a very high correlation between alcohol-insoluble solids content of tomato fruit, the viscosity of their juice and their firmness (Stevens and Rick, 1986). The study of the genetics of viscosity differences between a low viscosity cultivar and two high viscosity cultivars indicates that relatively few (<3) genes are involved (Stevens, 1976). The heritability estimates were high (0.68 and 0.75) and genetic variance was mostly additive.

Schuch, Kanczler, Robertson, Hobson, Tucker, Grierson, Bright and Bird (1991) have analysed the quality and composition of transgenic tomato fruit modified by the expression of antisense RNA to polygalacturonase (PG). Among other things they found that the tomato juice made from the PG antisense fruit had significantly higher viscosity than the juice from the control fruit.

CHAPTER 3
MATERIALS AND METHODS

3.1 Experimental material

Six inbred tomato genotypes, *Lycopersicon esculentum* Mill. (2n=2x=24), were used as parental lines in a diallel (Method 2 of Griffings) analysis. Inbred lines p88/120, p88/140, p88/164, p88/179 and p88/192 were bred at the ARC-Roodeplaat Vegetable and Ornamental Plant Institute. The cultivar UC82B was bred in the USA by the University of California.

Breeding line p88/120 was selected from a cross between the cultivars Rotam 1 and Rotam 2 which was developed at the ARC-Roodeplaat. Rotam 2 was selected from a crossing between an imported line M79-430-2 and an ARC-Roodeplaat line E325 (this local line was used because it had resistance against Bacterial Wilt; *Pseudomonas solanacearum*). Rotam 1 was selected from a crossing between M79-430-2 and an ARC-Roodeplaat cultivar Rolong (Nematode resistant).

The inbred line p88/140 was the result of a cross between Peto 98 and an ARC-Roodeplaat line E614. Inbred line E614 was developed from a cross between UC 134 and ED02, which was the result of a cross between the cultivar Pearson and *Lycopersicon peruvianum*.

Inbred line p88/164 was selected from a cross between inbred line E615 and PETO 94. Inbred line E615 was developed from a cross between UC 134 and ED02.

Inbred line p88/179 was selected from a cross between the inbred line E615 and cultivar CX 8012 (Source: Campbell Institute for Agricultural Research).

Inbred line p88/192 was selected from a cross between line E618 and CX 8012. Line E618 was also selected from a cross between cultivar UC134 and line ED02.

3.2 Production of F_1 hybrids

Seeds of the six parents were planted on 5 May 1994 in 24 unit seedling trays filled with a commercial seedling mixture and placed in a heated glasshouse provided by the University of the Orange Free State. Seedling trays were watered twice daily and were fertilised once every week with Chemicult at the concentration recommended by the manufacturer.

After four weeks the seedlings were transplanted into 2 litre plastic pots. The pots were filled with a pre-sterilised commercial potting medium to reduce the possibility of soilborne diseases. A total of five plants from each parental line were used. The crossing block and entry numbers are given in Table 3.1. Plants were watered as required and fertilised weekly with Chemicult at the concentration recommended by the manufacturer.

Emasculation for the purpose of controlled-pollination was done one day prior to anthesis as recommended by Tigchelaar and Edward (1986) to avoid accidental self-pollination because the stigma become receptive 16 to 18 hours before anthesis and remained receptive up to 6 days after anthesis (Kalloo, 1991).

Table 3.1 The crossing block according to Griffing (1956a,b) model 2.

	UC82b	P88/120	P88/140	P88/164	P88/179	P88/192
UC82b	16[1]	3	2	5	6	4
P88/120		17	12	7	15	14
P88/140			18	10	1	11
P88/164				19	9	8
P88/179					20	13
P88/192						21

[1] Entry numbers

Pollen was transferred from the donor plant to the female by breaking up the anthers by rolling them between the fingers. The anther cone was then placed over the stigma and squeezed lightly in order to transfer the pollen. The fruit resulting from the pollination were harvested when fully matured (red ripe stage).

Seed extraction was done as recommended by Opeña and Chen (1993). Fruit of the different F_1 crosses was harvested and put into plastic bags. The fruit within each bag was crushed and a pectolytic enzyme was added to help in breaking down the sell walls. Natural fermentation continued for 24 hours after which the seed mucilage was broken down and the seed separated from their gelatinous coating. When fermentation was complete, water was added to the fermented mass and stirred. With stirring, the seed's crushed flesh, skin and jelly separate, float and then sink. The refuse was sieved out until the clean seeds were left at the bottom. Seeds were immediately dried after washing by placing the seed in the sun for two to three days. The dry seed was then stored in pre-marked envelopes.

3.3 Experimental method

The parental genotypes as well as their 15 F_1 hybrid combinations were planted in seedling trays filled with a sterilised seedling mixture. The seedlings were watered and fertilised as previously described.

The land was cultivated according to standard practices and fumigated with EDB (Ethylene dibromide) for the control of nematodes and weeds. After four weeks the seedlings were transplanted into a field at ARC-Roodeplaat according to a randomised complete block design with four replications. Each of the plots contained 20 plants planted in a single row. The plants were spaced 0.5m within rows that were 1.5 m apart. The plant density was 13 600 plants per hectare. Border rows were used in order to limit side effects. seedlings that died were replaced one week after the original planting date. This was done to ensure that there were 20 plants per plot.

The plots were fertilised according to a soil analysis and drip irrigated. Weeds were removed manually. Preventative spraying against pests and diseases was done on a weekly basis. The plots were harvested twice during the growing season. The first harvest was at 50 percent total fruit ripeness with the second harvest when most of the fruits were ripe. Processing tomatoes differ from fresh-market tomatoes in the sense that the tomatoes were harvested at the red ripe stage and not in the breaker stage. Fifteen fruits from each plot were randomly chosen for quality measurements.

3.4 Measurements

3.4.1 Yield characteristics

Total yield: Total yield is the mass in kilogram (kg) of marketable, unmarketable and green fruit harvested from a plot.

Marketable yield and unmarketable yield: Marketable yield is that mass of fruit with no physiological or other defects while unmarketable yield is the mass of fruit with physiological and other defects. Physiological defects include catface, growth cracks, sunscald and puffiness. Other defects refer to fruit that has been damaged by insects or birds. Marketable and unmarketable tomatoes were picked and weighed separately.

Green yield: Green yield is the mass in kilogram of all the unripe or green fruit harvested at the second (last) harvest.

Average fruit mass: Average fruit mass (g) was determined from 100 randomly selected fruit.

3.4.2 Soluble solid content (SSC)

Fifteen fruits were collected randomly, cut up and blended in a commercial food blender. This juice was then filtered using Whatman no. 4 filter paper. Soluble solid content was determined from the filtrate as % Brix using an ATAGO digital refractometer. This instrument automatically compensates for temperature based on the temperature detected on the side of the prism by a platinum resistance thermometer.

3.4.3 Fruit acidity (pH)

The pH of the tomato juice was measured with a Beckman pH-meter. A portion of the blended sample was used to measure fruit pH.

3.4.4 Fruit colour

Approximately twenty randomly chosen red ripe fruit of each entry and replication were flown to Cape Town to be evaluated in the quality laboratories of Langeberg Foods.

The hot break procedure was used for making pulp of all the samples as explained by Gould (1983). The raw tomatoes were washed, sorted, and trimmed to remove all visible defects. The tomatoes were then chopped and conveyed to a pre-heater, followed by cycloning in the hot-break procedure. In the hot-break procedure, the preliminary heating completely destroys the enzymes and protects the constituents of the tomato (especially pectin) from enzymatic change. The tomatoes were crushed with a minimum inclusion of air and quickly heated to 220°C. Concentration or evaporation was carried out in vacuum tanks made of stainless steel. At temperatures of 190°C or higher, it was then poured into cans, which were then sealed and sterilised. After cooling down the cans were opened and the pulp was used to determine the colour.

The colour parameters L, a_L , b_L , and T_P were determined by using the Hunterlab colorimeter. The Hunterlab colour and colour difference meter is a tristimulus colorimeter that measures colour on 3 scales by the use of 3 filters that approximate the X, Y, Z functions of the CIE system (Gould, 1974; Pomeranz and Meloan, 1994).

3.4.5 Fruit viscosity (consistency)

Viscosity of the parents and their F_1 hybrids were measured by using a GOSUC consistometer. Viscosity was measured by using a GOSUC consistometer (Fig. 3.1). The modified efflux tube viscometer was developed at the Ohio State University Food Processing and Technology Laboratory (Gould, 1983). It consists of a blown glass reservoir sloped into a 2 mm orifice on the efflux and a ¾-in. orifice at the top, which allows pouring the sample into the reservoir through a funnel. A piece of rubber tubing is attached to a metal plug with a 2 mm precision-bore orifice. This allows the flow to be stopped by a pinch clamp and the instrument to be accurately standardised by adjusting the length of the rubber tube. The instrument was standardised by filling it with water at room temperature and adjusting the metal plug to efflux 200 ml in 32 seconds. Viscosity measurement utilising the GOSUC consistometer is easily accomplished by timing with a stopwatch the efflux of tomato juice between two graduate marks. Results are recorded in second's (s) per 200ml tomato juice. Thus the longer the tomato juice takes to flow out of the consitometer the higher the viscosity and vices versa.

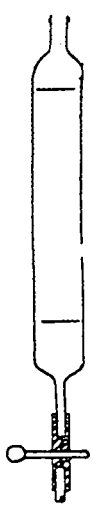

Fig. 3.1 GOSUC consistometer used in the determination of viscosity of tomato juice (Gould, 1983).

3.5 Statistical analysis

3.5.1 Analysis of variance (ANOVA)

All yield and quality parameters were analysed as a randomised block design with 21 treatments and four replications. The parameters being total, marketable, unmarketable and green yield as well as soluble solid content, pH, colour and viscosity. *Least Significant Difference* (LSD) was determined as described in Snedecor and Cochran (1972).

3.5.2 Correlation

Phenotypic correlation coefficients (Pearson r correlation) were calculated between yield and the different quality characteristics to determine if these parameters are correlated to each other. The correlation coefficients were calculated using the programme STATISTICA.

3.5.3 Diallel analysis

The diallel experimental method 2 ($\frac{p(p+1)}{2}$ combinations and inbred parents) of Griffing (1956a,b) and as further described by Snijders (1990), was used. In a fixed model analysis of data from single cross progeny in a diallel cross, the average performance of each progeny is broken into components relating to general combining ability (main effects) and to specific combining ability (interactions). The diallel analysis was calculated using GENSTATS 5.

3.5.4 Variance components and heritability

Variance ratios were calculated as descibed by Baker (1978) and Barten, Elkind, Scott, Vadavski and Kedar (1993). Narrow sense heritability was estimated using the method described by Falconer (1981), Wricke and Weber (1986) and Narain (1990).

3.5.5 Heterosis

The level of heterosis was determined for yield and related quality characteristics. Heterosis was determined for all F_1 hybrids as the superiority over the mid-parent and also over the better parent. In addition, the superiority over the best within that specific cross was also calculated. The levels of heterosis over the mid-parent or parental average, heterosis over the better parent and superiority over the best parent were calculated (Sarawat, Stoddard, Marshall, and Ali, 1994):

Heterosis over mid parent (Hmp) =

$$\frac{(F_1 - mp)}{mp} \times 100\%$$

Heterosis over better parent (Hbp) =

$$\frac{(F_1 - bp)}{bp} \times 100\%$$

Superiority over the best parent (Scm) =

$$\frac{(F_1 - cm)}{cm} \times 100\%$$

where F_1, mp, bp, and cm were the means for F_1 hybrids, mid-parent, better parent of each cross and the best parent of all crosses, respectively.

CHAPTER 4
RESULTS AND DISCUSSION

4. Analysis of variance

4.1 Yield characteristics

The analysis of variance for total yield and various yield components is given in Table 4.1. Significant differences were recorded between all the entries (genotypes) for total, marketable, unmarketable, green yield as well as for average fruit mass. No significant differences were recorded among the six parental inbred lines for total and marketable yield although significant differences were recorded for unmarketable and green yield as well as for average fruit mass. Significant differences were recorded among the 15 F_1 hybrids for total yield, marketable yield, unmarketable yield, green yield and average fruit mass. No significant difference was recorded for total yield and marketable yield between the parental lines.

4.1.1 Total yield

Total yield of the parental lines and their F_1 hybrids is given in Figure 4.1. The highest ranking F_1 hybrid was p14 (p88120 x p88/192) which yielded 71 $t.ha^{-1}$ with p12 (p88/120 x p88/140) ranked second with a total yield of 69.07 $t.ha^{-1}$. The lowest yielding genotype was parent line p16 (UC82b) with a total yield of 40.17 $t.ha^{-1}$. The highest yielding parent was line p17 (p88/120) with a total yield of 52.97 $t.ha^{-1}$. The average total yield of all the F_1 hybrids was 22.17 % higher than the average total yield of all the parent lines.

Hybrid p14 had a significantly ($LSD_{T(0.05)}$ = 15.31) higher total yield than p13, p9, p6, p5 and p3. There was no significant difference between the parental

lines regarding total yield. Parent line p17 has a significantly lower total yield than the hybrid lines p11, p12 and p14.

Table 4.1 Analysis of variance for genotypes, parents, and F_1 hybrids for total yield, marketable, unmarketable, green yield and average fruit mass.

Source	d.f	Sum of sqr	Mean sqr	F-distribution	p-level
Total yield					
Replications	3	421.30	140.43	1.20	ns.
Genotypes	20	6880.70	344.04	2.94	< 0.001
Parents	5	567.68	113.54	1.89	ns.
F_1 hybrids	14	6313.02	450.93	3.85	< 0.01
Residue	60	7029.50	117.16		
Total	83	1433.60			
Marketable yield					
Replications	3	425.70	141.90	1.29	ns.
Genotypes	20	5666.40	283.32	2.58	< 0.01
Parents	5	392.28	78.46	1.22	ns.
F_1 hybrids	14	5274.12	376.72	3.43	<0.01
Residue	60	6595.70	109.93		
Total	83	12687.80			
Unmarketable yield					
Replications	3	0.14	0.05	0.59	ns.
Genotypes	20	4.85	0.24	3.11	< 0.01
Parents	5	2.46	0.49	9.96	< 0.01
F_1 hybrids	14	2.39	0.17	2.13	0.05
Residue	60	4.68	0.08		
Total	83	9.66			
Green yield					
Replications	3	0.29	0.10	6.35	< 0.001
Genotypes	20	1.54	0.08	5.12	< 0.001
Parents	5	0.76	0.15	6.51	< 0.002
F_1 hybrids	14	0.78	0.06	3.00	< 0.01
Residue	60	0.90	0.02		
Total	83	2.73			
Average fruit mass					
Replications	3	1185.26	395.09	14.65	< 0.001
Genotypes	20	2949.28	147.46	5.47	< 0.001
Parents	5	1030.55	206.11	5.92	0.05
F_1 hybrids	14	1918.73	137.05	5.08	0.01
Residue	60	1617.95	26.97		
Total	83	5752.49			

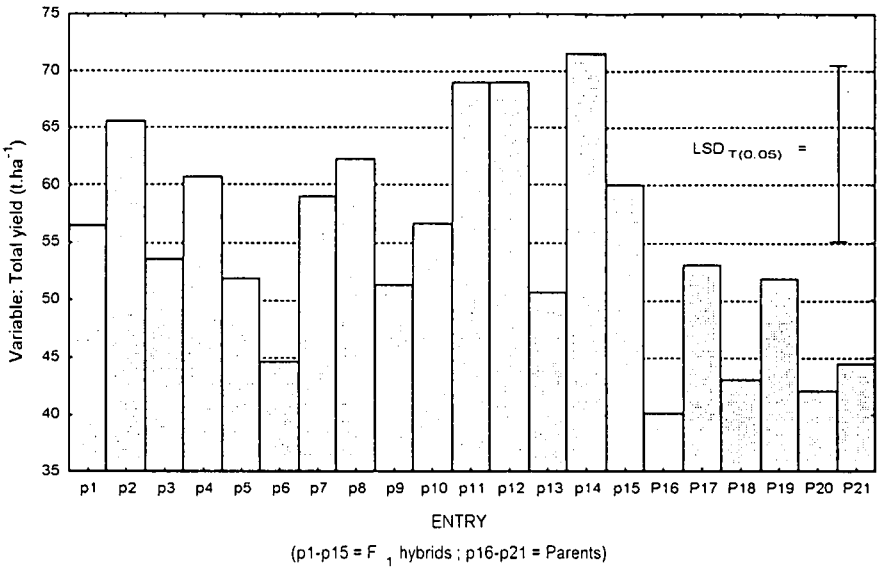

Fig. 4.1 Total yields of F_1 hybrids and their parents.

4.1.2 Marketable yield

Marketable yield for all parents and hybrids is given in Figure 4.2. The parental line p19 (p88/164) had the highest marketable yield of 39.89 t.ha^{-1}. The F_1 hybrid p11 (p88/140 x p88/192) was ranked first overall with a marketable yield of 57.79 t.ha^{-1} with the hybrid p14 (p88/120 x p88/192) in second place with a marketable yield of 57.08 t.ha^{-1}. Both these hybrids performed significantly ($LSD_{T(0.05)}$ = 14.83) better than all the parental lines (p16-p21) and better than the hybrids p3, p5, p6, p9 and p13. The hybrid line p6 (UC82b x p88/179) ranked last between the other hybrids with a marketable yield of only 29.68 t.ha^{-1}. The average marketable yield of all the F_1 hybrids is 24.64% higher than the average marketable yield of all the parental lines.

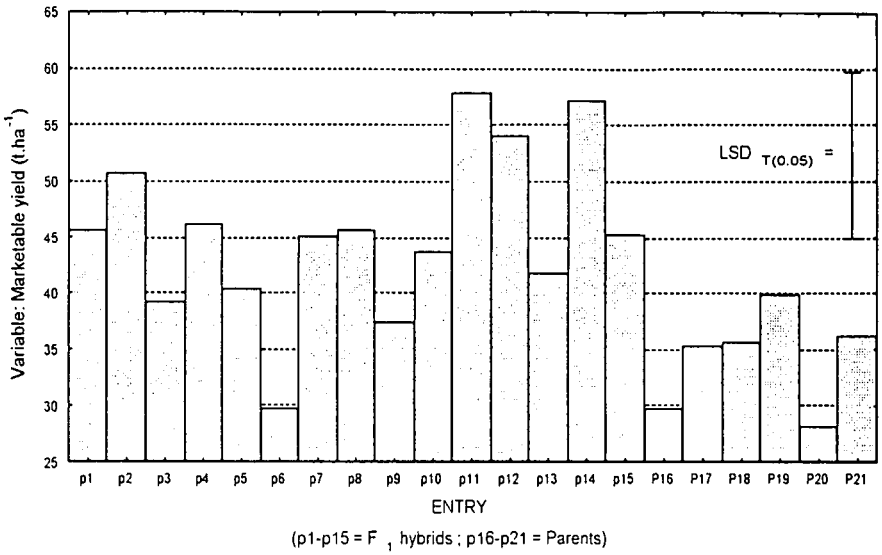

Fig. 4.2 Marketable yields of F_1 hybrids and their parents.

4.1.3 Unmarketable yield

Unmarketable yield for both the parental lines and their F_1 is given in Figure 4.3. Parental line p18 (p88/140) had the lowest unmarketable yield of 7.48 $t.ha^{-1}$ of all the parental and F_1 hybrid entries with the parental line p21 (p88/192) in the second place with an unmarketable yield of 8.12 $t.ha^{-1}$. The best F_1 hybrid was p13 (p88/179 x p88/192) with an unmarketable yield of 8.82 $t.ha^{-1}$. The parental line p17 (p88/120) had the highest unmarketable yield of 17.55 $t.ha^{-1}$ of all the genotypes with hybrid line p8 (p88/164 x p88/192) in second place with an unmarketable yield of 16.83 $t.ha^{-1}$.

The parental line p18 and p21 has significantly lower ($LSD_{T(0.05)}$ = 0.39) unmarketable yields than parental lines p12 and p20 as well as most of the F_1 hybrid lines (excluding p1, p5, p11 and p13). The first ranking hybrid line p13 had significant lower unmarketable yields than most other hybrid lines

(excluding line p1, p4, p5, p10, p11 and p13). The average of the parental lines was 13.16 % better than the average unmarketable yield of all the F_1 hybrids.

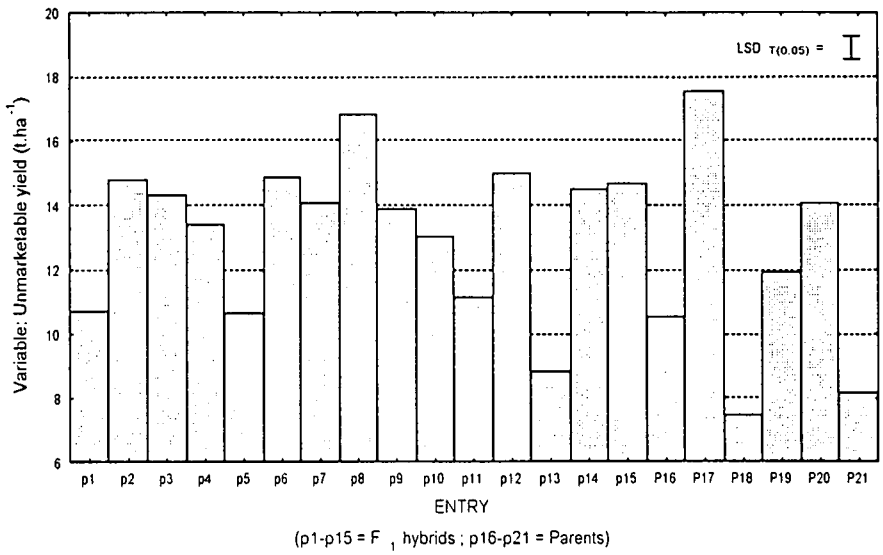

Fig. 4.3 Unmarketable yields of F_1 hybrids and their parents.

4.1.4 Green yield

The green yield of both the parent lines and their F_1 hybrids is given in Figure 4.4. Parental line p19 (p88/164) was ranked first with the lowest green yield (0.93 $t.ha^{-1}$) of all the tested genotypes. The lowest green yield between all the hybrids was recorded for p5 (UC82b x p88/164) with a green yield of 1.18 $t.ha^{-1}$. The highest green yield was recorded from parental line p21 (p88/192) yielding 10.69 $t.ha^{-1}$ green fruit. Parental line p18 (p88/140) was ranked second highest with 8.47 $t.ha^{-1}$. The highest yielding hybrid line was p1 (p88/140 x p88/179) with 7.94 $t.ha^{-1}$.

Parental line p19 was significantly lower ($LSD_{T(0.05)} = 0.17$) in green yield than parental lines p18 and p21 and significantly lower than hybrid lines P1, p10,

p11 and p13. The parental line p21 has significant higher green yield that most of the genotypes (excluding line p1, p18 and p21). The average green yield for all the parental lines were 33.88 % higher than the average for all the hybrid lines.

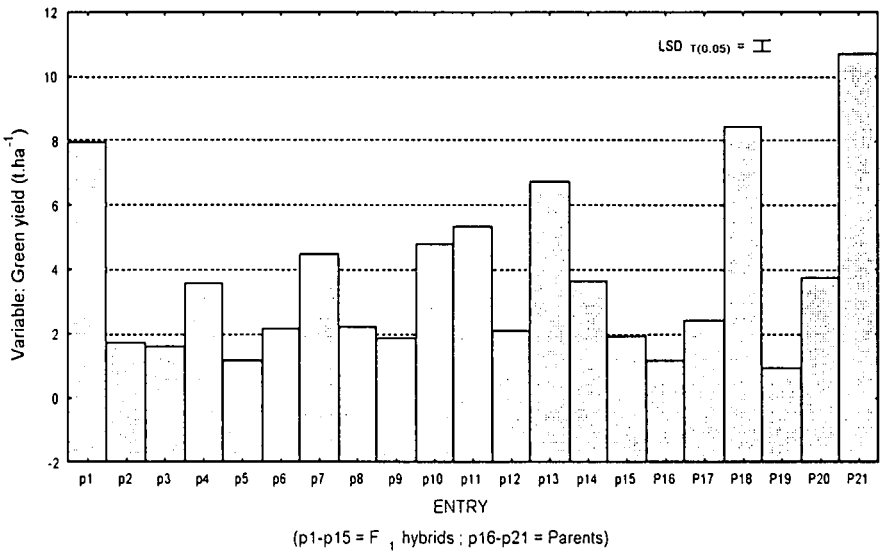

Fig. 4.4 Average green yield of F_1 hybrids and their parents.

4.1.5 Average fruit mass

The average fruit mass of both the parental and F_1 hybrid lines is given in Figure 4.5. Hybrid p12 (p88/120 x p88/120) had the highest average fruit mass of 80.18g with p15 (p88/120 x p88/179) in second place. Entry p12 was also one of the top ranking entries regarding total and marketable yield (see Fig. 4.1 and Fig 4.2). The highest average fruit mass between the parent lines was recorded for p18 (p88/140) an average fruit mass of 79.10g. Parent line p16 (UC82b) had the lowest average fruit mass of 59.25g.

The parental line p18 had a significant ($LSD_{T(0.05)}$ = 7.34) higher average fruit mass than parental lines p16, p19 and p20 as well as significantly higher than the hybrid lines P2, P4, P5, p8 and p14. The average fruit mass of all the hybrid lines was 2.65% higher than the average fruit mass of all the parental lines.

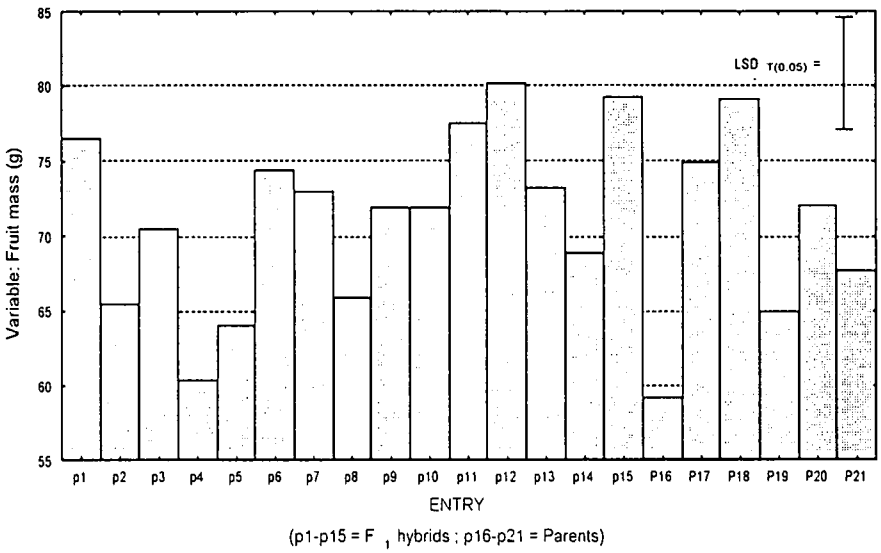

Fig. 4.5 Average fruit mass of F_1 hybrids and their parents.

4.2 Quality characteristics

Analysis of variance for fruit quality characteristics is given in Table 4.2. Significant differences were recorded between the genotypes for soluble solid content, fruit pH and colour but no significant differences was recorded for viscosity. Fruit pH was the only quality characteristic that shows a significant difference between the parental lines. Significant differences among the 15 F_1 hybrids were recorded for soluble solid content and fruit pH.

Table 4.2 Analysis of variance for genotypes, parents, and F_1 hybrids for soluble solid content, fruit pH, fruit colour and fruit viscosity.

Source	df	Sum of sqr	Mean sqr	F-distribution	p-level
Soluble solid content					
Replications	3	0.06	0.02	0.24	Ns.
Genotypes	20	4.19	0.21	2.80	< 0.001
Parents	5	0.95	0.19	2.53	ns.
F_1 hybrids	14	3.24	0.23	2.89	< 0.05
Residue	60	4.49	0.08		
Total	83	8.74			
Fruit pH					
Replications	3	0.02	0.01	3.99	< 0.05
Genotypes	20	0.07	0.00	2.88	< 0.001
Parents	5	0.04	0.01	9.29	< 0.001
F_1 hybrids	14	0.03	0.00	1.72	<0.001
Residue	60	0.08	0.00		
Total	83	0.17			
Fruit colour					
Replications	3	0.12	0.04	1.77	ns.
Genotypes	20	0.78	0.04	1.77	< 0.05
Parents	5	0.32	0.06	2.17	ns.
F_1 hybrids	14	0.44	0.03	1.57	Ns.
Residue	60	1.32	0.02		
Total	83				
Fruit viscosity					
Replications	3	1.21	0.40	5.89	< 0.001
Genotypes	20	1.36	0.07	1.00	ns.
Parents	5	0.11	0.02	0.73	Ns.
F_1 hybrids	14	0.44	0.03	0.45	Ns.
Residue	60	4.11	0.07		
Total	83	6.68			

4.2.1 Soluble solid content

The soluble solid content of the various parental lines is given in Figure 4.6. The parental line p17 (p88/120) had the highest soluble solid content of 4.23 % of all the genotypes evaluated. Second highest soluble solid content of 4.05 % was recorded for F_1 hybrid line p14 (p88/120 x p88/192). The lowest soluble solid content of 3.28 % was recorded for F_1 hybrid line p8 (p88164 x p88/192).

Parental line p17 differed significantly ($LSD_{T(0.05)}$ = 0.4) from most genotypes except from parental lines p17, p20 and p21 as well as F_1 hybrid lines p10, p13

and p14. The average soluble solid content of all the parent lines were 6.22% higher than the average soluble solid content of all the F_1 hybrids.

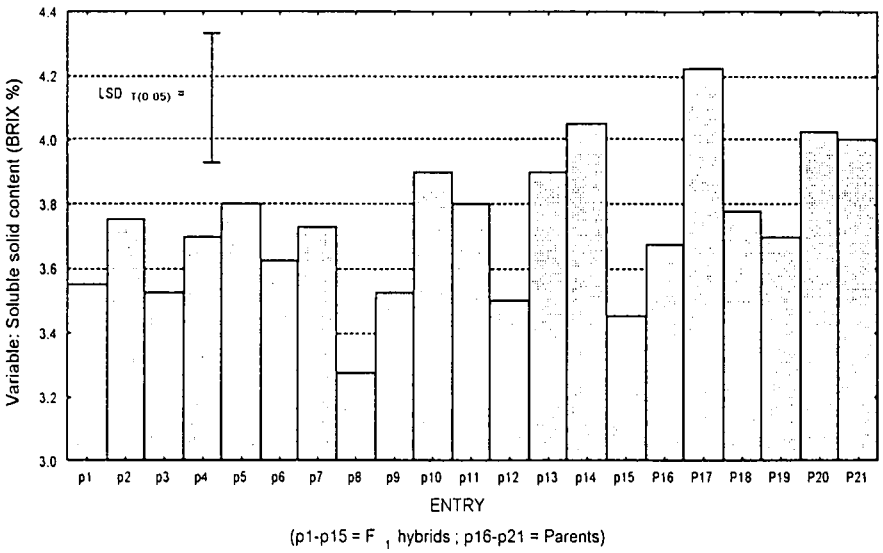

Fig. 4.6 Average soluble solid content of F_1 hybrids and their parents.

4.2.2 Fruit pH

The pH levels for all the genotypes ranged from 4.10 to approximately 4.25 (Fig. 4.7). The lowest pH levels were recorded for the parent lines p16 (UC82b), p18 (p88/140) and p19 (p88/164) with p8 (p88164 x p88/192) having the lowest pH level of all the F_1 hybrids.

The F_1 hybrid line p8 and the parental lines p16, p18 and p19 differed significantly ($LSD_{T(0.05)}$ = 0.05) from lines p1, p3, p7, p12, p13, p17, p20 and p21. The average pH value of all the parent lines was 0.08 % lower than the average pH value of all the F_1 hybrids.

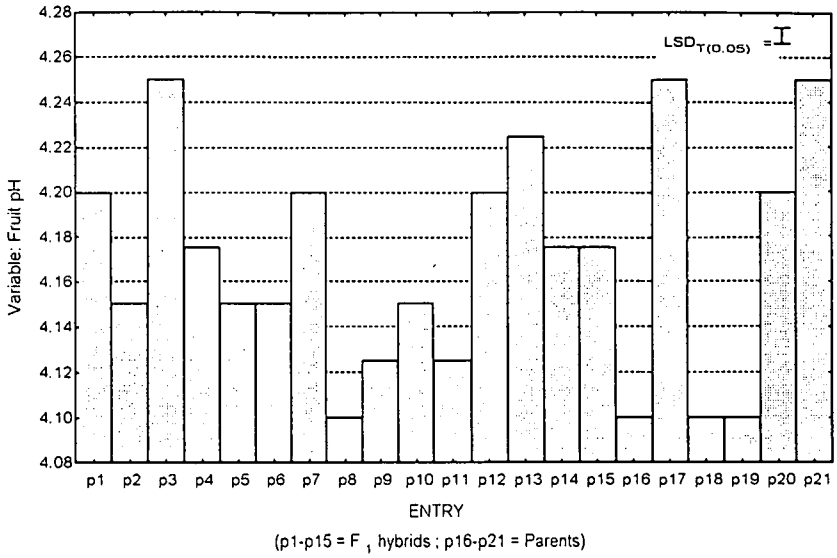

Fig. 4.7 Average fruit pH of F_1 hybrids and their parents.

4.2.3 Fruit colour

Differences regarding fruit colour between the various parents and their F_1 hybrids are given in Figure 4.8. Overall there was not much difference between the genotypes regarding fruit colour. The highest fruit colour was recorded for parental line p21 (p88/192) with a $L_{a/b}$ value of 2.19 with the hybrid p13 (p88/179 x p88/192) in second place with a $L_{a/b}$ value of 2.17. The hybrid p10 and parental line p16 with La/b values of 1.85 and 1.87 had the lowest value for fruit colour, respectively.

The parental line p21 differed significantly ($LSD_{T(0.05)}$=0.2) from the parental lines p16, p17 and p19 as well as significantly from the hybrid lines p6, p9 and p10. The average fruit colour of all the F_1 hybrids was only 0.96 % higher than the average fruit colour of all the parental lines.

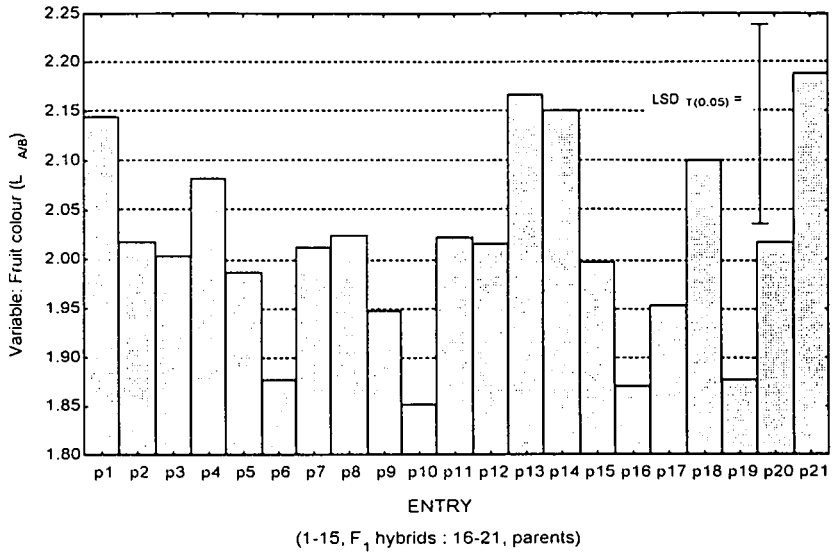

Fig. 4.8 Average fruit colour of F_1 hybrids and their parents.

4.2.4 Fruit viscosity

Fruit viscosity for the various parental and F_1 hybrids are given in Figure 4.9. The hybrid line p6 had the best viscosity of 4.43 seconds with the hybrid lines p9 and p13 in second place with a viscosity of 4.50 seconds. The best parent line was p21 with a viscosity of 4.53 seconds.

The line p6 had a significantly ($LSD_{T(0.05)}$=0.37) better viscosity than line p8, p11 and p14. There was no significant difference between all the parental lines for viscosity. The average fruit viscosity of all the parental lines was only 0.77% better than that of their F_1 hybrids.

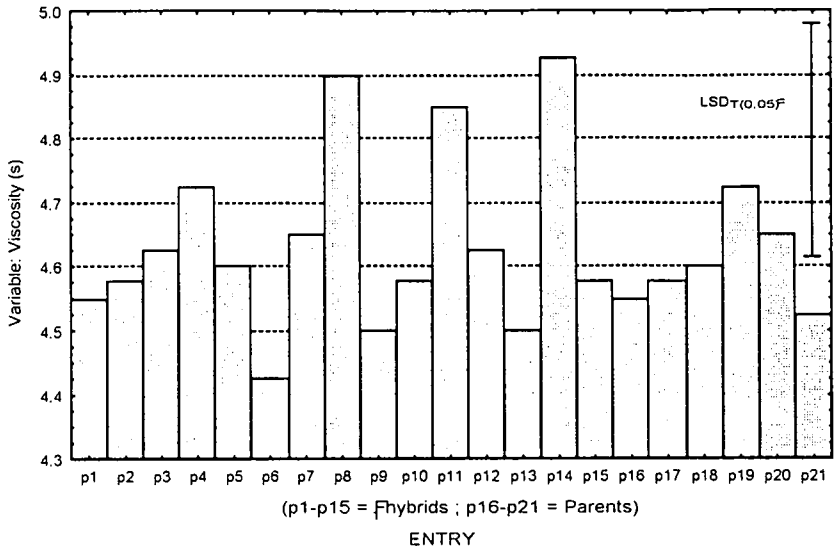

Fig. 4.9 Average fruit viscosity of F_1 hybrids and their parents.

Summary

The parental lines showed significant differences for the yield components unmarketable yield, green yield and average fruit mass and a significant difference for fruit pH. The F_1 hybrid lines show significant differences for total yield, marketable yield, unmarketable yield, green yield and for average fruit mass. Regarding the quality characteristics, the F_1 hybrids showed significant differences for soluble solid content and fruit pH.

4.3 Correlations between yield and fruit quality characteristics.

The phenotypic correlation coefficients were used to study the relationships between yield and quality characteristics. The correlation coefficients are shown in Table 4.3.

Total yield and marketable yield were significantly correlated (r=0.95) indicating that a breeder can select on the basis of marketable yield for total yield. Significant correlations were found for unmarketable yield and total yield

(r=0.3), fruit pH and marketable yield (r=-0.2), unmarketable yield and green yield (r=-0.37), green yield and average fruit mass (r=0.41) and between green yield and fruit colour (r=0.45). The magnitude of these correlations is so low that it will have little impact on a breeding and selection program.

Overall the no correlation of considerable interest to the plant breeder with regards to the tested yield and quality characteristics.

Table 4.3 Correlation coefficient between all variables (yield and fruit characteristics)

	Total Yield	Marketable yield	Unmarketable Yield	Green Yield	Fruit mass	Fruit pH	Soluble solid content	Colour	Viscosity
Total yield	1	0.9545 **	0.3263 *	-0.0157 ns	0.1057 ns	-0.1890 ns	-0.1096 ns	0.1052 ns	0.1090 ns
Marketable yield	0.9545 **	1	0.0351 ns	0.0989 ns	0.0897 ns	-0.2281 *	-0.1093 ns	0.1768 ns	0.0670 ns
Unmarketable yield	0.3263 *	0.0351 ns	1	-0.3646 *	0.0874 ns	0.0966 ns	-0.0391 *	-0.2088 ns	0.1441 ns
Green yield	-0.0157 ns	0.0989 ns	-0.3646 *	1	0.4051 *	0.0692 ns	0.1512 ns	0.4498 *	-0.0162 ns
Fruit mass	0.1057 ns	0.0897 ns	0.0874 ns	0.4051 *	1	0.1113 ns	-0.0747 ns	0.1244 ns	0.0169 ns
Fruit pH	-0.1890 ns	-0.2281 *	0.0966 ns	0.0692 ns	0.1113 ns	1	0.1477 ns	0.1625 ns	-0.0643 ns
Soluble solid content	-0.1096 ns	-0.1093 ns	-0.0391 *	0.1512 ns	-0.0747 ns	0.1477 ns	1	0.1798 ns	0.1045 ns
Colour	0.1052 ns	0.1768 ns	-0.2088 ns	0.4498 *	0.1244 ns	0.1625 ns	0.1798 ns	1	0.1789 ns
Viscosity	0.1090 ns	0.0670 ns	0.1441 ns	-0.0162 ns	0.0169 ns	-0.0643 ns	0.1045 ns	0.1789 ns	1

ns, *, **: non-significant, significant at levels 0.05 and 0.01.

4.4 Combining ability and heritability

4.4.1 Analysis of variance

Mean squares for general combining ability (GCA) and specific combining ability (SCA) are given in Table 4.4 for all the yield characteristics and table 4.5 for all the quality characteristics. Mean squares for all the yield characteristics show a significant difference for GCA. The SCA for the various yield component differ significantly except for the SCA of fruit mass, which show no significant difference.

Table 4.4 Mean squares for general combining ability and specific combining ability for yield characteristics.

Source	Total yield	Marketable yield	Unmarketable yield	Green yield	Fruit mass
GCA	101.4078 **	103.3703 **	12.7071 **	19.5033 **	119.1281 **
SCA	80.8769 **	59.9830 *	5.6630 **	3.3113 **	1.4010 ^{ns}
Error	29.2897	27.4820	0.0159	0.0038	6.7414

$^{ns, *, **}$ non-significant, significant at levels 0.05 and 0.01.

Significant differences were recorded for the mean squares of SCA for soluble solid content, SCA and GCA for fruit pH, and GCA for fruit colour (Table 4.5). Soluble solid content and fruit viscosity show no significant differences regarding GCA. The SCA show no significant difference for fruit colour and fruit viscosity.

Table 4.5 Mean squares for general combining ability and specific combining ability for quality characteristics.

Source	Soluble solid content	Fruit pH	Fruit colour	Fruit viscosity
GCA	0.0270 ^{ns}	0.0057 **	0.0244 **	0.0207 ^{ns}
SCA	0.0608 **	0.0015 **	0.0049 ^{ns}	0.0158 ^{ns}
Error	0.0187	0.0003	0.0055	0.0171

$^{ns, *, **}$ non-significant, significant at levels 0.05 and 0.01.

4.4.2 General combining ability

There were significant differences between the GCA's of line p88/120 and p88/179 for total yield. The GCA's of line p88/140 and p88/179 differ significantly for marketable yield (Table 4.6). Line p88/120 were significantly better than p88/140, p88/179, p88/192 and UC82b for unmarketable yield. Significant differences in GCA between all the lines were found for green yield. Lines p88/164, p88/192 and UC82b was significantly lower in fruit mass than lines p88/120, p88/140 and p88/179.

The three parental lines with the best GCA for total yield are respectively p88/120 (4.2131), p88/192 (2.1706) and p88/140 (2.1559). These lines were also the best three lines regarding marketable yield. The GCA's of the rest of the parental lines were negative for total yield. Lines p88/120, p88/164 and p88/179 had the highest GCA's for unmarketable yield with lines p88/140, p88/179 and p88/192 having the highest GCA's for green yield. The lines p88/120, p88/140 and p88/179 recorded the highest GCA for fruit mass.

Table 4.6 General combining ability effects for yield characteristics.

	Total Yield	Marketable yield	Unmarketable yield	Green yield	Fruit mass
P88/120	4.2131	2.0728	2.1918	-0.9520	3.0833
P88/140	2.1559	3.5594	-1.3157	1.5796	4.1208
P88/164	-0.1044	-0.3538	0.2761	-1.2298	-2.5510
P88/179	-4.8013	-4.8428	0.1177	0.2298	2.7802
P88/192	2.1706	3.2441	-1.1401	2.0774	-1.9698
UC82B	-3.6341	-3.6797	-0.1298	-1.7051	-5.4635
$LSD_{T(0.05)}$	7.65	7.41	0.20	0.09	3.67

There was no significant difference between the parental lines for soluble solid content and fruit viscosity (Table 4.7). The GCA of the parental line p88/120 differs significantly from parental line p88/140, p88/164 and UC82b. Parental line p88/192 differ significantly from p88/164 and p88/140 and the GCA of line p88/179 is significantly higher than p88/164. The parental lines with the best overall GCA for quality characteristics are p88/120 and p88/192 and UC82B is the parental line with the worst GCA for quality.

Table 4.7 General combining ability effects for quality characteristics.

	Soluble solid content	Fruit pH	Fruit colour	Fruit viscosity
P88/120	0.0677	0.0396	-0.0025	0.0177
P88/140	-0.0135	-0.0198	0.0188	-0.0042
P88/164	-0.0667	-0.0323	-0.0653	0.0333
P88/179	-0.0073	0.0115	0.0084	-0.0698
P88/192	0.0708	0.0146	0.0900	0.0677
UC82B	-0.0510	-0.0135	-0.0494	-0.0448
$LSD_{T(0.05)}$	0.19	0.03	0.12	0.19

4.3.3 Specific combining ability

Estimates of specific combining ability (SCA) for yield and quality characteristics are given in Table 4.8 and Table 4.9 respectively. The SCA values varied to a great extend for the yield and quality characteristics, although no pattern of variation was evident.

Out of the 135 values, 74 were positive (55%). Approximately 61% of all the SCA values of the yield characteristics were positive in comparison to the only 46% positive values recorded for the quality SCA values. The positive SCA values between the crosses for the yield characteristics were mostly higher than

for the quality characteristics. The cross between p88/164 and UC82B resulted in 7 positive SCA values, which is the best specific combination. It was only unmarketable yield and fruit viscosity that was negative. For total yield it had a value significantly higher than for the cross p88/120 x p88/192, p88/140 x UC82B and p88/140 x p88/192. For marketable yield there was no significant differences recorded and for unmarketable yield it had a value significantly higher than all other hybrids. It also had a SCA effect for green yield significantly higher than that of p88/120 x p88/140, p88/120 x p88/164, p88/120 x UC82B, p88/140 x p88/164, p88/140 x p88/179 and p88/179 x p88/192.

Table 4.8 Estimates of specific combining ability effects for yield characteristics.

Cross	Total Yield	Marketable yield	Unmarketable yield	Green yield	Fruit mass
p88/120 x p88/140	7.6284	6.2964	1.2388	-2.2652	1.9768
p88/120 x p88/164	-0.1063	1.2095	-1.3005	2.9342	1.4237
p88/120 x p88/179	5.5306	6.0111	-0.5146	-1.0880	2.3924
p88/120 x p88/192	10.1362	9.6592	0.5857	-1.2655	-3.1576
p88/120 x UC82B	-2.1416	-1.3720	-0.5971	0.5070	1.7862
p88/140 x p88/164	-0.5666	-1.6020	1.1820	0.7126	-0.6138
p88/140 x p88/179	3.9903	4.8095	-0.9571	2.3829	-1.3451
p88/140 x p88/192	9.5209	8.8851	0.7082	-2.0646	4.4049
p88/140 x UC82B	11.9506	8.7714	3.3604	-1.8871	-4.1513
p88/164 x p88/179	1.1756	0.5476	0.6410	-0.9252	0.6768
p88/164 x p88/192	5.1937	0.5858	4.8163	-2.3577	-0.6232
p88/164 x UC82B	0.4209	2.2670	-2.3540	0.3623	1.1205
p88/179 x p88/192	-1.8844	1.2373	-3.0377	0.6601	1.3455
p88/179 x UC82B	-2.0972	-3.8989	1.9945	-0.1249	6.0393
p88/192 x UC82B	7.1159	4.4067	1.7823	-0.5424	-3.1607
$LSD_{0.05}$	7.65	7.41	0.18	0.09	3.67

For fruit mass it had a value significantly higher than for the cross p88/120 x p88/192, p88/140 x UC82B, p88/179 x UC82B and p88/192 x UC82B. Regarding soluble solid content and fruit pH it had a value significantly better than all the crosses with a negative SCA value while for fruit colour it had a value significantly better than p88/140 x p88/164, p88/140 x p88/192 and p88/179 x UC82B. For fruit viscosity it had a value significantly better than that of p88/120 x p88/192. It is clear that the cross between p88/162 and UC82B had the best SCA values.

Table 4.9 Estimates of specific combining ability effects for quality characteristics.

Cross	Soluble solid content	Fruit pH	Fruit colour	Fruit viscosity
P88/120 x p88/140	-0.2911	0.0112	-0.0159	-0.0183
P88/120 x p88/164	-0.0129	0.0237	0.0657	-0.0308
P88/120 x p88/179	-0.3473	-0.0451	-0.0231	-0.0027
P88/120 x p88/192	0.1746	-0.0482	0.0479	0.2097
P88/120 x UC82B	-0.2286	0.0549	0.0397	0.0223
P88/140 x p88/164	0.2433	0.0330	-0.1156	-0.0839
P88/140 x p88/179	-0.1661	0.0393	0.1032	-0.0058
P88/140 x p88/192	0.0058	-0.0388	-0.1009	0.1567
P88/140 x UC82B	0.0777	0.0143	0.0335	-0.0058
P88/164 x p88/179	-0.1379	-0.0232	-0.0103	-0.0933
P88/164 x p88/192	-0.4661	-0.0513	-0.0143	0.1692
P88/164 x UC82B	0.1808	0.0268	0.0875	-0.0183
P88/179 x p88/192	0.0996	0.0299	0.0544	-0.1277
P88/179 x UC82B	-0.0536	-0.0170	-0.0962	-0.0902
P88/192 x UC82B	-0.0567	0.0049	0.0272	0.0723
$LSD_{0.05}$	0.19	0.03	0.12	0.19

The crosses p88/120 x p88/192, p88/140 x p88/192, p88/140 x UC82B, p88/179 x p88/192 and p88/192 x UC82B all had 6 positive SCA values out of the possible 9 characteristics. The hybrid p88/120 x p88/192 was ranked first

regarding marketable yield and soluble solid content but not significantly better than the other crosses. This hybrid was also ranked first for fruit viscosity and was significantly better than the cross p88/179 x p88/192.

4.4.4 GCA : SCA ratio

The ratios of GCA and SCA were calculated and are given in Table 4.10. The ratio between GCA and SCA would reveal the nature of genetic variance. The characteristics total yield, marketable yield, soluble solid content and fruit viscosity have a GCA : SCA ratio of nearly 1 and indicate that the relations between additive and dominant genes are equally important with respect to the inheritance of these characteristics.

The ratios were positive for both yield and quality characteristics and vary between 0.44:1 for soluble solid content to 85.03:1 for average fruit mass. Average fruit mass and green yield had the highest GCA : SCA ratio, which indicate that additive genes are involved. It is thus fairly easy to select for fruit mass in a pedigree breeding program but much more difficult for the other yield and quality characteristics.

Table 4.10 The ratio between the mean squares of general combining ability and specific combining ability.

Parameters	GCA : SCA ratio
Total yield	1.2539 : 1
Marketable yield	1.7233 : 1
Unmarketable yield	2.2439 : 1
Green yield	5.8899 : 1
Average fruit mass	85.0308 : 1
Soluble solid content	0.4441 : 1
Fruit pH	3.8000 : 1
Fruit colour	4.9796 : 1
Fruit viscosity	1.3101 : 1

4.3.5 Variance components and heritability

The relative importance of parental GCA effects in predicting hybrid performance was evaluated using the variance ratio $2\sigma^2_{GCA} / (2\sigma^2_{GCA} + \sigma^2_{SCA})$ as described by Baker (1978) and Barten *et al.* (1993). The variance components for all the yield characters (Table 4.11) and for fruit viscosity (Table 4.12) were very low, indicating that hybrid performance could not only be predicted by using the GCA but SCA as well.

Narrow sense heritability (H^2_n) was determined and given in Tabel 4.11. Narrow sense heritability was low for unmarketable yield (23.72%) but high for green yield (55.01%) and average fruit mass (74.38%). Total and marketable yield has low heritabilities of 5.97% and 15.31% respectively. The breeder can either select against unmarketable and green yield. To reduce the unmarketable yield he can select for larger fruited genotypes.

Table 4.11 Estimated variance components for yield characteristics.

Variance components	Total Yield	Marketable yield	Unmarketable yield	Green yield	Fruit mass
σ^2_{GCA}	2.5664	5.4234	0.8805	2.0241	13.7104
σ^2_{SCA}	51.5872	32.5011	5.6435	3.3076	2.7034
σ^2_E	29.2897	27.4820	0.0195	0.0038	6.7414
$\sigma^2_G = 2\sigma^2_{GCA} + \sigma^2_{SCA}$	56.7200	43.3479	7.4045	7.3558	30.1242
$2\sigma^2_{GCA} / \sigma^2_G$	0.0905	0.2502	0.2378	0.5503	0.9103
$\sigma^2_P = \sigma^2_G + \sigma^2_E$	86.0096	70.8299	7.4240	7.3596	36.8656
$\sigma^2_A = 2\sigma^2_{GCA}$	5.1328	10.8468	1.7610	4.0482	27.4208
$H^2_n = (\sigma^2_A / \sigma^2_P) \times 100\ \%$	5.9677	15.3139	23.7204	55.0057	74.3805

Soluble solid content has a negative heritability (-16.15%) due to negative variance components (Table 4.12). The heritability of fruit pH and fruit colour

was 29.16% and 50.04% respectively and both these traits could be improved through selection in a pedigree breeding program. Fruit viscosity has a low heritability of only 7.08%.

Table 4.12 Estimated variance components for fruit quality characteristics.

Variance components	Soluble solid content	Fruit pH	Fruit colour	Fruit viscosity
σ^2_{GCA}	-0.0042	0.0005	0.0024	0.0006
σ^2_{SCA}	0.0421	0.0012	-0.0006	-0.0013
σ^2_E	0.0187	0.0013	0.0055	0.0171
$\sigma^2_G = 2\sigma^2_{GCA} + \sigma^2_{SCA}$	0.0336	0.0022	0.0042	-0.0001
$2\sigma^2_{GCA} / \sigma^2_G$	-0.2493	0.4545	1.1429	-12.0000
$\sigma^2_P = \sigma^2_G + \sigma^2_E$	0.0523	0.0035	0.0097	0.0170
$\sigma^2_A = 2\sigma^2_{GCA}$	-0.0084	0.0010	0.0049	0.0012
$H^2_n = (\sigma^2_A / \sigma^2_P) \times 100$ %	-16.1520	29.1608	50.0411	7.0783

4.5 Heterosis

Heterosis was evident in all characteristics (Table 4.13). The average level of heterosis over the mid-parent (Hmp) was positive for all the characteristics except for soluble solid content (-5.46%). Total yield, marketable yield and unmarketable yield had the highest heterosis over mid-parent. Heterosis over the best parent was negative for fruit mass (-4.00%), soluble solid content (-7.65%) and fruit colour (-3.45%) but positive for total yield (21.58%), marketable yield (24.24%), unmarketable yield (11.84%), fruit pH (1.22%) and for fruit viscosity (1.70%). Average superiority over the best parent (Scm) was negative for unmarketable yield (-25.49%), fruit mass (-10.44%), soluble solid content (-13.61%), and fruit colour (-8.67%). Non of the 15 crosses showed high levels of heterosis for most of the characters measured.

Table 4.13 Mean and range of heterosis of the F_1 hybrids over the mid-parent value (Hmp), heterosis over the better parent (Hbp) and superiority over the best parent (Scm).

Character	Hmp (%)			Hbp (%)			Scm (%)		
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Total yield	30.04	8.25	57.55	21.58	-0.89	55.33	11.44	-15.92	35.15
Marketable yield	33.75	2.86	61.56	24.24	-6.12	59.64	14.17	-25.60	44.87
Unmarketable yield	20.68	67.38	-36.58	11.84	-37.30	77.60	-25.49	-49.80	-4.10
Fruit mass	2.69	60.40	80.18	-4.00	-17.19	5.74	-10.44	-23.64	1.36
Fruit pH	0.17	-1.80	1.80	1.22	-1.76	3.66	1.79	0.00	3.66
Soluble solid content	-5.46	-16.36	4.35	-7.65	-18.34	3.31	-13.61	-22.49	-4.14
Fruit colour	0.55	-6.85	5.09	-3.45	-11.79	5.86	-8.67	-15.31	-0.91
Viscosity	0.67	-4.00	8.24	1.70	-3.23	8.84	2.62	-2.21	8.84

The characteristics total yield, marketable yield, fruit pH and viscosity had positive mean heterosis values over the mid-parent, better parent and best parent. Soluble solid content has a negative mean heterosis value over the mid-parent, better parent and best parent.

CHAPTER 5
SUMMARY

1. The main objective of this study was to determine the combining ability of several tomato genotypes, the heritability of various yield and quality characteristics and the expression of heterosis in the F_1 hybrids.

2. Six inbred tomato genotypes were used as parental lines in the diallel cross. Crosses were made in glasshouses at the University of the Orange Free State. The F_1 hybrids and their parental lines were planted at the ARC - Roodeplaat Vegetable and Ornamental Plant Institute. Various yield and quality characteristics were analysed.

3. Significant differences among the six parental lines were recorded for total yield, marketable yield, green yield and average fruit mass. The 15 F_1 hybrids showed significant differences for total yield, marketable yield, unmarketable yield, green yield and average fruit mass.

4. Significant genetic variation among the six parental genotypes was recorded for fruit pH. The 15 F_1 hybrids show no significant differences for soluble solid content and fruit pH.

5. A significant positive phenotypic correlation (r=0.95) was found between total yield and marketable yield.

6. Inbred line p88/120 was the best general combiner for most of the yield characteristics while p88/120 and p88/192 is the best general combiners for most of the quality characteristics.

7. Crosses p88/140 x UC82B, P88/120 x p88/192 and p88/140 x p88/192 were the best specific combiners for total and marketable yield. The best specific combination was the cross between p88/164 and UC82B, which had 7 positive SCA values.

8. A GCA:SCA ratio of 85:1 was recorded for average fruit mass indicating that additive genes are involved.

9. Narrow sense heritability were relatively high for average fruit mass (H^2_n= 74.38%), green yield (H^2_n=55.01%) and fruit colour (H^2_n= 50.04%). The breeder can select effectively for larger fruited genotypes as well as selecting against green yield to increase the total yield.

10. The average level of heterosis over the best parent exceeds 10% for total and marketable yield between all the F_1 hybrids. Heterosis of the F_1 hybrids over mid-parent value (Hmp), heterosis over the better parent (Hbp) and superiority over the best parent (Scm) was mostly negative for all the quality characteristics.

HOOFSTUK 5
OPSOMMING

1. Die doel van hierdie studie was om die kombineervermoeë van verskeie kultivars, die oorerflikhede van verskeie opbrengs en kwaliteit karakteristieke en die uidrukking van heterose in die F_1 basters te bepaal.

2. Ses ingeteelde tamatie genotiepes was gebruik as die ouer lyne in 'n dialeel kruising. Kruisings was gemaak in glashuise by die Universiteit van die Oranje Vrystaat. Die F_1 basters en hul ouer lyne is uitgeplant by die Instituut vir Groente en Sierplante (LNR-Roodeplaat). Verskeie opbrengs en kwaliteits karakteristieke is bepaal.

3. Betekenisvolle verskille was gekry tussen die ses ouer lyne vir totale opbrengs, bemarkbare opbrengs, groen opbrengs en gemiddelde vrug massa. Die 15 F_1 basters het betekenis van mekaar verskil t.o.v. totale opbrengs, bemarkbare opbrengs, onbemarkbare opbrengs, groen opbrengs en gemiddelde vrug massa.

4. Betekenisvolle genetiese variasie was verkry tussen die ses ouer genotiepes vir vrug pH. Die 15 F_1 basters toon geen betekenisvolle verskille tussen oplosbare vastestowwe en vrug pH.

5. 'n Betekenisvolle positiewe fenotiepiese korrelasie ($r=0.95$) is gevind tussen totale opbrengs en bemarkbare opbrengs.

6. Die ingeteelde lyn p88/120 was die beste algemene kombineerder vir meeste van die opbrengs karakteristieke terwyl p88/120 en p88/192 die beste algemene kombineerders was vir die meeste van die kwaliteit karakteristieke.

7. Die kruisings p88/140 x UC82B, p88/120 x p88/192 en p88/140 x p88/192 was die beste spesifieke kombineerders vir totale en bemarkbare opbrengs. Die beste spesifieke kombinasie was die kruising tussen p88/164 en UC82B wat 7 positiewe spesifieke kombineer waardes gehad het.

8. 'n Algemene tot spesifike kombineervermoeë verhouding van 85:1 was behaal vir gemiddelde vrug massa wat aandui dat additiewe gene betrokke is.

9. Noue sin oorerflikheid was relatief hoog vir gemiddelde vrug massa (H^2_n= 74.38%), groen opbrengs (H^2_n=55.01%) en vrugkleur (H^2_n= 50.04%). Die teler kan effektief selekteer vir groter vrugte asook selekteer teen groen opbrengs om sodoende die totale opbrengs te verhoog.

10. Die gemiddelde vlak van heterose oor die beste ouer oorskry 10% vir totale opbrengs en bemarkbare opbrengs tussen al die F_1 basters. Heterose van die F_1 basters oor middel-ouer waarde, heterose oor die beter ouer en heterose oor die beste ouers was meestal negatief gewees vir die kwaliteits karakteristieke.

CHAPTER 6
RECOMMENDATIONS

Heterosis was high for total and marketable yield and it appears that a hybrid breeding programme will improve total and marketable yield. The breeder can select for larger fruited genotypes to improve total yield. The lines with the highest GCA values for total and marketable yields were p88/120, p88/140 and p88/192 and could be used to improve total and marketable yields.

Because of the high narrow sense heritability it should be possible to select for larger fruited lines. The high GCA:SCA ratio for fruit mass indicated that additive effects of the inbred were more important than the non-additive effects in determining performance in crosses. The lines p88/140, p88/120 and p88/179 had the highest GCA for average fruit mass and could be used by the breeder to improve average fruit mass.

To improve quality characteristics would be very difficult because of the low heterosis, GCA and SCA values.

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