"BREEDING TOMATO FOR IMPROVED JTRITIVE VALUE BY REDUCING OXALATE CONTENT"

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"BREEDING TOMATO FOR IMPROVED NUTRITIVE VALUE BY REDUCING OXALATE CONTENT"

By

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..... Dedicated

to

My Mother

Dr. R.R.Sharma
Principal Scientist

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CERTIFICATE

This is to certify that the thesis entitled "**Breeding tomato for improved nutritive value by reducing oxalate content**", submitted in partial fulfilment of the requirements for the award of the Degree of **Doctor of Philosophy in Horticulture**, to the Faculty of the Post Graduate School, New Delhi, embodies the results of *bona fide* research work carried out by **Ms. P.Anitha**, under my guidance and supervision. No part of this thesis has been submitted for any other degree or diploma. The assistance and help received during the course of investigation has been duly acknowledged by her.

R Raman

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1. INTRODUCTION

Tomato (*Lycopersicon esculentum* Mill.) is one of the most important vegetable crops throughout the world both for its fresh fruits and for processed food industries. Tomato has a global annual production of 898.28 lakh MT and is grown over an area of 31.69 lakh ha (F.A.O. Year Book 1998) and according to Indian Horticulture Database (2000) the production of tomato in India is 82.711 lakh MT and grown over an area of 4.633 lakh ha.

Tomato is also an important protective food because of its special nutritive value. The nutritional composition of tomato per 100 g of edible portion (Aykrod, 1963) is as follows: Moisture 91.3 g, protein 1.9 g, fat 0.1 g, potassium 114 mg, copper 0.1mg, sulphur 24.0 mg, chlorine 38.0 mg, minerals 0.6 g, fibre 0.7 g, carbohydrates 3.6 g, sodium 45.8 mg, vitamin A 320 IU, thiamin 0.07 mg, riboflavin 0.01 mg, nicotinic acid 0.4 mg, vitamin C 31.0 mg, calcium 20 mg, magnesium 15 mg, oxalic acid 2.0 mg, phosphorus 36.0 mg, and iron 1.8 mg. Tomato is probably the most versatile vegetable available to the food industry. In fresh form it is generally consumed as salad. It has a valuable place among the cooking ingredients both in the kitchen and in the processing industry.

With the advent of transgenic agricultural products due to recent advances in biotechnology, much attention has been focused on food safety. Tomato was the first transgenic food product to be marketed. The fact that tomato has been occupying and continues to find an important role in human

nutrition, is indeed a sure indication of its important place among vegetable crops. Nevertheless, the content of anti-nutritional factors present in tomato cannot be underestimated. Recently, considerable interest has emerged among the scientific community over the anti-nutritional factors present in food items.

Calcium oxalate is an anti-nutritional factor present in tomato. Oxalate content of food is of serious concern as free oxalates would bind essential dietary divalent minerals, primarily calcium and magnesium, thus making them nutritionally unavailable and reduces the level of calcium in the blood. According to Hodghinson (1977) in developed countries it does not pose a health risk since calcium intake exceeds that of oxalate as much as a factor of ten. However, in developing countries oxalate intake in many cases may exceed that of calcium. In such cases, the amount of oxalate in the diet would become a significant contributing factor for an inadequate calcium metabolism. Moreover, oxalates has a positive involvement in the formation of urinary calculii contributing to oxalurea. Almost equal concern to the consumer is the safety of their food. The quality of food which the consumers are becoming increasingly aware is the nutritional composition. In many developed countries, there is emphasis on labelling food items to get an idea of its nutritional composition.

Breeding efforts directed towards improving the important quality characters achieved rather variable results. This was due to little attention paid to the correlation among plant-fruit characteristics and fruit composition. Yield, of course, is the most important varietal character. So varieties having only certain quality characters cannot get too much success. Therefore, it is

necessary that breeding for one or a few quality characters be replaced by breeding for an overall improvement of quality traits concerned in a particular crop.

As such very little work has been undertaken to lessen the oxalic acid content in tomato. Hence, there is scope for evaluating superior types with respect to less oxalic acid content in this crop. Information on sources of variability for various aspects of nutritive value particularly oxalic acid content is practically unavailable. Therefore, it is necessary to evaluate wide germplasm in this regard. Although the role of calcium oxalate as a potential anti-nutrient factor has long been realized, very little efforts were made to find out the calcium oxalate content in tomato and its association with important nutritive compounds in it.

Keeping in view the importance of low oxalate content in tomato, the present investigation was undertaken with the following objectives.

1. To study the gene action as per generation mean model for qualitative and quantitative characters in tomato.
2. To study the character association and path coefficient analysis in tomato with respect to calcium oxalate and lycopene.

2. REVIEW OF LITERATURE

The review of literature pertaining to various characters determining the quality of tomato and their pattern of inheritance is briefly dealt in this chapter.

2.1 Quality Parameters

2.1.1 Oxalates

Literature is scanty, in particular, about calcium oxalate content in tomato and studies on pattern of inheritance of oxalate is not reported so far. Hence, it is worth while to consider works reported on occurrence of oxalate in other vegetable crops.

Oxalic acid is of common occurrence in plants and animals. One of the biological function generally attributed to oxalic acid is that it would bind the dietary divalent cations, thus causing physiological deficiency of these nutrients. So an absolute amount of these nutrients are of little value unless, considered in relation to the oxalic acid content. Foods with high oxalate are reported to cause various disorders and even death, Jeghers and Murhpy (1945). Animals fed with diet including *Amaranthus hybridus*, did not show any clinical signs of ill health. This was in agreement with the finding reported by Talapatra *et al.* (1948) that high protein content of amaranthus offset the toxic effect of oxalates. But poisoning had been observed on those animals fed by plants containing over 6.0 % oxalates, Mathams and Sutherland (1952). They also observed that calcium present in amaranthus leaves was poorly absorbed. When amaranthus leaves were given along with milk, they rendered milk calcium less

available for absorption. The authors inferred that poor absorption of calcium from amaranthus leaves was due to high oxalate content.

The calcium value of food was expressed on the basis of calcium : oxalate ratio, Iengar and Rau (1952). They observed that foods having calcium : oxalate ratio below 0.3 were not good sources of calcium and those below 0.2 should be considered very poor source. Accordingly, the authors pointed out the leaves of amaranthus were not a good source of calcium and those of *Chenopodium* were very poor source. Ackerman and Ge beauer (1957) had also studied the calcium value of food on the basis of calcium : oxalic acid ratio.

Srivastava and Krishnan (1959) observed the presence of oxalate in varying degrees in all parts (leaves, leaf stalk, flower, tuber and roots) of several vegetables they analyzed. They found that water soluble oxalate formed 12-80 % of total oxalates. The roots in general, contain highest amount of water soluble oxalates.. An interesting variation was found in the total oxalates content among the leaves of different age of *Alocasia* and *Colocasia* sp. The young leaves just emerged from inside the stalk, contained the lowest percentage of oxalate per gram dry weight. The mature leaves contained the highest percentage of oxalates, whereas the leaves those started to ripen, there was a decrease in the oxalates. They also pointed out that the young leaves contained larger proportion of water soluble oxalate as compared to mature and old leaves.

Singh and Sur (1962) observed that with maturity both water soluble and water insoluble oxalates increased till the flowering stage. Subsequently there was a decrease in the soluble oxalate content and enormous increase in the

insoluble oxalate content. The total oxalate content of the *Bathua* leaves as usually consumed varied from 14- 20 % on dry weight basis. According to Singh and Sharma (1968) some leaves, like the leaves of kulfa, though very rich in calcium and proteins, are not fit for health, owing to high content of oxalic acid.

Schmidt *et al.* (1971) made an assessment of the total and soluble oxalate content of leaves of *Amaranthus cruentus* L. *Basella alba* L. *Brassica oleraeca* var. a*cephala* and *Ipomea aquaticus* L. and found that oxalate was present in the range of 8. 68 %, 10.62 %, 1.2 % and 2.8 % (on dry weight basis), respectively. Singh (1973) carried out comprehensive screening of various Indian foods for their oxalates content which showed that oxalate consumption is fairly high in India. He evaluated ten types of leaves, edible portion of fifteen leafy vegetables and one hundred and five other food stuffs. Out of the ten leaves examined, three have been found to be rich in oxalate (on dry weight basis), namely *Chenopodium murale* L. *C. amaranticolor* L. *Amaranthus gangeticus* L. He estimated a total oxalate (on dry weight basis) concentration of 5.8 % in *Amaranthus* sp., 9.5 % in palak (*Beta vulgaris* var. *Vulgaris* L.), 12.0 % *C. album* 11.33 % in *C. murale*, 6.8 % spinach (*Spinacea oleracea*) and 6.3 % in sorrel (*Rumex vesicarius* L.)

According to Mugerwa and Bevabye (1974) the whole part of *Amaranthus hybridus* sub sp. *incurvatus* contains 6.7 % oxalic acid. Ndyonab (1974) reported that Ugandan graminaceous forage was rich in oxalates. He further, observed that forage which contained high levels of calcium and nitrogen also contained high levels of oxalates, but low soluble oxalates.

According to Mugerwa and Stafford (1976) oxalate levels both in *A. hybridus* sub sp. *incurvatus* and *A. hybridus* sub sp. *hybridus* were higher than that of Ugandan graminaceous forage. The total oxalate content of *A. hybridus* sub sp. *hybridus* was 5.25 % of which 1.13 % was water soluble, while the same for *A. hybridus* sub sp. *incurvatus* was 4.89 % and 2.0 % respectively. They pointed out that most of the oxalates occurred as calcium and protein bound oxalates.

Marderosian *et al.* (1980) analysed the oxalates the nitrates levels of vegetable amaranth. In *A. blitum* oxalates was 6.6%, *A. cruentus* 7.8%, *A. gangeticus* 7.8% *A. gangeticus* 7.8%, *A. gangeticum* (var. white leaf) 8.2% and *Beta vulgris* (chard) 8.4%. The authors pointed out that about 40% of oxalate in amaranthus was free and thus available for binding calcium. But they concluded that the oxalate contents, though quite high in amaranthus, there was no need of concern of the potentially adverse nutritional effect when consumed in normal dietary regimes.

According to Finch *et al.* (1981) oxalate in urine was mainly due to dietary oxalates. Hill and Rawate (1982) reported that *A. retroflexus* (pig weed) had 5.56%, oxalic acid in leaves and 2.6% stems. Sunel and Heley (1985) found out calcium oxalate crystals in the leaves of taro. The analytical resolution of crystalline sand pyramid was studied in Solanaceae and Rubiaceae by Cody and Horner (1985) and they reported that the crystal sand to be calcium oxalate monohydrate.

Gold speckles and sand crystals in tomato fruits (*Lycopersicon esculentum* Mill.) was studied by Jause *et al.* (1988) and Outer *et al.* (1988).

They reported that tomato fruit walls often possess tiny yellowish spots around the calyx and shoulder of the fruit. In such fruit crystal sand was present in separate cells. This crystal sand causes gold speckles. Also raphid crystals occur in great quantities in the pulp of tomatoes which display numerous gold speckles. Both sand crystals and raphid crystals were proved to be organic calcium salts, probably calcium oxalates. The long raphid crystals may perforate the neighouring paranchyma cells while picking and transport of the fruits hence, limits its storage life. Nutrient substances used in substrate culture, especially those with a high nitrate ion concentration may partially be responsible for the formation of calcium oxalate crystals.

Gupta and Wagle (1988) reported that spinach contains calcium oxalate as an anti-nutritional factor. George *et al.* (1989) and Gupta *et al.* (1989) also reported the presence of oxalates as an anti-nutritional factor present in vegetable amaranth.

The incidence of calcium oxalate crystals on the fruit walls of tomato (*Lycopersicon esculentum* Mill.) as affected by humidity, phosphate and calcium supply was studied by Kreji *et al.* (1992) and revealed that fruits with gold speckles had reduced shelf life and can be considered as a symptom of excess calcium. Paiva *et al.* (1998) analysed the composition and quality of tomato fruits, cultivated in nutrient solution containing different concentration of calcium and found that when calcium concentration was low (0.2 mM) in nutrient solution, tomato seeds formed were small, malformed and black in colour. Magnesium and potassium concentration decreased with increasing

calcium concentration. Total lycopene and carotene concentration decreased with increasing calcium concentration.

The effect of water stress on oxalic acid concentration in spinach was studied by Sugiyama *et al.* (1999). They found that oxalic acid plays a minor role in osmotic adjustment though potassium oxalate is a major osmoticum in spinach leaves. According to Ombodi *et al.* (1999) spinach contains large amount of oxalates and nitrates causing health hazard. Santamaria *et al.* (1999) conducted a survey and found that nitrate and oxalates were present in fresh vegetables (celery, parsely and spinach). They found that higher levels of nitrate were present in leafy vegetables. Higher oxalate was found in spinach and swischard. According to Fujiwara *et al.* (1999) the oxalic acid content exhibited negative relationship with spinach fresh weight.

Arnott and Webb (2000) found that among the higher plants that accumulate oxalates, many characteristically produce raphids (needle shaped crystals). They indicated that raphid functions in plant defence against herbivores and their shape is a critical component in the proposed defence mechanism. Weekly foliar calcium application resulted in a decreased percentage of tomatoes that peeled completely during processing. There was a significant increase in rupture distance of cuticle with the addition of calcium. The average fruit weight decreased with the application of calcium. There was no effect of calcium application on fruit pH or soluble solids but calcium decreased titrable acidity.

2.1.2. Lycopene

Lycopene is the most important colour constituent of tomato which contributes to over all colour and appearance to tomato products.

Anwar (1979) observed that four of the seven hybrids have shown heterosis for high lycopene content with respect to the parental mean value. Screening and diallel study for yield and quality characters in tomato (*Lycopersicon esculentum* Mill.) was done by Bhutani (1981). According to Daskaloff *et al.* (1981) there was a dominant gene effect for a low lycopene content. Genetics of carotenoids and lycopene in tomato was studied by Bhutani and Kalloo (1983). Significant variation for lycopene has been reported among tomato varieties by Madaiah *et al.* (1986). In a diallel crossing involving eight parents, Babu (1987) observed significant relative heterosis for lycopne in eight hybrids and heterobeltiosis in one.

Combining ability and component analysis showed a preponderance of non-additive gene action for most characters including lycopene content. They reported that non-additive gene action was more important than additive and had a moderate heritability estimates.

Significant variation for lycopene has been reported among tomato varieties by Setty *et al.* (1987). Combining ability for processing characters in tomato was studied by Raijadhav and Kale (1987) and reported non-additive components were most important for lycopene content and *sca* effects were highest in the cross Breech x Pusa Ruby for lycopene content. Rao and Yadav (1988) in preliminary evaluation of some tomato varieties found that Pusa Ruby had a high lycopene (3.75 mg/100g) content. While studying the bacterial wilt

resistance and processing qualities of tomato F_1 hybrids, Narcisco and Rosario (1988) reported that heterosis and heterobeltiosis were not established in fruit and processing qualities except for lycopene content.

β-carotone and lycopene were measured in mature fruits of parental, F_1, F_2 and backcross populations by Stommel and Haynes (1994). They found that segregation pattern for fruit pigmentation and percentage beta-carotene showed a single dominant gene conditioning a high percentage bet-carotene and resulting orange pigmentation. Significant *sca* effect for lycopene in Pusa Sheethal x Chiku was reported by Kumar (1994).

2.1.3. Ascorbic acid

Man realized, very early, the importance of vitamin C in human nutrition and its availability in considerable quantity in tomato. Although tomato contains intermediate levels of ascorbic acid, it could make an important contribution to the intake of this vitamin due to consumption of large quantity of tomato. A large number of studies were carried out on ascorbic acid content in tomato fruits and its variation due to environmental and genetic factors and its inheritance.

According to Ma Clevin and Fellers (1938), about 25 % of the original ascorbic acid present in tomato juice was destroyed when juice was concentrated. Brown and Moser (1941) reported an inverse relationship between vitamin C and size of the fruits and observed no loss of vitamin C in fruits held in cold storage. Hamner and Maynard (1942) observed ascorbic acid content was dependent primarily on variety, location where it was grown and seasonal conditions. Murphy (1942), Mc Collum (1944) and Hassan and

Mc Collum (1954) have concluded that tomato fruits exposed to direct sunlight contained higher ascorbic acid compared to the shaded fruits and ascorbic acid content varied with the intensity of light reaching the fruit but not the leaves. Reynard and Kanepause (1942) and Kidson (1943) estimated the vitamin C content of different tomato varieties and species and found wide difference among the same specious. The authors reported high vitamin C content in *L. pervianum* followed by *L. pimpinellifolium* compared to *L. esulentum*. Among the cultivars of *L. esculentum*, higher values of vitamin C was recorded in pear shaped varieties than commercial ones. They also found in crosses of small fruited high ascorbic acid and content with large fruited low ascorbic acid content, the F_1 generation was intermediate in both size and ascorbic acid content but exhibited negative correlation between fruit volume and ascorbic acid content in second generation. In crosses between lines of similar fruit size and ascorbic acid content, the F_1 and F_2 did not differ significantly from the parental lines in either character. Similar results were obtained by Gardner (1950). From studies on vitamin C content of tomatoes, Lincoln *et al.* (1950) concluded that many genes were involved in inheritance of high ascorbic acid content.

According to Currence *et al.* (1961) fruit weight negatively correlated with ascorbic acid content. Lomoljako and Simonov (1968) observed that hybrids were inferior to the parents in their ascorbic acid content. Popisilova (1969) found that ascorbic acid content corresponded with the arithmetic mean of the parents during first third of fruit development and ripening and thereafter with the geometric mean.

Tesi *et al.* (1970) found heterosis over 40 % for ascorbic acid content in crosses between wild form *L. pimpinellifolium* and cultivated variety Krakowsbeewezisw. Large variations in vitamin C levels had been reported by Roy and Choudhury (1972). Significant general combining ability (*gca*) variance for female parents for Vitamin C was reported by Dhillon *et al.* (1979). Significant *sca* for ascorbic acid content was reported by Fedrowitz and Tigchelaar (1979). Babu and Babu (1978) while studying heterosis in tomato reported that some hybrids showed heterorsis for ascorbic acid content.

According to Daskaloff *et al.* (1981) there was dominance effect for high vitamin C content. Arora *et al.* (1982) observed high heritability coupled with low genetic advance which suggested involvement of non-additive gene action for all characters studied including ascorbic acid. Sethi *et al.* (1982) had reported variations in ascorbic acid content among different tomato varieties. Ascorbic acid content has a positive correlation with fruits per plant, seed percentage and yield as reported by Rattan *et al.* (1983). While studying the heterosis for ascorbic acid content in fruits of cultivated tomato, Vien-Chu-Thi-Ngoe and Stain (1983) found that none of the F_1 hybrids showed positive heterosis relative to the better parent. According to Jamwal *et al.* (1984) there is heterorsis for ascorbic acid content. Patil and Bojappa (1987) observed that ascorbic acid content and total soluble solids were negatively correlated with yield, mainly due to their negative direct effects. While studying the combiners and combinations of quality components of tomato, Patil and Patil (1988) reported that contribution of *sca* variance was more prominent for ascorbic acid.

According to Chen and Zhao (1990) heterosis for ascorbic acid was not found significant. Heterobeltiosis for ascorbic acid was found by Kumar (1994). Gene effects in quality traits of tomato was studied by Dod *et al.* (1995) and found that additive x additive effects were more prominent for ascorbic acid content. Kanthaswamy *et al.* (1995) reported additive genetic effects for ascorbic acid.

2.1.4. Acidity

Acids not only contribute to the sourness of tomato but also a major factor in flavour intensity. High acidity reduces the processing time and improved colour, flavour and vitamin C retention in the final product as reported by Leonard *et al.* (1959).

Early varieties of tomato had a high maleic acid : citric acid ratio, whereas late varieties contained more citric acid as reported by Koch (1960). Obviously this finding should open up the possibility of selecting parents with maleic acid content while breeding for early varieties of tomato. Videki (1963) reported citric acid and maleic acid account for 75 per cent and 25 per cent, respectively of the total acids present in tomato. Walkof and Hyde (1963) from their findings concluded that inheritance of tomato acidity was under mono-factorial control with dominance for acidity. According to Thompson *et al.* (1964) acidity of locular contents was found to be generally high as compared to the pericarp. Bradly (1964) found that acidity levels and acid composition of tomato fruits varied with variety and place of origin.

Acid contents in tomato were generally intermediate between the parents with some maternal effects as reported by Mezsoly and Videki (1967).

However, these characters were found to have been affected by the climatic conditions and in general, parental varieties were not consistent in their effect upon chemical constituents of their hybrids. According to Okubo and Maezawa (1967) fruit acidity decreased rapidly during storage at high temperatures while other constituents remained fairly constant.

Stevens (1971) observed significant correlation between total reducing sugars and total acids, and citrate concentration with titrable acidity. Stevens and Long (1971) reported that inheritance of malate content in tomato is controlled by a single gene with low content dominant. However, inheritance of acidity was largely quantitative and in certain segregating population found a major factor contributing high acidity. They also reported that the major component of genetic variance was additive with heritability estimates of 37.6 and 64.62 per cent for pH and titrable acidity, respectively. They also found that citric, maleic, acconitic, acetic, formic, glutamic and traces of lactic acid were found but only citric acid followed by maleic acid predominated.

However, Kalloo *et al.* (1974) found a non-additive gene action for acidity. Singh and Nandpuri (1975) found predominance of additive gene effects. Babu and Babu (1978) reported that some hybrids showed heterosis for total acidity. Bhutani (1981) observed high heritability estimates for acidity on the basis of divergence studies, using 84 lines, eight parents selected from different clusters and crossed in all possible combinations, excluding reciprocals. He also reported a partial dominance for acidity from graphic analysis.

According to Daskaloff *et al.* (1981) there is full dominance or over dominance for high total acid content. From a variability and heritability study in intervarietal crosses of tomato Sonone *et al.* (1986) found a high heritability and low genetic advance for titrable acidity suggesting a non-additive (dominance and epistasis) gene effects. Raijadhav and Kale (1987) reported non-additive components of variance for acidity. From a preliminary study of combiners and combinations for quality in tomato, Patil and Patil (1988) found combinations of *sca* variance was more prominent for titrable acidity.

2.1.5. Total Soluble Solids

Among the quality components of tomato, total soluble solids have attracted more attention than any other. Generally, the attempts for achieving higher soluble solids have not been successful due to negative relationship between total soluble solids and yield.

According to Videki (1963) fructose and glucose were present 1.0 : 1.3 ratio in *Lycopersicon esculentum* and sucrose was found in fruits of *L. pernvianum* and *L. hirsutum*. However, Stoner and Thompson (1966) indicated the presence of dominant genes for high total soluble solids. Lower and Thompson (1967) found that variation in soluble and total solids was due to variations in sampling dates and sampling methods. Meszoly and Videki (1967) reported heterosis for sugar content in tomato. Lower and Thompson (1967) reported heterotic increase in the F_1 and transgressive segregation for both high and low solids in the F_2. The major component of genetic variation was reported to be additive with a relatively low heritability estimates. Significant variations for TSS has been reported among tomato varieties by Saimbhi

(1969). Ibarbia *et al.* (1969) reported that small fruited breeding lines showed superior general combining ability. The presence of additive genetic effects are indicative of the scope for selection potential for this trait.

According to Daskaloff *et al.* (1970) sugars improved through recurrent plant selection. Sinnadurai and Amuti (1970) found that the soluble solid content was higher in long days than those grown in short days. Emery and Munger (1970) studied the effects of inherited difference in growth habit on fruit size and soluble solids in tomato and found that intermediate and joint-less plants had larger fruit and higher soluble solids than determinate plants in all varieties at different spacing.

According to Padda *et al.* (1971) round varieties showed most variation in total soluble solid content and there was high heritability and genetic advance for this character. They also observed that total soluble solids was positively correlated with acidity and TSS : acid ratio negatively correlated with acidity and locule number. Farkas *et al.* (1972) found that determinate (sp) growth habit resulted in lower soluble solid content due to reduced photosynthetic capacity. Kalloo *et al.* (1974) opined that fruit size and TSS were negatively correlated. Studies on heterosis in tomato by Babu and Babu (1978) showed heterosis for total soluble solids. Dhillon *et al.* (1979) while studying the combining ability in tomato reported that except for total soluble solids variance due to *gca* for males were significant for all characters.

The inheritance of some quantitative characters determining tomato fruit quality was studied by Daskaloff *et al.* (1981). They reported an incomplete dominance for high soluble solids content in tomato. According to Govindarasu

et al. (1981) combining ability for high yield and its components in tomato, specific combining ability *sca* were higher than general combining ability *gca* variance for total soluble solids indicates non-additive gene action. Arora *et al.* (1982) found that high heritability coupled with low expected genetic advance for the quantitative characters suggested non-additive gene action. Similarly, Swami and Mathai (1982) opined that TSS of fruits was predominantly controlled by non-additive gene action as indicated by larger variance due to *sca* than *gca*. However, Gibrel (1983) reported that additive genetic variance was more important than non-additive genetic variance for TSS. Bhutani *et al.* (1983) observed that heritability was highest for content of reducing sugars. Saraladevi (1984) observed positive and significant correlation between TSS and acidity. According to Das and Chakraborty (1987) Pusa Ruby had good TSS content.

Promising tomato forms for breeding for improved fruit quality was studied by Luk-Yaneko-E-Kh (1985) with the result that those forms with best contents for dry matter, sugars, free acids, ascorbic acid and carotene were identified and recommended for breeding for quality. According to Sonone *et al.* (1986) the predicted genetic advance was highest (>30%) for total soluble sugars. Correlation and path analysis for quality and yield in tomato was studied by Patil and Bojappa (1987) brought out that total soluble solids was negatively correlated with yield mainly because of negative direct effect. According to Raijadhav and Kale (1987) non-additive components were most important for total soluble solid and Pusa Ruby was a good combiner for TSS. Patil and Patil (1988) pointed out that both *sca* and *gca* variance contributed

significantly for quality traits while contributions of *sca* variance was more prominent for total soluble solids. Khalil *et al.* (1988) observed no heterosis for total soluble solids and suggested that incomplete dominance was involved in the expression of this character.

According to Chen and Zhao (1990) heterosis for total soluble solids content was not significant but the effect of *gca* on characters differed significantly among the characters. Gosh *et al.* (1995) studied the mean performance for seventeen characters of tomato hybrids. The highest variation was found for T.S.S. Dod *et al.* (1995) opined that dominance, additive x dominance and dominance x dominance gene effects appeared to be important in the control of total soluble solids. In a study of generation mean analysis in tomato Kanthaswamy *et al.* (1995) noted that both additive and dominance gene effects were important for total soluble solids. However, Dhaliwal *et al.* (1999) had reported a preponderance of non-additive genetic variance for total soluble solids.

2.2 Physical parameters

2.2.1 Locule number

In general, large fruit size is accompanied by oblate shape and high number of locules while small fruit size by round or elongate shape and low number of locules, as reported by Dennett and Larson (1953) and Bergh (1956). According to Ahuja (1968) locule number in tomato have a lower limit of 2 where as theoretically there is no upper limit.

High heritability along with high genetic advance for locule number was reported by Singh *et al.* (1974). Nandpuri and Tyagi (1976) and

Peter and Rai (1978) could not observe heterorsis for locule number per fruit. According to Singh and Mital (1978) there is high *gca* for locule number per fruit. Bhutani (1981) reported a partial dominance and high heritability for number of locules in tomato. The character of five locules was controlled by single recessive gene designated as 'le' was reported by Peter *et al.* (1981). Specific combining ability *sca* was significant for locule number as reported by Lapaushner *et al.* (1981). Arora *et al.* (1982) reported a high heritability coupled with low expected genetic advance for locule number suggesting the involvement of non-additive gene action.

According to Gonzalez (1985) the number of locules had an important influence on fruit firmness, which provided resistance to mechanical damage. He also recommended the use of path coefficient for the investigation of independent characters as an aid for planning for indirect solution. Kanno and Kamimura (1985) observed that fruit weight was positively correlated with locule number. According to Sonone *et al.* (1986) there is high heritability and high genetic advance estimates for locule number indicating control by additive gene effects. Significant positive correlation ($r = 0.96$) between fruit firmness and locule number was observed by Babu (1987). For locule number partial or complete dominance was observed by Khalil *et al.* (1988).

Inheritance studies on number of locules in tomato was done by Bhutani and Kalloo (1991). They observed that in both F_1 and F_2, the additive component was highly significant and higher than non-additive component. So the authors concluded that a desirable higher locule number could be brought about by simple selection. Ramos *et al.* (1993) reported that over dominance

effect for locules per fruit, the alleles acting in the direction of increasing values for locules per fruit was dominant.

The relationship between deformed fruit and early maturing or ventricular number of tomato and their genotypes were studied by Yao-Jiang Ming *et al.* (1995). They observed a partially negative dominance in most of the F_1 hybrids. Broad sense and narrow sense heritability estimates for deformed fruits ranged between 78% to 83.24% and 51.14% to 62.58%, respectively. According to Dod *et al.* (1995) dominance, additive x dominance and dominance x dominance gene effects were appeared to be important in the control of locule number. Takac *et al.* (1995) observed that locule number was varietal characteristic in the range of mean values being 2.08 to 6.18. There was significant positive correlation (r = 0.71) between locule number and fruit weight whereas negative correlation (r = -0.60) existed between locule number and fruit number per plant. Dhaliwal *et al.* (1999) observed a preponderance of additive genetic variance for number of locules in tomato.

2.2.2 Seediness

In tomato varieties used for the preparation of tomato products, low seed content is a desirable character. Thus the negative *gca* and *sca* effects will be preferred.

Mital *et al.* (1974) observed significant heterosis for quantity of dry seeds per kg of fresh fruits. Anwar (1979) reported none of the hybrids showed negative heterosis for seed content below the parent with the lower seed content. The hybrid with the highest yield showed intermediate seed content

between the parents. Partial dominance governed the seed percentage of the fruits and additive gene action was observed.

Anbu *et al.* (1981) reported heterosis for increase in seed content. The highest heterosis was 15.59 per cent and excelled the better parent. Presence of non-additive gene action controlling the seediness trait was reported by Dhoke (1990). He further noted that heterosis breeding would be helpful to improve this trait. Lupaseu *et al.* (1996) reported that number of seeds per fruit was a reliable indicator of fruit weight.

2.2.3 Yield

Yield is the most important varietal character. Number of plants per unit area, number of fruits per plant and weight per fruit are the main components of yield. Heterosis is a highly efficient breeding method to develop high yielding uniform cultivars. Combining ability of parents and type (s) of gene action determine the success of heterosis breeding programme.

The earliest reports on heterosis in tomato was by Hedrick and Both (1907). Then many authors like East and Hayes (1912), Wellington (1912) and Tschermark (1918) in that order had reported heterosis in tomato. Significant heterosis for total yield was reported by Power (1945), Finlay (1951), Haskell and Brown (1955) and Currence (1960). Heterosis for number of fruits per plant in tomato was reported by Buiatti *et al.* (1964). Heterosis for yield was reported by Kesavan (1967), Choudhury and Khanna (1972), Baroncelli *et al.* (1972), Avdeev (1974), Conti (1974) and Lobo and Marin (1975) in that order. According to Singh and Mital (1978) small-fruited lines were the best combiners for fruits per plant compared to large fruited lines. Significant

heterosis for total yield reported by Babu and Babu (1978) and Popova *et al.* (1979). According to Courtney and Peirce (1979) there is significant correlation between yield and *gca* for yield.

According to Tikoo and Anand (1980) there is significant heterosis for yield. Anbu *et al.* (1981), Peter and Rai (1980) and Govindarasu *et al.* (1981) observed significant *sca* for yield and the magnitude was higher than *gca.* Khotyleva and Kileheviskii (1984) reported inter-varietal variation in combining ability for yield in parental lines. Sonone *et al.* (1986) reported that heritability and predicted genetic advance was highest (>30%) for fruit yield. According to Raijadhav and Kale (1987) Pusa Ruby was a good general combiner for yield. Performance of F_1s and their parental lines were evaluated by Narcisco and Rosario (1988) and found that hybrids exhibited heterosis and heterobeltiosis for yield. According to Chandrasekhar and Rao (1989) five out of fifteen crosses which recorded significant *sca* effect for yield also showed positive *sca* for number of fruits per plant.

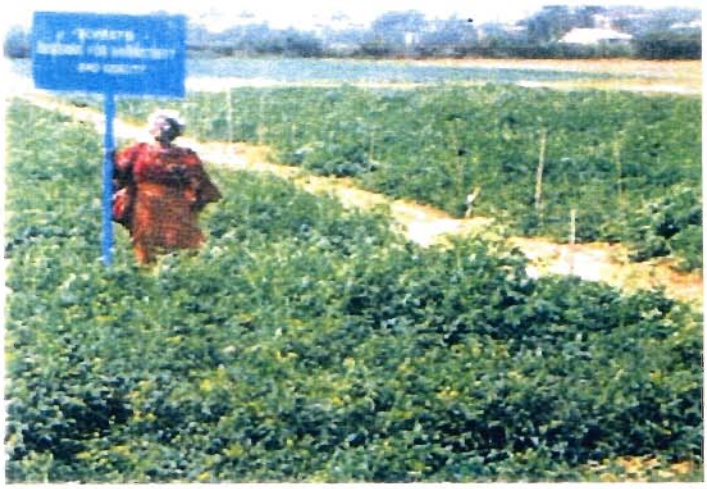
According to Kumar (1994) there exists a significant heterosis for fruit yield per plant. In a study of mean performance for seventeen characters of ten tomato hybrids by Gosh *et al.* (1995) revealed that values for heritability and genetic advance (as a percentage of mean) were high for yield per plant. According to Lupaseu *et al.* (1996) total yield (1.6 to 2.8 kg per plant) were strongly influenced by environmental conditions and showed high heritability. Path coefficient applied to correlations among the characters indicated that number of seeds per fruit was reliable indicator of fruit weight.

3. MATERIALS AND METHODS

The present investigation entitled **"Breeding tomato for improved nutritive value by reducing oxalate content"** was carried out at the Division of Vegetable Crops, Indian Agricultural Research Institute, New Delhi-12, during 1997-2001.

Delhi lies on latitude of $28^0.04'$ North and longitude of $77^0.12'$ East and at elevation of 228.6 meters (750 feet) above mean sea level. The climate of Delhi is typically semi arid subtropical with hot summers and cool winters. During summer months maximum temperature ranges from 26.0^0C to 39.9^0C and minimum ranges from 12.8^0C to 27.6^0C, whereas during winter maximum and minimum temperature ranges from 20.2 to 27.6^0C and 5.8^0C to 7.7^0C, respectively. The annual normal rainfall is 708.6 mm of which an average of 597 mm (84 per cent) is received from June to September and 85 mm (12 per cent) during winter months i.e. November to March.

Tomato (*Lycopersicon esculentum* Mill.) cultivars and lines used in the present study were obtained from the seed materials maintained at the Division of Vegetable Crops. Field studies including raising of parents, making crosses and final trial using all the six generations were carried out at the experimental plots of the Division of Vegetable Crops. Analyses for quality parameters were carried out at the Division of Biochemistry and the Division of Fruits and Horticultural Technology.



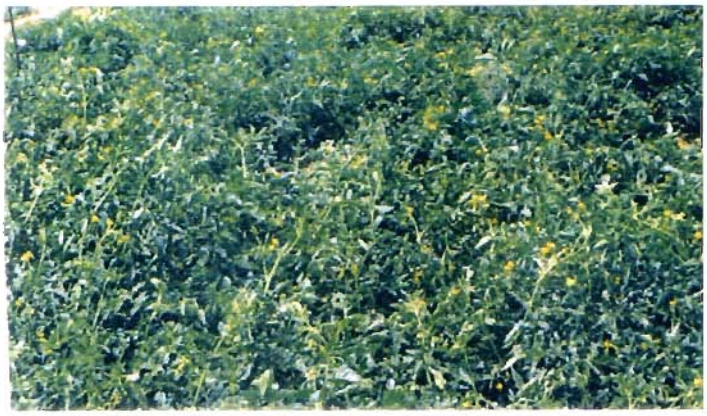


Plate 1 : Field overview of the tomato crop

3.1 SELECTION OF PARENTS

From the germplasm collection of tomato, sown and maintained during spring- summer season of the year 1998, fifty cultivars / lines were selected and evaluated for their oxalate content. A few flower clusters of each of fifty cultivars/ lines were selfed and seeds were collected. Based on preliminary evaluation, a total of six cultivars/lines were finally selected as parental material for the study (Table 1). The selected parental material was arranged into two groups *viz.*, three with low oxalate content and three with high oxalate content. Parental material was used for making crosses to study the pattern of inheritance of different characters contributing towards quality of tomato in general and calcium oxalate content in particular.

3.2 MATERIALS FOR INHERITANCE STUDIES

Selfed seeds obtained from the selected parental material from the spring-summer season of the year 1998 were utilized for raising parental material in the spring-summer season of the year 1999. In this parental material, crosses were attempted following 6x6 diallel mating design excluding the reciprocals. A total of fifteen crosses were made. The fruits obtained from the crosses were carefully collected, the F_1 hybrid seeds extracted and stored properly. Simultaneously, a few flower clusters of each of the parental material was selfed and seeds collected.

A part of the F_1 hybrid seeds was kept aside and remaining F_1 hybrid seeds along with parents were sown for raising the crop during the spring - summer season of the year 2000. The F_1 hybrids were backcrossed with their respective parents to get backcross seeds (B_1 and B_2). A total of fifteen crosses

were made with either of the respective parents to get 15 B_1 and 15 B_2. Large number of flower clusters of each of F_1 were bagged to get selfed seeds, which constituted the respective F_2.

The genetic material for the present study, therefore, included six generations, namely the six parents, the fifteen F_1s, the fifteen F_2s, the fifteen B_1s and the fifteen B_2s (Table1 and Table 1a). For studying the pattern of inheritance of characters concerned, the above said six generations were raised in the experimental plot during the spring-summer season of the year 2001. Seeds were sown in the nursery on 20th October 2000 and seedlings were transplanted on 22nd November 2000. Normal cultural practices including plant protection measures needed for raising healthy crop were followed.

3.3 EXPERIMENTAL MATERIALS AND DESIGN

The parental materials utilized in the present investigation were grouped as follows.

I. Cultivars/ lines with low calcium oxalate content

1) Pusa 120
2) Line 1234
3) Line 362

II. Cultivars / lines with high calcium oxalate content

1) Arka Vikas
2) Pusa Ruby
3) Line 25-7-4.

Table 1. Selected parents and their characteristics

Characters	Selected cultivars/lines					
1. Source	Pusa120 IARI	Line 1234 IARI	Line 362 IARI	Arka Vikas IIHR	Pusa Ruby IARI	Line 25-7-4 IARI
2. Plant type	Semi indeterminate	Determinate	Determinate	Semi indeterminate	Indetrminate	Determinate
3. Fruits wt (g)	80.00	60.52	50.25	58.25	57.93	70.41
4. Days to first picking	128.66	120.32	90.23	124.56	131.48	126.68
5. Locule number	5.67	2.51	2.51	4.32	5.26	4.24
6. Shape index	0.74	1.27	1.30	0.82	0.68	0.66
7. TSS Fruit (^{0}Brix)	4.62	4.91	3.43	3.52	5.51	4.45
8. Lycopene (mg/100ml juice)	1.34	1.60	1.68	1.64	1.90	1.42
9. Vitamin C (mg/100ml juice)	18.2	18.13	16.28	17.47	19.38	13.50
10. TSS Juice (^{o}Brix)	4.80	4.93	3.53	3.67	5.68	4.52
11. Acidity (g/100g juice)	0.55	0.54	0.58	0.36	0.65	0.36
12. Seediness (g/kg fruit)	0.78	1.89	0.53	0.71	2.39	2.12
13. Yield (kg/plant)	2.52	1.50	1.25	2.10	2.18	2.54

Table 1(a) Materials generated through crossing

List of F1 crosses		List of F2 crosses		
1. Pusa 120 x Line 1234	(1x2)	1. Pusa 120 x Line 1234	⊗	(1x2)
2. Pusa 120 x Line 362	(1x3)	2. Pusa 120 x Line 362	⊗	(1x3)
3. Pusa 120 x Arka Vikas	(1x4)	3. Pusa 120 x Arka Vikas	⊗	(1x4)
4. Pusa 120 x Pusa Ruby	(1x5)	4. Pusa 120 x Pusa Ruby	⊗	(1x5)
5. Pusa 120 x Line 25-74	(1x6)	5. Pusa 120 x Line 25-74	⊗	(1x6)
6. Line 1234 x Line 362	(2x3)	6. Line 1234 x Line 362	⊗	(2x3)
7. Line 1234 x Arka Vikas	(2x4)	7. Line 1234 x Arka Vikas	⊗	(2x4)
8. Line 1234 x Pusa Ruby	(2x5)	8. Line 1234 x Pusa Ruby	⊗	(2x5)
9. Line 1234 x Line 25-74	(2x6)	9. Line 1234 x Line 25-74	⊗	(2x6)
10. Line 362 x Arka Vikas	(3x4)	10. Line 362 x Arka Vikas	⊗	(3x4)
11. Line 362 x Pusa Ruby	(3x5)	11. Line 362 x Pusa Ruby	⊗	(3x5)
12. Line 362 x Line 25-7-4	(3x6)	12. Line 362 x Line 25-7-4	⊗	(3x6)
13. Arka Vikas x Pusa Ruby	(4x5)	13. Arka Vikas x Pusa Ruby	⊗	(4x5)
14. Arka Vikas x Line 25-7-4	(4x6)	14. Arka Vikas x Line 25-7-4	⊗	(4x6)
15. Pusa Ruby x Line 25-7-4	(5x6)	15. Pusa Ruby x Line 25-7-4	⊗	(5x6)

List of B_1 crosses (First generation back crosses)		List of B_2 crosses (First generation back crosses)	
1. (Pusa 120 x Line 1234) x Pusa 120	B_1	1. (Pusa 120 x Line 1234) x Line 1234	B_2
2. (Pusa 120 x Line 362) x Pusa 120	B_1	2. (Pusa 120 x Line 362) x Line 362	B_2
3. (Pusa 120 x Vikas) x Pusa 120	B_1	3. (Pusa 120 x Vikas) x Arka Vikas	B_2
4. (Pusa 120 x Pusa Ruby) x Pusa 120	B_1	4. (Pusa 120 x Pusa Ruby) x Pusa Ruby	B_2
5. (Pusa 120 x Line 25-7-4) x Pusa 120	B_1	5. (Pusa 120 x Line 25-7-4) x Line 25-7-4	B_2
6. (Line 1234x Line 362) x Line 1234	B_1	6. (Line 1234x Line 362) x Line 362	B_2
7. (Line 1234 x Arka Vikas) x Line 1234	B_1	7. (Line 1234 x Arka Vikas) x Arka Vikas	B_2
8. (Line 1234 x Pusa Ruby) x Line 1234	B_1	8. (Line 1234 x Pusa Ruby) x Pusa Ruby	B_2
9. (Line 1234 x Line 25-7-4) x Line 1234	B_1	9. (Line 1234 x Line 25-7-4) x Line 25-7-4	B_2
10. (Line 362 x Arka Vikas) x Line 362	B_1	10. (Line 362 x Arka Vikas) x Arka Vikas	B_2
11. (Line 362 x Pua Ruby) x Line 362	B_1	11. (Line 362 x Pua Ruby) x Pusa Ruby	B_2
12. (Line 362 x Line 25-7-4) x Line 362	B_1	12. (Line 362 x Line 25-7-4) x Line 25-7-4	B_2
13. (Arka Vikas x Pusa Ruby) x Arka Vikas	B_1	13. (Arka Vikas x Pusa Ruby) x Pusa Ruby	B_2
14. (Arka Vikas x Line 25-7-4)x Arka Vikas	B_1	14. (Arka Vikas x Line 25-7-4)x Line 25-7-4	B_2
15. (Pusa Ruby x Line 25-7-4) x Pusa Ruby	B_1	15. (Pusa Ruby x Line 25-7-4) x Line 25-7-4	B_2

The parameters studied in the present investigations are listed below.

A. Quality parameters

1) Calcium oxalate

2) Lycopene

3) Ascorbic acid

4) Acidity

5) Total soluble solids (TSS)

B Physical parameters

1) Locule number

2) Seediness

3) Yield.

The experimental design followed in the present investigation consisted of Randomised Block Design (R.B.D.) with three replications. The experiment has been laid out in the following fashion.

The final trial was laid out on 22nd November 2000. For every cross, one row each of parental material (P_1 and P_2), two rows each of F_1, three rows each of B_1 and B_2 and four rows each of F_2 were randomly allotted as such to one plot consisting of fourteen rows. The generations were randomly distributed within a plot. There were fifteen crosses in each replication (Blocks) and three such replications comprised the experimental field. The row length was of 4.0 m and row to row distance of 60 cm and plant to plant distance was

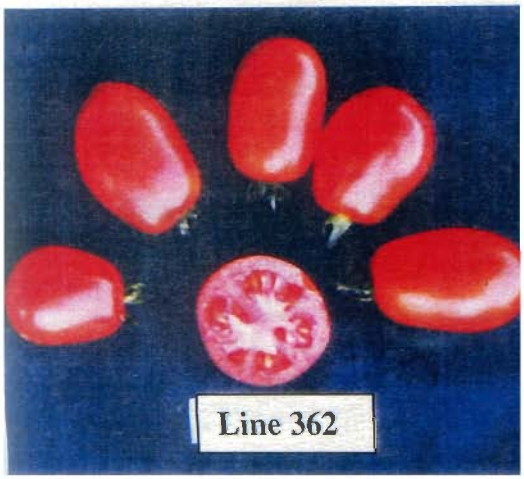


Plate 2 : Showing fruits of the six parental lines

45 cm was kept. From each row five plants were randomly selected and labelled for taking observations.

3.4 OBSERVATIONS

3.4.1. Quality parameters

For evaluating quality parameters a sample of five fruits from each selected plant from each row were collected. All the progenies of a cross were sampled on the same day. The fruits from individual plants were placed in properly labelled alkathene bags and kept at controlled temperature (20 ± 1^0C) for seven days for complete ripening before analysis.

For analyzing calcium oxalate the ripe tomatoes taken out of cold storage chamber were washed dried and cut into pieces with a stainless steel knife. The samples were dried and ground into fine powder.

For analyzing lycopene, ascorbic acid, acidity and total soluble solids, the ripe tomatoes taken out of cold storage were washed, dried and cut into pieces with a stainless steel knife and blended. The pulp was passed through 40 mesh sieve and juice obtained was used for analysis.

3.4.1.1 Estimation of total oxalates

A colourimetric method described by Burrows (1950) and modified by Marderosian *et al.* (1980) was employed with certain modification(s) to determine the total oxalate content in dry sample.

Reagents

The reagents used in this procedure were an iron ferron reagent and a citric acid reagent. The iron ferron reagent was prepared by dissolving 4.0 g of ferron (7-iodo-8-hydroxy quinoline-5-sulfonic acid) in 500 ml of hot distilled

Plate 3 : Showing fruits of the F_1's

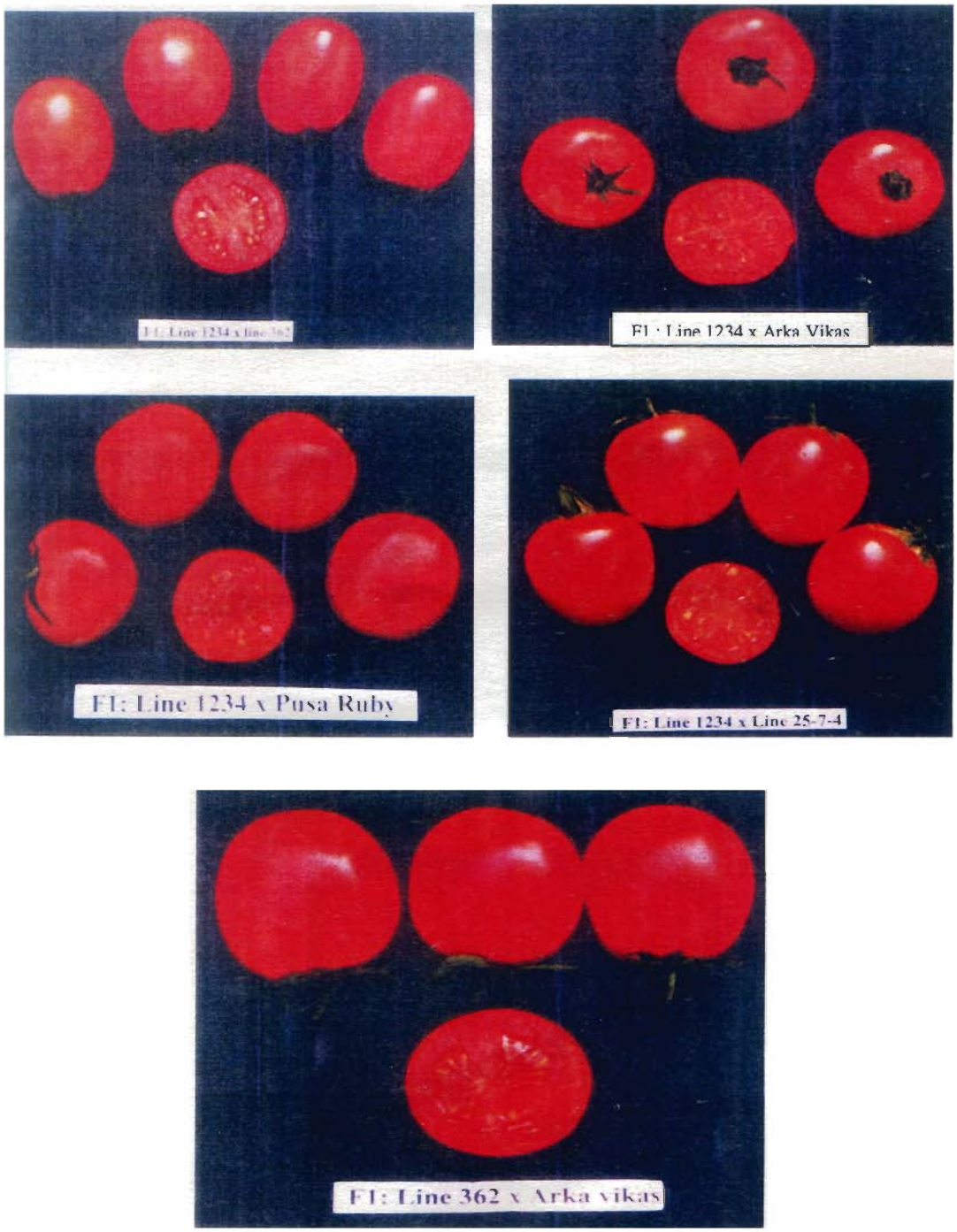


Plate 3 Contd…

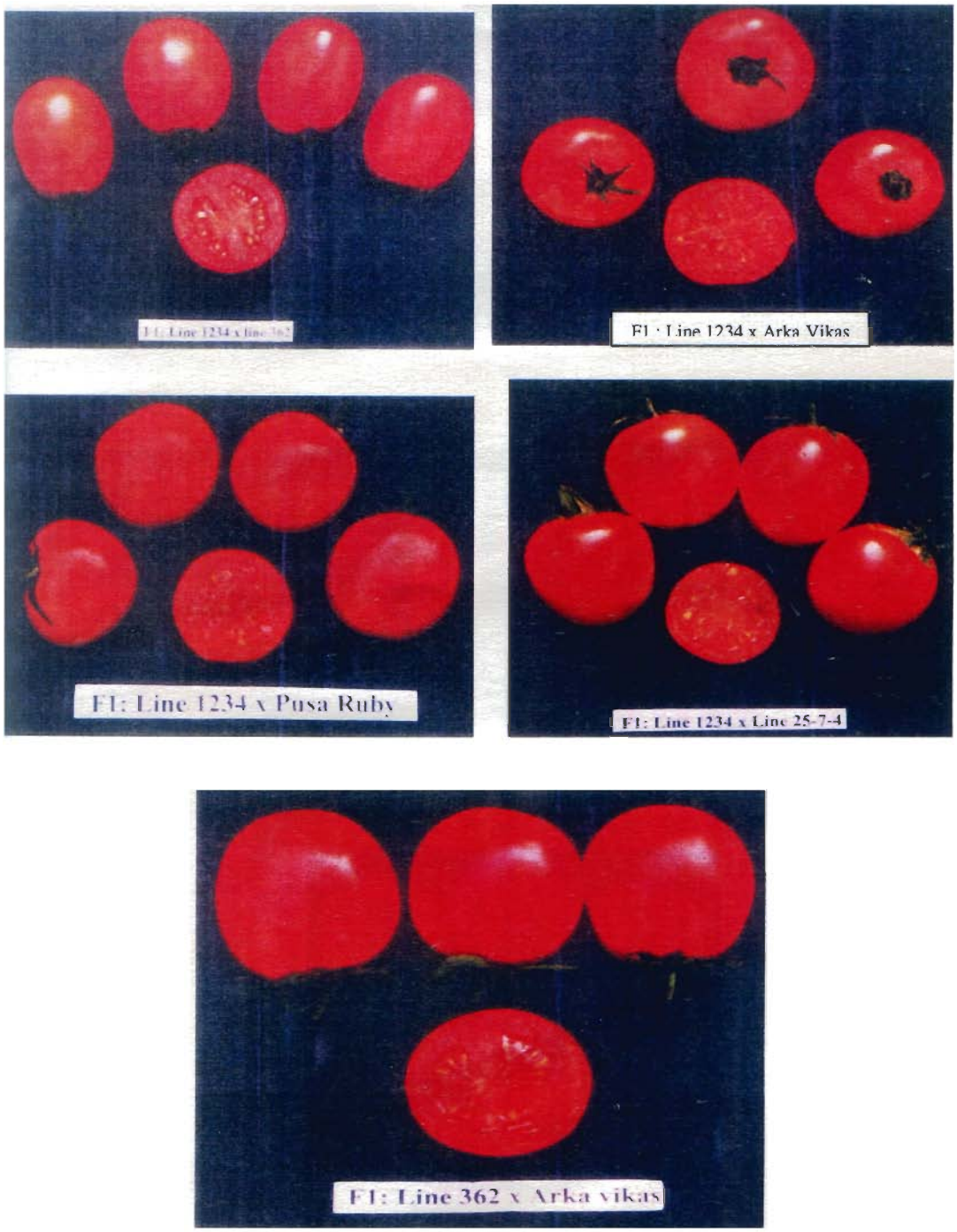


Plate 3 Contd…

water containing 1.0 g of ferric chloride in 300 ml of 2.0 N HCl and 68.0 g of sodium acetate. The mixture was cooled and made upto one litre.

The citric acid reagent was prepared by dissolving 20.0 g of citric acid and 50.0 g anhydrous calcium chloride in water and making upto one litre. The solution was heated to boiling and saturated ammonium oxalate solution was added drop by drop until a permanent turbidity was formed. The mixture was boiled, kept aside overnight and then filtered.

Procedure

One gram of dried plant material was added to 10.0ml of distilled water and 10.0 ml of citric acid reagent in a 250 ml of Erlenmeyer flask. The sample was extracted by shaking on a shaker for 10 minutes at room temperature. Heating upto 90^0C or longer extraction time did not give increased oxalate levels. The extract was filtered through Whatman No.42 filter paper. The precipitate on the filter paper was dissolved in 50.0 ml of 0.4 N HCl by shaking in 250 ml Erlenmeyer flask for 10 minutes. The same was filtered through Whatman No.40 filter paper. Two ml of the filtrate was added to three ml of ferron reagent and the volume was made up to 9.0 ml by adding 4.0 ml of 0.4 N HCl. The absorbance was read at 540 nm with a Bausch and Lomb Spectronic 20. Oxalic acid added to the plant sample indicated a 95-100 per cent recovery with this technique.

The above mentioned method was found to be reliable only in case of green plant material. In case of red and red-green plant material, anthocyanin pigment was found to mask the colour of ferron reagent. Out of several organic solvents tried, 20 per cent alcohol solution was found to be the best to remove

Plate 4 : Showing fruits of the F$_2$'s

red colour. The technique appears to be reasonably good as it gave 95-100 per cent recovery of added oxalates.

The method involved treatment of one gram plant material with 20 per cent alcohol. The mixture was kept on a shaker for 15 minutes. Thereafter, well-shaken material was subjected to centrifugation at 10,000 rpm for 10 minutes. The red pigment got separated in the supernatant. The green pellet collected and oxalate estimated as mentioned earlier.

However, the above mentioned method had to be modified as the technique of using 20 per cent alcohol did not completely remove the red colour in tomato (lycopene) and another technique was employed for removing the red colour from tomato samples in the present investigation. The method employed for removing the red colour from tomato samples in the present investigation was the use of activated charcoal. The method consisted of treating the required amount of plant sample (1.0 g) with equal amount activated charcoal and was subjected to shaking for 10 minutes and then filtered. The resulting colourless extract was used for estimation of oxalate in tomato fruit sample, as mentioned earlier.

3.4.1.2 Lycopene

Lycopene was extracted from 5.0 g of juice into acetone by repeatedly grinding the juice till a colourless residue was left. This colour was transferred into petroleum other using a separating funnel by repeated washing with water containing Na_2SO_4. Extracted colour was made up to known volume with petroleum ether and colour was red at 503 ηm using Spectrophotometer (Ranganna, 1986).

Plate 5 : Showing fruits of the BC_1's

3.4.1.3 Ascorbic acid

Ascorbic acid was estimated using 2, 6-dichloro-phenol indophenol dye and was expressed as gram of ascorbic acid per 100 ml of juice (Ranganna, 1986).

3.4.1.4 Acidity

Acidity was determined by titrating a known quantity of juice with 0.1 N sodium hydroxide using phenolphthalein as indictor. The acidity was expressed as gram of dry ascorbic acid per 100 ml of juice.

3.4.1.5 Total soluble solids (TSS)

A Hand Refractometer was used for the direct estimation total soluble solids (^{0}Brix) for fresh juice and the value corrected to 20^{0}C (Ranganna 1986).

3.4.2 PHYSICAL PARAMETERS

3.4.2.1 Locule number

The number of locules were counted in ten transversely cut fruits and average number was recorded.

3.4.2.2. Seediness

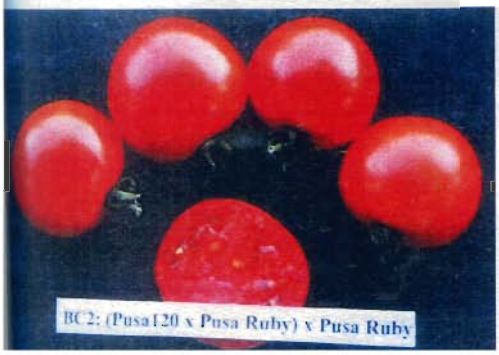
The seed was extracted from one kg of ripe fruit after fermenting for 24 hrs. The seeds were dried in shade at room temperature and weighed.

3.4.2.3. Yield

Ripe fruits were harvested four times at ten days interval from five selected plants for the study from each treatment and weight of the fruits were calculated by summing up the yield record of each harvest.


BC2: (Pusa 120 x Arka vikas) x Arka Vikas


BC2: (Line 362 x Arka Vikas)x Arka Vikas


BC2: (Pusa120 x Pusa Ruby) x Pusa Ruby

3.5. STATISTICAL METHODS

The data obtained on the above mentioned characters were subjected to the following statistical analysis.

1. Analysis of variance
2. Generation mean analysis
3. Correlation coefficients analysis
4. Path coefficient analysis.

3.5.1. Analysis of variance

The analysis of variance for various characters were carried out as suggested by Panse and Sukhatme (1967).

The difference between the treatments mean and the block mean were tested for their significance in analysis of variance. Method following the 'F' The analysis of variance table was set up as under :

Source of variation	**d.f.**	**s.s**	**m.s**	**F**
Blocks	r-1	$\frac{\sum B_j^2}{V}$ - C.F.	M_B	$\frac{M_B}{M_E}$
Treatments	v-1	$\frac{\sum T_i^2}{r}$ -C.F.	M_T	$\frac{M_T}{M_E}$
Error	(r-1)(t-1)	By subtraction S_E	M_E	-
Total	**r x t-1**	$\sum yij^2 - G^2/N$		-

In the above table, the term treatment refers to parental materials and the crosses (F_1, F_2, B_1 and B_2) and whenever sb was not significant the data from all the replications were pooled and combined and variance were calculated.

3.5.2. Generation mean analysis

3.5.2.1. Mean and variance

The mean variance and variance of mean were calculated as follows.

$$\text{Mean } (\bar{X}) = \frac{\sum x_i}{n}$$

$$\text{Variance} = \frac{1}{n}\left[\sum x_i^2 - \frac{\left(\sum x_i^2\right)}{n}\right]$$

$$\text{Variance of mean} = \frac{\text{Variance of the generation}}{\text{Total no. of observation}}$$

3.5.2.2. Detection of gene effects

Scaling test was used to detect digenic interaction components as per Mather (1949) and Hayman and Mather (1955). The estimates of gene effects were derived from the generation mean analysis joint scaling test (Cavalli, 1952) and perfect fit solution of Mather and Jinks (1971).

Before estimating the gene effects from the generation mean analysis, following assumptions were made.

a. normal diploid segregation

b. homozygous parents

c. absence of reciprocal cross differences

d. absence of multiple allelism

e. absence of linkage

f. equal viability of genotypes

g. absence of genotype x environment interaction.

3.5.2.3. Scaling test

The sealing test for judging the adequacy of simple additive dominance model was followed for those characters which exhibited significant difference among generation means. The sealing test as suggested by Mather (1949) and Hayman and Mather (1955) gave the following effects

$$A = 2\overline{B_1} - \overline{P_1} - \overline{F_1}$$

$$B = 2\overline{B_2} - \overline{P_2} - \overline{F_1}$$

$$C = 4\overline{F_2} - 2\overline{F_1} - \overline{P_1} - \overline{P_2}$$

$$D = 2\overline{F_2} - \overline{B_1} - \overline{B_1}$$

Where, $\overline{P_1}$ = mean of the parent (First)

$\overline{P_2}$ = mean of the parent (Second)

$\overline{F_1}$ = mean of the F_1 generation

$\overline{F_2}$ = mean of the F_2 generation

$\overline{B_1}$ = mean of backcross population with first parent

$\overline{B_2}$ = mean of backcross population with second parent

when the scale is adequate the value of A,B,C and D should be zero (A = B = C = D = 0) within the limits of their respective standard error as

$$S.E.(A) = (4\bar{V}B_1 + \bar{V}P_1 - \bar{V}F_1)^{1}/_{2}$$

$$S.E.(B) = (4\bar{V}B_2 + \bar{V}P_2 - \bar{V}F_1)^{1}/_{2}$$

$$S.E.(C) = (16\bar{V}F_1 + 4\bar{V}F_1 - \bar{V}P_1 - 4\bar{V}P_2)^{1}/_{2}$$

$$S.E.(D) = (4\bar{V}F_1 + \bar{V}P_1 - 4\bar{V}B_1)^{1}/_{2}$$

where, $\bar{VP}_1, \bar{VP}_2, \bar{VF}_1, \bar{VF}_2 \bar{VB}_1$ and $\bar{VB}_2$ where the mean of variances of P_1, P_2, F_1, F_2, B_1 and B_2 respectively.

The significance of each scale whether deviate significantly or not from the expected were tested by 't' test.

$$t(A) = {}^{A}/_{S.E.(A)}$$

$$t(B) = {}^{B}/_{S.E.(B)}$$

$$t(C) = {}^{C}/_{S.E.(C)}$$

$$t(D) = {}^{D}/_{S.E.(D)}$$

The calculated 't' values were compared with the tabulated 't' at 5 per cent and 1 per cent level of significance. If any of the scale is found to be significant, the additive dominance model is considered not adequate, indicating, the presence of non-allelic (epislasis) interactions, where as, if not significant, the model is adequate and non-allelic (epistatic) interactions were absent.

3.5.2.3. Joint sealing test

Adequacy of the additive-dominance model was further tested by joint sealing test proposed by Cavalli (1952). It consists of estimating the parameters (m), (d) and (h) from mean of the available generations followed

by a comparison of the observed generation means with expected values derived from the estimates of three parameters.

The adequacy of additive -dominance model was tested by chi-square test. The model is adequate when x^2 was non-significant, if otherwise, inadequate. This test thus provides the best possible estimates of all the parameters required to amount for differences among family means when the model is adequate.

3.5.2.4. Estimation of gene effects (non-allelic interaction interacting crosses)

When simple additive - dominance model was inadequate i.e. in the presence of non-allelic interactions six parameter model of Hayman (1958) was fitted and various components accordingly were

m = mean

d = additive

h = dominance

i = additive x additive

j = additive x dominance

l = dominance x dominance

All the above components were estimated from the population means of P_1, P_2, F_1, F_2, B_1, and B_2.

Where

$$m = \bar{F}_2$$
$$d = \bar{B}_1 - \bar{B}_2$$
$$h = \tfrac{1}{2}\bar{P}_1 - \tfrac{1}{2}\bar{P}_2 - \bar{F}_1 + 4\bar{F}_2 + 2\bar{B}_1 + 2\bar{B}_2$$
$$i = 2\bar{B}_1 + 2\bar{B}_2 - 4\bar{F}_2$$
$$j = \bar{B}_1 - \tfrac{1}{2}\bar{P}_1 - \bar{B}_2 + \tfrac{1}{2}\bar{P}_2$$
$$l = \bar{P}_1 + \bar{P}_2 + 2\bar{F}_1 + 4\bar{F}_2 - 4\bar{B}_1 - 4\bar{B}_2$$

The variance for the above gene effects were obtained as follows:

$$Vm = V\bar{F}_2$$
$$Vd = V\bar{B}_1 - V\bar{B}_2$$
$$Vh = \tfrac{1}{4}(V\bar{P}_1 - V\bar{P}_2) + V\bar{F}_1 + 16V\bar{F}_2 + 4(V\bar{B}_1 + V\bar{B}_2)$$
$$Vi = 16V\bar{F}_2 + 4(V\bar{B}_1 + V\bar{B}_2)$$
$$Vj = \tfrac{1}{4}(V\bar{P}_1 - V\bar{P}_1) + V\bar{B}_1 + V\bar{B}_2$$
$$Vl = V\bar{P}_1 + V\bar{P}_2 + 4\bar{F}_1 + 16\bar{F}_2 + 16V\bar{B}_1 + 16\bar{B}_2$$

The standard errors for each components were computed as follows:

$$S.E.(m) = \sqrt{V(m)}$$
$$S.E.(d) = \sqrt{V(d)}$$
$$S.E.(h) = \sqrt{V(h)}$$
$$S.E.(i) = \sqrt{V(i)}$$
$$S.E.(j) = \sqrt{V(j)}$$
$$S.E.(l) = \sqrt{V(l)}$$

The 't' values were calculated as follows

$t(m) = m/S.E(m)$
$t(d) = d/S.E(d)$
$t(h) = h/S.E(h)$
$t(i) = i/S.E(i)$
$t(j) = j/S.E(j)$
$t(l) = l/S.E(l)$

The significance of each genetic effect was tested by comparing the 't' calculated with 't' tabulated values at 5 per cent and 1 per cent levels of significance.

3.5.2.5. Estimation of gene effects (non-epistatic/non-interacting crosses/ three parameter model)

In the absence of non-allelic interaction or epistasis, gene effects for three parameters *viz.*, *m* (mean), *d* (additive) and *h* (dominance) were estimated by Jinks and Jones (1958).

$$m = \tfrac{1}{2}\bar{P}_1 + \tfrac{1}{2}\bar{P}_2 + 4\bar{F}_2 - 2\bar{B}_1 - 1\bar{B}_2$$
$$d = \tfrac{1}{2}P_1 - \tfrac{1}{2}\bar{P}_2$$
$$h = 6\bar{B}_1 + 6\bar{B}_2 - 8\bar{F}_2 - \bar{F}_1 - \tfrac{3}{2}P_1 - \tfrac{3}{2}\bar{P}_2$$

The variance for these estimated were computed as follows

$$Vm = \tfrac{1}{4}V\bar{P}_1 + \tfrac{1}{4}V\bar{P}_2 + 16\bar{F}_2 - 4V\bar{B}_1 + 4\bar{B}_2$$
$$Vd = \tfrac{1}{4}P_1 + \tfrac{1}{2}P_2$$
$$Vh = 36V\bar{B}_1 + 36V\bar{B}_2 + 64V\bar{F}_2 + V\bar{F}_1 + \tfrac{9}{4}VP_1 + \tfrac{9}{4}\bar{P}_2$$

The standard error (s) and 't' values were calculated as follows:

$$S.E.(m) = \sqrt{V(m)}$$
$$S.E.(d) = \sqrt{V(d)}$$
$$S.E.(h) = \sqrt{V(h)}$$

The 't' value was calculated as

$$t\,S.E.(m) = m/S.E(m)$$
$$t.S.E.(d) = d/S.E(d)$$
$$t\,S.E.(h) = h/S.E(h)$$

3.5.3. Correlation coefficients

With a view to study the different types of inter-relationship among various physical characters, the phenotypic and genotypic correlation coefficients were worked using the formula suggested by Al-Jibouri *et al.* (1958). The degree of correlation between two variables is measured by a correlation coefficients (P) and defined as :

$$\frac{\sigma xy}{\sigma x\,\sigma y}$$

where

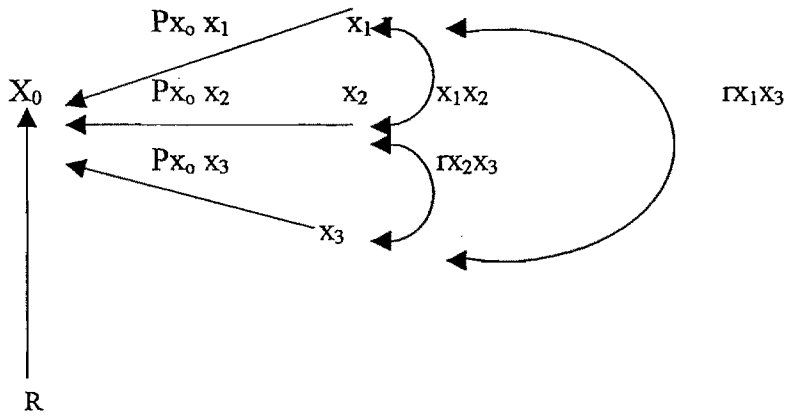
$$\sigma xy = \frac{\sum (x - \bar{x})(y - \bar{y})}{N}$$

In this expression σxy is known as covariance between x and y variables. Sign of σxy may be therefore, take a positive or negative sign. Estimate of *P* calculated from a ample is denoted by r. Whether positive or negative σxy does not exceed σx σy and consequently the correlation coefficient necessarily varies between +1 and -1.

3.5.4. Path coefficient analysis

Path coefficient analysis is based on standardized partial regression coefficient and helps to express the correlation coefficients in terms of direct

and indirect effects. It measures the direct and indirect contribution of independent variables on the dependent variable. Path coefficient analysis was carried out as suggested by Dewey and Lu (1959). Path analysis is a special type of multi-variate analysis, which deals with a 'closed' system of variables which are linearly related. X_0 is a character, which is linearly determined by correlated variables X_1, X_2 and X_3.



Where $Px_o : X_1$, $Px_o : X_2$, $Px_o : X_3$ represents the path coefficients form causes X_1, X_2 and X_3 respectively, rx_1,x_2, rx_1x_3 rx_2x_3 are the correlation coefficients and R is variation in X_o that is due to those agencies which are not known.

Path coefficient was calculated by Y solving the following set of *P* simultaneous equations.

Py.1 + Py.2r1.2 + Py.3r1.3 +Py.nr1.n ..... = r1.y

Py.1r1.2 + Py.2+Py.3r1.3 + Py.nr.2n .....= r2.y

⋮

Py.1r1.n+Py.2r2.n+Py.3r3.n+Py.n....= rn.y

Where, Py.1, Py.2, Py.3...Py.n are the direct path effect of variables 1,2,3...n on the dependent variable y.

r1.y, r2.y...rn.y are the total correlation coefficient between the independent variable and the dependent variable y.

Least square estimates of these equations give the value of the direct coefficients of Py.1, Py.2.... and Py.n. The indirect effect of i^{th} variable via the n^{th} variable was worked out as $Py.n^{r}i.n$.

The residual effect calculated as square root of the residual degree of determination was worked out from the following equation.

$$P^2y.0 = 1 - (P^2y.1 + 2Py.1^{r}\ 1.2\ Py.2 + 2Py.1^{r}\ 1.3$$

$$Py.3\ .....+ P^2y.2 + 2Py.2^{r}\ 2.3\ Py.3 +.....+ P^2y.3 +.....+P^2y.3)$$

4. EXPERIMENTAL RESULTS

Results of the present investigation are presented under the following heads :

4.1 Analysis of variance

4.2 Mean performance of parents, F_1's, F_2's, B_1's and B_2's

4.3 Estimates of gene effects

4.4 Correlations

4.5 Path coefficient analysis

4.1 Analysis of variance

Before taking up the genetical analysis, the analysis of variance was done for all the characters under study by taking the parents (P_1 and P_2), F_1's, F_2's and backcrosses (B_1 and B_2). Significant difference between the treatments (genotypes) was observed in all the characters except for lycopene and acidity. Block differences were not significant in any of the characters. On the basis of this, the ungrouped randomisation methods was followed under the present investigation. The results have been presented in Table 2.

4.2 Mean performance of parents, F_1's, F_2's, B_1's and B_2's

The overall mean performance the parents, F_1's, F_2's, B_1's and B_2's on all characters studied have been presented in Table 3.

4.2.1 Oxalates (mg/100g)

There was significant variation among treatments for the character concerned (Table 3). Among the parents, the lowest content of oxalates (1.06 mg/100g) was found in Pusa 120, followed by Line362 (1.18 mg/100g). The

Table 2 : Analysis of variance for characters studied in a 6 x6 diallel cross of tomato

Source of variation	d.f.	Mean sum of squares							
		Oxalate (mg/100 g)	Lycopene (mg/100 ml juice)	Ascorbic acid (mg/100 ml juice)	Acidity (g/100g juice)	Total soluble Solids (^{o} Brix)	Locule number (per fruit)	Seediness (g/kg fruit)	Yield (kg/plant)
Replications	2	0.0811	0.0026	0.2187	0.0007	0.0129	0.0308	0.0051	0.0167
Treatments	65	1.857**	0.0406	5.3582**	0.0187	0.7403**	2.4675**	0.7948**	0.5131**
Errors	130	0.0103	0.0030	0.1861	0.0009	0.0119	0.0232	0.0369	0.0104
C.D. P=0.05%		**0.162**	**0.098**	**0.690**	**0.048**	**0.175**	**0.244**	**0.308**	**0.165**

highest content of oxalates (3.51 mg/100g) was found in Line25-7-4, followed by Arka Vikas (3.45 mg/100g).

In the F_1 generation, the lowest content of oxalates (1.08 mg/100 mg) was observed in Pusa 120 x Line362 followed by Pusa 120 x Line1234 (1.13 mg/100g). The highest content of oxalates was found in Arka Vikas x Pusa Ruby (3.23 mg/100g) followed by Arka Vikas x Line25-7-4 (3.06 mg/100g). In the F_2, generation two crosses, namely Pusa 120 x Line1234 (1.12 mg /100mg) and Line1234 x Line362 (1.21 mg/100g) had the lowest content of oxalates. The highest content of oxalates was found in Arka Vikas x Line25-7-4 (3.29 mg /100mg) followed by Arka Vikas x Pusa Ruby and Pusa Ruby x Line 25-7-4 (3.13 mg /100mg).

Among the B_1 generation, the lowest content of oxalates (1.15 mg /100mg) was found in (Pusa 120 x Line362) x Pusa 120 whereas, the highest content of oxalates (3.40 mg /100mg) was recorded in (Arka Vikas x Pusa Ruby) x Arka Vikas. In the B_2 generation, oxalates content was lowest in (Pusa 120 x Line362) x Line362 (1.15 mg /100mg) followed by (Line1234 x Line362) x Line362 (1.19 mg /100mg) which was at par. The highest content of oxalates (3.34 mg /100mg) was recorded in (Pusa Ruby x Line25-7-4) x Line25-7-4 and (Arka Vikas x Pusa Ruby) x Pusa Ruby.

4.2.2. Lycopene (mg/100 ml)

The overall mean performance of different generations on lycopene content have been presented in Table 3. No significant variation was observed among different generations for the character studied. In the parents, Pusa 120

Table 3 : Mean performance of parents F_1's F_2's B_1's and B_2's in a 6 x 6 diallel crosses of tomato

Pedgree	Characters							
	Oxalates (mg/100 g)	Lycopene (mg/100g)	Ascorbic acid (mg/100g)	Acidity (g/100g juice)	TSS (juice ^{0} brix)	Locule No. per fruit	Seediness (g/kg fruit)	Yield (kg/plant)
	1	2	3	4	5	6	7	8
Parents								
Pusa 120	1.06	1.34	18.20	0.55	4.80	5.67	0.78	2.52
Line 1234	1.23	1.60	18.13	0.54	4.93	2.51	1.89	1.50
Line 362	1.18	1.68	16.28	0.58	3.53	2.51	0.53	1.25
Arka Vikas	3.45	1.64	17.47	0.36	3.67	4.32	0.71	2.10
Pusa Ruby	3.22	1.90	19.38	0.65	5.68	5.26	2.39	2.18
Line 25-7-4	3.51	1.42	13.50	0.36	4.52	4.24	2.12	2.54
F_1 Crosses								
Pusa 120 x Line 1234	1.13	1.45	17.92	0.52	4.87	4.11	1.04	2.03
Pusa 120 x Line 362	1.08	1.52	17.98	0.55	4.09	2.49	0.66	1.90
Pusa 120 x Arka Vikas	1.96	1.55	17.71	0.52	4.32	5.01	0.70	3.14
Pusa 120 x Pusa Ruby	2.05	1.71	18.53	0.61	5.13	4.34	1.62	2.41
Pusa 120 x Line 25-7-4	2.20	1.30	15.05	0.42	4.01	5.04	1.93	2.55
Line 1234 x Line 362	1.17	1.53	17.85	0.52	4.24	2.22	1.05	1.40
Line 1234 x Arka Vikas	2.14	1.53	16.03	0.48	3.68	3.78	1.26	1.85
Line 1234 x Pusa Ruby	2.26	1.61	17.77	0.60	4.25	2.16	2.17	1.85
Line 1234 x Line 25-7-4	2.23	1.41	17.14	0.47	4.68	3.33	2.01	2.02
Line 362 x Arka Vikas	2.46	1.59	16.14	0.47	3.46	3.35	0.62	1.93

Contd.....

	1	2	3	4	5	6	7	8
Line 362 x Pusa Ruby	2.50	1.67	17.45	0.62	4.68	2.35	1.51	1.82
Line 362 x Line 25-7-4	2.32	1.54	15.87	0.48	4.02	2.18	1.77	1.96
Arka Vikas x Pusa Ruby	3.23	1.63	18.44	0.59	4.74	4.25	1.55	2.11
Arka Vikas x Line 25-7-4	3.06	1.58	16.40	0.36	4.13	4.53	1.33	2.35
Pusa Ruby x Line 25-7-4	3.02	1.55	16.45	0.55	5.12	4.55	2.28	2.38
F_2 Crosses								
Pusa x Line 1234	1.12	1.55	17.77	0.49	4.20	4.07	1.20	1.63
Pusa 120 x Line 362	1.17	1.53	17.89	0.48	3.98	3.25	0.67	1.85
Pusa 120 x Arka Vikas	2.17	1.60	17.96	0.51	4.44	4.35	0.69	2.96
Pusa 120 x Pusa Ruby	2.14	1.68	18.02	0.60	4.93	5.48	1.57	2.37
Pusa 120 x Line 25-7-4	2.14	1.33	14.12	0.38	3.94	3.88	1.85	2.33
Line 1234 x Line 362	1.21	1.61	17.00	0.49	4.03	2.52	0.97	1.24
Line 1234 x Arka Vikas	3.02	1.59	15.10	0.46	4.11	2.25	1.03	1.78
Line 1234 x Pusa Ruby	2.13	1.74	17.47	0.62	4.10	3.89	2.00	1.81
Line 1234 x Line 25-7-4	2.74	1.54	14.85	0.45	4.21	2.98	1.98	1.88
Line 362 x Arka Vikas	2.58	1.56	16.07	0.47	3.25	3.13	0.59	1.78
Line 362 x Pusa Ruby	2.63	1.66	16.00	0.58	4.12	2.48	1.50	1.68
Line 362 x Line 25-7-4	2.21	1.63	15.08	0.48	3.75	2.69	1.42	1.90
Arka Vikas x Pusa Ruby	3.13	1.63	18.02	0.47	4.20	4.07	1.49	1.90
Arka Vikas x Line 25-7-4	3.29	1.56	16.77	0.33	3.95	3.21	1.40	2.18
Pusa Ruby x Line 25-7-4	3.13	1.69	16.05	0.51	4.87	3.28	2.10	2.28
Backcrosses B_1								
(Pusa 120 x Line 1234) x Pusa 120	1.18	1.48	17.17	0.48	4.04	4.09	0.96	1.74
(Pusa 120 x Line 362) x Pusa 120	1.15	1.46	16.75	0.50	4.01	3.56	0.60	1.81
(Pusa 120 x Arka Vikas) x Pusa 120	2.08	1.45	18.38	0.49	4.06	3.00	0.69	3.06
(Pusa 120 x Pusa Ruby) x Pusa 120	1.84	1.69	17.87	0.58	4.60	3.85	1.58	2.39
(Pusa 120 x Line 25-7-4) x Pusa 120	2.20	1.32	12.72	0.41	4.12	4.49	1.44	2.31

Contd.....

	1	2	3	4	5	6	7	8
(Line 1234 x Line 362) x Line 1234	1.21	1.60	16.72	0.50	4.05	2.08	1.05	1.19
(Line 1234 x Arka Vikas) x Line 1234	2.58	1.58	15.92	0.47	4.03	2.82	1.03	1.73
(Line 1234 x Pusa Ruby) x Line 1234	2.88	1.64	16.76	0.58	3.95	3.18	1.95	1.81
(Line 1234 x Line 25-7-4) x Line 1234	2.34	1.46	16.12	0.48	4.39	2.14	1.90	1.83
(Line 362 x Arka Vikas) x Line 362	2.18	1.56	15.96	0.45	3.39	2.84	0.59	1.55
(Line 362 x Pusa Ruby) x Line 362	2.12	1.69	16.68	0.57	3.94	3.39	0.91	1.80
(Line 362 x Line 25-7-4) x Line 362	2.03	1.59	14.77	0.51	3.44	2.51	1.40	1.75
(Arka Vikas x Pusa Ruby) x Arka Vikas	3.40	1.58	16.92	0.51	3.90	2.33	1.07	1.64
(Arka Vikas x Line 25-7-4) x Arka Vikas	3.36	1.59	16.91	0.33	4.07	4.20	1.04	2.16
(Pusa Ruby x Line 25-7-4)x Pusa Ruby	3.26	1.74	15.52	0.60	4.95	3.09	2.14	2.18
Back crosses B_2								
(Pusa 120 x Line 1234) x Line 1234	1.21	1.53	18.08	0.49	4.24	3.18	1.14	1.60
(Pusa 120 x Line 362) x Line 362	1.15	1.54	16.98	0.51	3.93	4.00	0.54	1.67
(Pusa 120 x Arka Vikas) x Arka Vikas	2.54	1.45	18.14	0.39	3.94	4.08	0.68	3.13
(Pusa 120 x Pusa Ruby) x Pusa Ruby	3.13	1.85	18.25	0.62	5.23	3.75	1.61	2.26
(Pusa 120 x Line 25-7-4) x Line 25-7-4	2.33	1.38	15.58	0.39	4.08	4.22	1.92	2.36
(Line 1234 x Line 362) x Line 362	1.19	1.60	16.54	0.51	3.66	2.23	0.82	1.25
(Line 1234 x Arka Vikas) x Arka Vikas	3.25	1.54	14.98	0.42	3.55	3.24	1.00	1.80
(Line 1234 x Pusa Ruby) x Pusa Ruby	3.18	1.70	16.91	0.59	4.10	4.50	2.03	1.95
(Line 1234 x Line 25-7-4) x Line 25-7-4	3.17	1.54	15.65	0.46	4.19	3.14	2.00	1.95
(Line 362 x Arka Vikas) x Arka Vikas	3.00	1.54	15.78	0.44	3.38	3.07	0.61	1.87
(Line 362 x Pusa Ruby) x Pusa Ruby	2.72	1.75	17.41	0.60	4.87	2.50	1.01	1.93
(Line 362 x Line 25-7-4) x Line 25-7-4	2.68	1.60	14.31	0.44	4.00	2.92	1.36	1.70
(Arka Vikas x Pusa Ruby) x Pusa Ruby	3.34	1.71	17.95	0.49	4.08	4.03	1.49	1.91
(Arka Vikas x Line 25-7-4) x Line 25-7-4	3.31	1.50	15.83	0.32	4.04	4.15	1.24	2.05
(Pusa Ruby x Line 25-7-4)x Line 25-7-4	3.34	1.68	14.89	0.54	4.58	3.20	2.09	2.25

had the lowest content of lycopene (1.34 mg/100 ml) whereas, the highest content (1.90 mg /100ml) was recorded in Pusa Ruby.

In the F_1generation, the content of lycopene was lowest in Pusa 120 x Line 25-7-4 (1.30 mg /100ml) followed by Line1234 x Line25-7-4 (1.41 mg /100ml). The highest content (1.71 mg /100ml) was observed in Pusa 120 x Pusa Ruby followed by Line362 x Pusa Ruby (1.67 mg /100ml). In the F_2 generation, the lowest content (1.33 mg /100ml) of lycopene was recorded in Pusa 120 xLine25-7-4. Lycopene content was highest (1.74 mg /100ml) in Line1234 x Pusa Ruby followed by Pusa Ruby x Line25-7-4 (1.69 mg /100ml).

In the B_1 generation, the lycopene was lowest (1.32 mg /100ml) in (Pusa 120 x Line25-7-4) x Pusa 120 whereas, the highest content (1.74 mg /100ml) was observed in (Pusa Ruby x Line25-7-4) x Pusa Ruby. In B_2 generation, the lowest content (1.38 mg /100ml) of lycopene was observed in (Pusa 120 x Line25-7-4) x Line25-7-4. While two crosses, namely (Line362 x Pusa Ruby) x Pusa Ruby (1.75 mg /100ml) followed by (Arka Vikas x Pusa Ruby) x Pusa Ruby (1.71 mg /100ml) had the highest contents.

4.2.3. Ascorbic acid (mg/100ml)

The mean performance of different generations on ascorbic acid content have been presented in Table 3. There was significant variation among different generations for the character under study. Among the parents, the lowest content (13.50 mg /100ml) of ascorbic acid was found in Line25-7-4 whereas the highest content (19.38 mg /100ml) was recorded in Pusa Ruby. In the F_1 generation, ascorbic acid content was lowest (15.05 mg/100 ml) in Pusa 120 x Line25-7-4. The highest content was recorded in Pusa 120 x Pusa Ruby (18.53

mg/100 ml) followed by Arka Vikas x Pusa Ruby (18.44 mg/100 ml) which were at par. In the F_2 generation, lowest content (14.12 mg/100 ml) of ascorbic acid was recorded in Pusa 120 x Line25-7-4 followed by Line1234 x Line25-7-4 (14.85 mg/100 ml) whereas, the highest ascorbic acid content (18.02 mg/100 ml) was recorded in two crosses, namely Arka Vikas x Pusa Ruby and Pusa 120 x Pusa Ruby. In the lowest ascorbic acid content (12.72 mg/100 ml) of ascorbic acid was recorded in (Pusa 120 x Line25-7-4) x Pusa 120 in the B_1 generation, whereas, the highest content (18.38 mg/100 ml) was found in (Pusa 120 x Arka Vikas) x Pusa 120. In B_2 generation, ascorbic acid was lowest (14.31 mg/100 ml) was found in (Line 362 x 25-7-4) x Line25-7-4. The highest content (18.25 mg/100 ml) was recorded in (Pusa 120 x Pusa Ruby) x Pusa Ruby.

4.2.4. Acidity (g/100g)

The overall mean performance of different generations for the character under study has been presented in the Table 3. Differences were not significant among treatments. In parents, acidity varied from 0.36 g/100g (Arka Vikas and Line25-7-4) to 0.65 g/100g (Pusa Ruby).

In the F_1 generation, the acidity was found lowest (0.36 g/100g) in Arka Vikas x Line25-7-4. The highest (0.62 g/100g) content of acidity was recorded in Line362 x Pusa Ruby. In F_2 generation, the lowest acidity (0.33 g/100g) was recorded in Arka Vikas x Line 25-7-4 whereas, the highest acidity (0.62 g/100g) was recorded in Line1234 x Pusa Ruby.

In the B_1 generation, the acidity was lowest (0.33 g/100g) in (Arka Vikas x Line 25-7-4) x Arka Vikas and the maximum acidity (0.60 g/100g) was recorded in (Pusa Ruby x Line25-7-4) x Pusa Ruby. In the B_2 generation, the

acidity was found lowest (0.32 g/100g) in (Arka Vikas x Line 25-7-4) x Line 25-7-4 x whereas, the maximum (0.62 g/100g) was found in (Pusa 120 x Pusa Ruby) x Pusa Ruby.

4.2.5. Total Soluble solids (TSS ^{0}Brix)

The overall mean performance of different generations for the character under study has been presented in Table 3. Differences were significant among different treatments. Among the parents TSS ranged from 3.53 ^{0}Brix (Line362) to 5.68 ^{0}Brix (Pusa Ruby).

In the F1 generation, TSS was found lowest (3.46 ^{0}Brix) in Line362 x Arka Vikas. Maximum TSS (5.13 ^{0}Brix) was recorded in Pusa 120 x Pusa Ruby followed by Pusa Ruby x Line25-7-4(5.12 ^{0}Brix) which was at par. Line362 x Arka Vikas exhibited the lowest (3.25 ^{0}Brix) TSS in the F_2 generation. The maximum TSS (4.93 ^{0}Brix) was recorded in Pusa 120 x Pusa Ruby, followed by Pusa Ruby x Line25-7-4 (4.87 ^{0}Brix) which was at par.

In B_1 generation, the lowest TSS was found in two crosses, namely (Line362 x Arka Vikas) x Line362 and in (Line362 x Line25-7-4) x Line362, 3.39 ^{0}Brix and 3.44 ^{0}Brix, respectively. Maximum TSS (4.95 ^{0}Brix) was recorded in (Pusa Ruby x Line25-7-4) x Pusa Ruby. In the B_2 generation, (Line362 x Arka Vikas) x Arka Vikas had the lowest TSS (3.38 ^{0}Brix). The maximum TSS (5.23 ^{0}Brix) was recorded in (Pusa 120 x Pusa Ruby) x Pusa Ruby.

4.2.6. Locule number (per fruit)

The overall mean of different generations for the character concerned has been presented in Table 3. Differences were significant among the

treatments. The number of locules per fruit varied from 2.51 (Line1234 and Line362) to 5.67 in Pusa 120, among the parents.

In the F_1 generation, the minimum number of locules per fruit (2.16) was observed in Line1234 x Pusa Ruby followed by Line362 x Line25-7-4 (2.18) which was at par. The maximum number of locules (5.04 and 5.01) were observed in two crosses, namely Pusa 120 x Line25-7-4 and Pusa 120 x Arka Vikas, respectively. In F_2 generation, the minimum number of locules (2.25) was observed in Line1234 x Arka Vikas. The maximum number of locules (5.48) was recorded in Pusa 120 x Pua Ruby.

In the B_1 generation, two crosses recorded the minimum number of locules 2.08 and 2.14 (Line1234 x Line362) x Line1234 and (Line1234 x Line25-7-4) x Line1234, respectively. The maximum number of locules (4.49) was observed in (Pusa 120 x Line25-7-4) x Pusa 120. In the B_2 generation, the minimum number of locules (2.23) were observed in (Line1234 x Line362) x Line1234 while maximum number of locules (4.50) were observed in (Line1234 x Pusa Ruby) x Pusa Ruby.

4.2.7. Seediness (g/kg of fruit)

Differences were significant among different generations for the character under study. The overall mean performance of all the generations for the character seediness has been presented in Table 3. The trait, seediness showed significant difference among the parents. The lowest content of seed (0.53 g) was observed in Line362. The maximum seed content (2.39g) was recorded in Pusa Ruby.

Among the F_1 generation, the lowest content of seed (0.62 g) was recorded in Line362 x Arka Vikas followed by Pusa 120 x Line362 (0.66g). The maximum amount (2.28 g) of seed was observed in Pusa Ruby x Line25-7-4. In the F_2 generation, seediness was lowest (0.59 g) Line362 x Arka Vikas followed by Pusa 120 x Line362 (0.67 g). The maximum seed content (2.10 g) was recorded in Pusa Ruby x Line25-7-4.

In the B_1 generation, (Line362 x Arka Vikas) x Line362 recorded the lowest seediness (0.59 g) followed by (Pusa 120 x Line362) x Pusa 120 (0.60 g) which was at par. The maximum seediness (2.14 g) was observed in (Pusa Ruby x Line2-7-4) x Pusa Ruby. In B_2 generation, the minimum seediness (0.54 g) was observed in (Pusa 120 x Line362) x Line362, while the maximum seediness (2.09g) was reocrded in (Pusa Ruby x Line25-7-4) x Line25-7-4 followed by (Line1234 x Pusa Ruby) x Pusa Ruby (2.03 g) which was at par.

4.2.8. Yield (kg/Plant)

Significant differences were observed among the generations for the characters under study. The overall mean for yield of all the generations has been presented in Table 3. Among the parents, the lowest yield (1.25 kg) was recorded in Line362 whereas, Pusa 120 and Line25-7-4 recorded the highest yield of 2.52 kg and 2.54 kg, respectively.

In the F_1 generation, the lowest yield (1.40 kg) was observed in Line1234 x Line362 whereas, the highest yield (3.14 kg) was recorded in Pusa 120 x Arka Vikas. Among the F_2 generation, Line1234 x Line362 recorded the lowest yield of 1.24 kg per plant whereas, the highest yield (2.96 kg) was observed in Pusa 120 x Arka Vikas.

Among the B_1 generation, the lowest yield (1.19 kg) was recorded in (Line1234 x Line362) x Line1234, whereas, (Pusa 120 x Arka Vikas) x Pusa 120 recorded the highest yield of 3.06 kg per plant. In B_2 generation, (Line1234 x Line362) x Line362 recorded the lowest yield of 1.25 kg per plant. The highest yield (3.13 kg) was observed in (Pusa 120 x Arka Vikas) x Arka Vikas.

4.3. Estimates of gene effects (based on generation mean analysis)

Six parameters for gene effects *viz. m, d, h, I, j* and *l* were estimated for crosses showing non-allelic interactions (epistasis) whereas, three paramters *m, d, h* with D and H were estimated for those crosses showing absence of non-allelic interactions. The significance of the parameters was tested by means of the corresponding standard errors which were calculated using either the variance of the population means in a six parameter model or from error variance in a three parameter model. The crosses in which chi-square (χ^2) was significant were considered as interacting (non-allelic or epistasis) otherwise, non-interacting (allelic).

The interacting crosses have been further classified into two groups namely, complementary and duplicate epistasis. The epistasis was complementary when *h* and *l* had the same signs (either + or -). Epistatsis was duplicate when *h* and *l* had opposite signs.

Simple scaling test (Mather, 1949 and Hayman and Mather, 1995) was applied to detect the presence of non-allelic interaction. If any of the parameters (A, B, C and D) of the simple scaling test was significant it proved to be an interacting (non-allelic or epistasis) cross. In such cases, joint scaling that (Cavalli, 1952) was applied. In the joint scaling test, the weighted least

squares of estimates of gene effects were obtained from the simple additive - dominance model. Under the situation when three parameter model was inadequate (χ^2 significant), six parameter model was applied for detecting digenic interactions in addition to the main gene effects.

The character wise estimates of scaling tests, gene effects, and chi-square (χ^2) values has been presented in Table 4 to Table 11.

4.3.1. Oxalates

The estimates of simple scaling test, gene effects and χ^2 value for the character concerned has been presented in Table 4. Estimates for the scales (A, B, C and D) were significant. χ^2 values were also significant except in one cross, indicating non-allelic interaction. The main effect (*m*) was significant in all the crosses indicating significant variability among the hybrids.

Additive gene effects (*d*) were significant in nine crosses with negative estimates which were in desirable direction. The highest magnitude of negative additive effect (-1.29) was observed in Pusa 120 x Pusa Ruby. Six crosses were non-significant. In one cross, Line1234 x Line362, additive-dominance model was found to be adequate.

Significant dominant gene effects (*h*) were recorded in six crosses, out of which one cross (Line362 x Pusa Ruby) had significant negative estimate which was in the desirable direction and five crosses had significant positive estimates. In the rest of the nine crosses *h* estimates were non significant. The magnitude of dominant gene effects were higher than that of additive gene effects.

Table 4 Gene effects for oxalate content in a 6 x 6 diallel cross of tomato

Crosses	m	D	h	i	j	l	A	B	C	D	χ^2	Type(s) of gene acti
Pusa 120 x Line1234	**1.12****	**-0.03**	**0.28***	**0.38***	**0.06**	**-0.54***	**1.77****	**0.06**	**-0.06**	**-0.15**	**4.51***	D
	± 0.02	0.06	0.14	0.14	0.06	0.27	0.1	0.08	0.08	0.07		
Pusa 120 x Line362	**1.17****	**0.00**	**1.10**	**-0.07**	**0.06**	**-0.14**	**0.16**	**0.04**	**0.27**	**0.03**	**7.34***	D
	± 0.02	0.01	0.15	0.16	0.06	0.27	0.01	0.09	0.11	0.07		
Pusa 120 x Arka Vikas	**2.17****	**-0.46****	**0.26**	**0.56****	**0.74****	**-1.36****	**1.14****	**-0.34***	**0.25**	**-0.28***	**200.69****	D
	± 0.05	0.08	0.26	0.25	0.08	0.40	0.88	0.17	0.22	0.12		
Pusa 120 x Pusa Ruby	**2.14****	**-1.29****	**1.28****	**1.37****	**-0.21**	**-2.94****	**0.56****	**0.99***	**0.19**	**-0.69****	**133.82****	D
	± 0.05	0.20	0.45	0.45	0.20	0.84	0.51	0.41	0.20	0.22		
Pusa 120 x Line25-7-4	**2.14****	**-0.13****	**0.41****	**0.50****	**1.10****	**-0.58****	**1.14****	**-1.06****	**-0.41****	**-0.25****	**1073.99****	D
	± 0.02	0.03	0.12	0.11	0.03	0.17	0.06	0.06	0.11	0.06		-
Line1234 x Line362	**1.21****	**0.02**	**-0.07**	--	--	--	**0.01**	**0.03**	**0.07**	**0.02**	**1.05**	-
	± 0.02	0.03	0.09				0.05	0.06	0.07	0.04		
Line1234 x Arka Vikas	**3.02****	**-0.67****	**-0.62**	**-0.42**	**0.44****	**-2.27****	**1.79****	**0.91****	**3.12****	**0.21**	**226.26****	C
	± 0.08	0.14	0.44	0.43	0.14	0.67	0.14	0.26	0.34	0.21		
Line1234 x Pusa Ruby	**2.13****	**-0.30****	**3.80****	**3.60****	**0.52****	**-7.09****	**2.27****	**1.22****	**-0.11**	**-1.80****	**262.67****	D
	± 0.05	0.08	0.30	0.24	0.18	0.50	0.16	0.33	0.38	0.12		
Line1234 x Line25-7-4	**2.73****	**0.83****	**-0.07**	**0.06**	**0.31****	**-1.87****	**1.21****	**0.59****	**1.74****	**-0.03**	**121.47****	C
	± 0.07	0.09	0.34	0.34	0.09	0.50	0.12	0.14	0.30	0.17	-	-
Line362 x Arka Vikas	**2.57****	**-0.81****	**0.18**	**0.05**	**0.32****	**-0.86**	**0.72****	**0.08***	**0.76**	**-0.02**	**17.45****	D
	± 0.22	0.09	0.91	0.92	0.09	0.96	0.18	0.04	0.90	0.46		
Line362 x Pusa Ruby	**2.62****	**-0.60****	**-0.54****	**-0.83****	**0.42**	**0.55**	**0.56****	**-0.28***	**1.11****	**0.41****	**57.58****	D
	± 0.03	0.07	0.21	0.2	0.08	0.37	0.12	0.14	0.22	0.1		
Line362 x Line25-7-4	**2.21****	**-0.65****	**0.55**	**0.57**	**0.51****	**-0.66**	**0.56****	**-0.47**	**-0.48****	**-0.28**	**592.68****	D
	± 0.02	0.17	0.35	0.35	0.17	-0.69	0.03	0.34	0.08	0.6		
Arka Vikas x Pusa Ruby	**3.13****	**0.05**	**0.86****	**0.96****	**-0.06***	**-1.30****	**0.11****	**0.23****	**-0.61****	**-0.48****	**38.83****	D
	± 0.06	0.03	0.29	0.28	0.03	0.3	0.06	0.04	0.29	0.14		
Arka Vikas x Line25-7-4	**3.29****	**0.06**	**-0.24**	**0.18**	**0.09**	**-0.43**	**0.21**	**0.04**	**0.07**	**-0.09**	**2.81***	C
	± 0.02	0.07	0.17	0.17	0.07	0.31	0.14	0.04	0.1	0.08		
Pusa Ruby x Line25-7-4	**3.13****	**0.08**	**0.34**	**0.68****	**0.06***	**-1.11****	**0.28****	**0.15***	**-0.25**	**-0.34****	**37.37****	D
	± 0.03	0.18	0.18	0.18	0.03	0.22	0.06	0.07	0.19	0.09		

*, ** significant at 5 % and 1 %, respectively

In eight crosses additive x additive gene effects (*i*) were found to be significant out of which one cross, Line362 x Pusa Ruby, had significant negative estimate which was in the desired direction and the other crosses had significant positive estimates. The highest magnitude with significantly positive estimate (3.60) was recorded in Line1234 x Pusa Ruby. Additive x dominant gene effects (*j*) were found significant in nine crosses, out of which one cross, Arka Vikas x Pusa Ruby had significant and negative estimates (-0.06). The highest magnitude of significant and positive estimate (1.10) was recorded in Pusa 120 x Line25-7-4. In six crosses *j* effects were non- significant.

Significant dominant x dominant gene effects (*l*) were observed in nine crosses and were in negative direction, which was desirable in this trait. The highest magnitude of significantly negative estimate (-7.09) was recorded in Line1234 x Pusa Ruby. In the remaining six crosses *l* was non-significant. Three out of the fifteen crosses had the same sign in *h* and *l* which indicated complementary epistasis whereas, the eleven crosses had opposite sings of *h* and *l* which indicated duplicate type of epistasis.

4.3.2. Lycopene

Results of simple scaling test and gene effects has been presented in Table 5. Estimates of scales were significant and also χ^2 values were observed to be significant thirteen crosses. The main effects (*m*) were significant in all the crosses indicating significant variability among the hybrids. Additive-dominance model was adequate in three crosses, and these three crosses were considered as non-interacting.

Table 5 Gene effects for lycopene content in a 6 x 6 diallel cross of tomato

Crosses	m	D	h	i	j	l	A	B	C	D	χ^2	Type(s) of gene action
Pusa 120 x Line1234	**1.55****	**-0.05**	**-0.20****	**-0.20***	**0.08****	**0.01**	**0.17****	**0.01**	**0.36****	**0.09***	**20.11****	D
	± 0.02	0.03	0.01	0.09	0.03	0.15	0.06	0.05	0.10	0.05		
Pusa 120 x Line362	**1.53****	**-0.08****	**-0.12**	**-0.13**	**0.09****	**0.18**	**0.06**	**0.12****	**0.07**	**0.06**	**10.07***	D
	± 0.05	0.03	0.21	0.21	0.03	0.24	0.06	0.04	0.20	0.10		
Pusa 120 x Arka Vikas	**1.60****	**0.00**	**-0.60****	**-0.61****	**0.15****	**0.91****	**0.01**	**-3.00****	**0.32****	**0.31****	**98.86****	D
	± 0.01	0.03	0.08	0.07	0.04	0.16	0.07	0.07	0.09	0.04		
Pusa 120 x Pusa Ruby	**1.68****	**-0.14****	**0.38****	**0.29****	**0.15****	**-0.70****	**0.33****	**0.04**	**0.08**	**-0.14****	**147.48****	D
	± 0.01	0.03	0.09	0.08	0.03	0.14	0.03	0.06	0.07	0.04		
Pusa 120 x Line25-7-4	**1.33****	**-0.06***	**-0.00**	–	–	–	**0.01**	**0.04**	**-0.03**	**-0.04**	**1.32**	-
	± 0.02	0.03	0.08				0.04	0.04	0.07	0.04		
Line1234 x Line362	**1.61**	**-0.00**	**-0.15**	**-0.33****	**0.04**	**-0.53****	**0.08**	**0.01**	**0.12**	**0.02**	**4.05***	C
	± 0.02	0.03	0.10	0.10	0.03	0.15	0.05	0.04	0.09	0.05		
Line1234 x Arka Vikas	**1.59****	**0.04**	**-0.20**	–	–	–	**0.03**	**-0.08**	**0.06**	**0.06**	**2.33**	-
	± 0.04	0.04	0.20				0.06	0.08	0.20	0.10		
Line1234 x Pusa Ruby	**1.74****	**-0.06**	**-0.43****	**-0.29**	**0.09***	**0.33**	**0.07**	**-0.11**	**0.24**	**0.14**	**8.40***	D
	± 0.04	0.04	0.16	0.16	0.04	0.23	0.07	0.06	0.15	0.08		
Line1234 x Line25-7-4	**1.54****	**-0.07**	**-0.25**	**0.15**	**-0.17****	**-0.23**	**-0.08**	**0.25***	**0.32***	**0.07**	**8.94***	C
	± 0.04	0.07	0.22	0.22	0.08	0.35	0.12	0.11	0.16	0.11		-
Line362 x Arka Vikas	**1.56****	**0.02**	**-0.11**	**0.33**	**0.00**	**0.32**	**-0.15****	**-0.14****	**-0.25**	**0.02**	**12.93***	D
	± 0.04	0.04	0.18	0.19	0.04	0.23	0.06	0.06	0.17	0.09		
Line362 x Pusa Ruby	**1.66****	**-0.06**	**0.13**	**0.25**	**0.06**	**-0.20**	**0.03**	**-0.08**	**-0.30****	**-0.12**	**5.13***	D
	± 0.04	0.04	0.17	0.17	0.04	0.23	0.05	0.07	0.16	0.08		
Line362 x Line25-7-4	**1.63****	**0.02**	**-0.14**	**-0.13**	**-0.15****	**-0.08**	**-0.05**	**0.25****	**0.33**	**0.06**	**39.11****	C
	± 0.04	0.02	0.18	0.18	0.03	0.30	0.06	0.06	0.20	0.09		
Arka Vikas x Pusa Ruby	**1.63****	**-0.13****	**-0.72****	**0.07**	**0.00**	**0.13**	**-0.10**	**-0.10**	**-0.28****	**0.04**	**8.47***	D
	± 0.02	0.04	0.12	0.12	0.04	0.20	0.07	0.06	0.01	0.05		
Arka Vikas x Line25-7-4	**1.56****	**0.09****	**0.02**	–	—	–	**-0.04**	**0.00**	**0.00**	**0.02**	**1.95**	-
	± 0.02	0.02	0.11				0.03	0.05	0.10	0.05		
Pusa Ruby x Line25-7-4	**1.69****	**-0.06***	**-0.02**	**0.09**	**-0.17****	**-0.50**	**0.02**	**0.39**	**0.33**	**-0.04**	**41.31****	C
	± 0.03	0.04	0.20	0.14	0.03	0.31	0.14	0.14	0.29	0.07		

*, ** significant at 5 % and 1 %, respectively

Among the interacting crosses additive gene effects (*d*) was significant in five crosses with negative estimates in four crosses. The highest magnitude of positive estimate (0.09) of *d* was recorded in Arka Vikas x Line25-7-4. Dominant gene effects (*h*) was significant in five crosses. The highest magnitude of positive estimate (0.38) of *h* was recorded in Pusa 120 x Pusa Ruby.

Additive x additive gene effects (*i*) were found to be significant in four crosses with positive and significant estimate (0.29) in one cross, Pusa 120 x Pusa Ruby. Three crosses had *i* effects significant in negative direction. In the remaining crosses *i* estimates were non- significant. Eight crosses showed significant additive x dominant (*j*) gene effects. The positively significant magnitude (0.15) of the estimate was recorded in two crosses, namely Pusa 120 x Arka Vikas and Pusa 120 x Pusa Ruby. Three crosses showed *j* effect significant in negative direction.

Dominant x dominant (*l*) effects were significant in three crosses with positive estimate (0.91) in one cross, Pusa 120 x Arka Vikas and negative estimates in two crosses. In the remaining crosses *l* effects were non-significant. Out of the fifteen crosses eight had opposite signs in *h* and *l* effects showing duplicate type of epistasis. Four crosses had complementary epistasis due to the presence of the same sign in *h* and *l*. Three crosses were found to be non-interacting.

4.3.5. Ascorbic acid

The estimates of scaling tests, gene effects and χ^2 tests has been presented in the Table 6. The estimates of the scales (A, B, C and D were

Table 6 Gene effects for ascorbic acid content in a 6 x 6 diallel cross of tomato

Crosses	m	D	h	i	J	l	A	B	C	D	χ^2	Type(s) of gene action
Pusa 120 x Line1234	**17.77****	**-0.91****	**-0.85**	**-0.60**	**-0.94****	**2.27****	**1.78**	**0.10**	**-1.08****	**0.30**	**49.79****	D
	± 0.06	0.19	0.50	0.50	0.19	0.80	0.30	0.25	0.27	0.22		
Pusa 120 x Line362	**17.89****	**-0.23***	**-3.39****	**-4.13****	**-0.12**	**0.71**	**-2.68**	**-0.30***	**1.14****	**2.06****	**183.61****	D
	± 0.06	0.11	0.40	0.34	0.12	0.54	0.23	0.14	0.31	0.17		
Pusa 120 x Arka Vikas	**17.96****	**0.19**	**0.98***	**1.11***	**-0.17**	**-2.96****	**0.75**	**1.10****	**0.74**	**-0.55***	**23.66****	D
	± 0.09	0.17	0.50	0.48	0.18	0.09	0.41	0.28	0.60	0.24		
Pusa 120 x Pusa Ruby	**18.02****	**-0.38**	**-0.12**	**0.14**	**0.20**	**2.26****	**-0.99****	**1.41****	**-2.54****	**-0.07**	**340.22****	D
	± 0.02	0.20	0.41	0.41	0.20	0.82	0.38	0.16	0.14	0.20		
Pusa 120 x Line25-7-4	**14.12****	**-0.11**	**-4.15**	**-3.36****	**-3.47****	**12.03****	**-7.83****	**-0.86***	**-5.31****	**1.68****	**261.30****	D
	± 0.23	0.27	1.10	1.10	0.28	1.45	0.49	0.34	0.98	0.53		
Line1234 x Line362	**17.00****	**0.18**	**-0.83**	**-1.47****	**-0.75****	**5.03****	**-2.50****	**-1.04***	**-2.10****	**0.73****	**290.63****	D
	± 0.03	0.25	0.50	0.51	0.25	1.10	0.18	0.53	0.35	0.25		
Line1234 x Arka Vikas	**15.10**	**0.94****	**0.39**	**1.38****	**0.61****	**4.48****	**-2.32****	**-3.56****	**-7.24****	**-0.69****	**270.71****	C
	± 0.10	0.09	-0.49	0.46	0.12	0.67	0.24	0.23	0.54	0.23		
Line1234 x Pusa Ruby	**17.47****	**-0.15**	**-3.51**	**-2.53***	**0.48****	**8.25****	**-2.38****	**-3.34****	**-3.19****	**1.30***	**124.20****	C
	± 0.25	0.24	1.10	1.10	0.24	1.43	0.47	0.31	0.01	0.55		
Line1234 x Line25-7-4	**14.85****	**0.47**	**5.46****	**4.13****	**-1.84****	**-1.78**	**-3.02****	**0.66**	**-6.49****	**-2.07****	**174.59****	D
	± 0.19	0.35	1.03	1.02	0.36	1.62	0.27	0.69	0.81	0.52		
Line362 x Arka Vikas	**16.07****	**0.18**	**-1.53****	**-0.79****	**0.77****	**3.35****	**-0.50****	**-2.08****	**-1.76****	**0.40***	**50.58****	D
	± 0.07	0.16	0.44	0.40	0.19	0.74	0.18	0.33	0.35	0.21		
Line362 x Pusa Ruby	**15.99****	**-0.73***	**3.81****	**4.19****	**0.82**	**-1.81**	**-0.37**	**-2.01****	**-6.57****	**-2.10**	**192.68****	D
	± 0.04	0.29	0.66	0.61	-0.29	1.29	0.48	0.50	0.54	1.30		
Line362 x Line25-7-4	**15.08****	**0.46**	**-1.16***	**-2.13***	**-0.93****	**5.47**	**-2.60****	**-0.74**	**-1.21****	**1.06****	**66.03****	D
	± 0.04	0.27	0.58	0.56	-0.28	1.10	0.34	0.50	0.30	0.28		
Arka Vikas x Pusa Ruby	**18.02****	**-1.03****	**-2.31****	**-2.32****	**0.08**	**6.31****	**-2.07****	**-1.91**	**-1.65****	**1.16****	**328.09****	D
	± 0.07	0.16	0.44	0.43	0.18	0.07	0.35	1.10	0.34	0.22		
Arka Vikas x Line25-7-4	**16.77****	**1.10****	**-0.71**	**-0.16**	**-0.91****	**-0.08**	**-0.06**	**1.76****	**3.32****	**0.81***	**40.86****	C
	± 0.13	0.20	0.70	0.65	0.23	1.10	0.30	0.50	0.71	0.32		
Pusa Ruby x Line25-7-4	**16.05****	**0.62****	**-3.53****	**-3.36****	**-2.31****	**8.33****	**-4.80****	**-0.17**	**-1.60****	**1.68****	**703.42****	D
	± 0.11	0.13	0.52	0.51	0.16	0.73	0.18	0.28	0.50	0.25		

*, ** significant at 5 % and 1 %, respectively

significant and so also the χ^2 values in all the crosses indicating non-allelie interaction. Main effect (*m*) was significant in all the crosses indicating significant variability among the hybrids.

Additive gene effects (*d*) were significant in seven crosses with positive estimates in three crosses and negative estimates in the remaining four crosses. The highest magnitude (1.10) with significantly positive estimate was found in the cross, Arka Vikas x Line25-7-4. In the remaining crosses *d* effects were non- significant. Eight crosses exhibited significantly dominant (*h*) gene effects with negative estimates in seven crosses and positive estimates in three. The highest magnitude of positive estimate (5.46) was recorded in Line1234 x Line25-7-4. Rest of the crosses were found non-significant.

Additive x additive (*i*) gene effects were significant in twelve crosses with positive estimates in four crosses and negative estimates in nine crosses. The highest magnitude (4.19) of significant and positive estimate was recorded in Line362 x Pusa Ruby. Ten out of fifteen crosses additive x dominant (*j*) effects were significant out of which four had estimates in positive direction and seven had in negative direction. The highest magnitude (0.82) of positive estimate was observed in Line362 x Pusa Ruby. In the remaining crosses *j* effects were non- significant.

Dominant x Dominant (*l*) type of gene action was observed to be significant in ten crosses, of which ten crosses had significantly positive estimates and one cross had significantly negative estimate. The highest magnitude (12.03) of positive estimate was found in Pusa 120 x Line25-7-4. In the remaining crosses *l* effects were non- significant. Epistasis was duplicate in

twelve crosses due to the presence of opposite sign in *R* and *l*, while complementary epistasis was noted in three crosses while had some sign *h* and *l*.

4.3.4. Acidity

The estimates for either of A, B, C and D, gene effects and χ^2 values were found to be significant in fourteen crosses which indicated that additive dominance model was inadequate. One cross, in which χ^2 was not significant proved to be non-interacting i.e. additive-dominance model was adequate to explain the gene action in this cross, Table 7.

Among the interacting crosses, five crosses showed significant additive (*d*) effects, of which four had estimates in the positive direction and one had estimates in the negative direction. The highest magnitude (0.09) of positive estimate was found in Pusa 120 x Arka Vikas. In general, the estimates of dominant gene effects were higher than additive gene effects.

The dominant (*h*) gene effects were significant in two crosses. The significant positive estimate (0.35) was recorded in Pusa Ruby x Line25-7-4 and the other estimate was significant in negative direction. In the remaining crosses *h* effects were non-significant. Among the interaction effects, additive x additive (*i*) gene effects were highly significantly positive (0.23) in one cross, Pusa Ruby x Line25-7-4 and *i* effects were significant and negative in three crosses. In the remaining crosses (*i*) effects were non significant.

Four crosses showed significant additive x dominant (*j*) effects with negative estimates. In the remaining crosses *j* effect were non significant. Dominant x dominant (*l*) gene effects were significant in two crosses which had positive estimates. The highest magnitude (0.54) of positive and

Table 7 Gene effects for acidity in a 6 x 6 diallel cross of tomato

Crosses		m	d	h	i	j	l	A	B	C	D	χ^2	Type(s) of gene action
Pusa 120 x Line1234		**0.49****	**-0.01**	**-0.03**	**-0.02**	**-0.02**	**0.17**	**0.10***	**-0.07***	**-0.16****	**0.00**	**10.49***	D
	±	0.01	0.02	0.06	0.06	0.10	0.10	0.05	0.03	0.06	0.03		
Pusa 120 x Line362		**0.48****	**0.03**	**0.07**	**0.09**	**0.01**	**0.12**	**-0.09****	**-0.11**	**-0.30****	**-0. 04**	**18.91****	C
	±	0.02	0.03	0.09	0.09	0.03	0.13	0.03	0.06	0.08	0.04		
Pusa 120 x Arka Vikas		**0.51****	**0.09****	**-0.21****	**-0.27****	**0.00**	**0.46****	**0.10***	**-0.09***	**0.08**	**0.13****	**22.55****	D
	±	0.01	0.01	0.07	0.06	0.02	0.11	0.04	0.04	0.08	0.08		
Pusa 120 x Pusa Ruby		**0.60****	**-0.05***	**0.01**	--	--	--	**0.00**	**-0.01**	**-0.01**	**0.00**	**0.04**	-
	±	0.02	0.02	0.08				0.03	0.04	0.07	0.04		
Pusa 120 x Line25-7-4		**0.38****	**0.02**	**0.05**	**0.08**	**-0.08****	**0.04**	**-0.15****	**0.02**	**-0.21****	**-0.04**	**24.62****	C
	±	0.01	0.02	0.06	0.05	0.02	0.01	0.04	0.02	0.06	0.03		
Line1234 x Line362		**0.49****	**0.01**	**0.03**	**0.07**	**0.01**	**0.07**	**0.06**	**-0.08****	**-0.21****	**-0.03**	**15.76***	C
	±	0.02	0.01	0.08	0.08	0.02	0.10	0.00	0.02	0.08	0.04		
Line1234 x Arka Vikas		**0.46****	**0.05***	**-0.05**	**-0.07**	**-0.04***	**0.14**	**-0.07***	**0.00**	**0.003**	**0.04**	**7.07***	D
	±	0.01	0.02	0.05	0.05	0.02	0.09	0.03	-0.04	0.05	0.03		
Line1234 x Pusa Ruby		**0.62****	**0.01**	**-0.15**	**-0.15****	**0.05**	**0.21**	**0.02**	**-0.07**	**0.10**	**0.08**	**6.23***	D
	±	0.21	0.03	0.1	0.01	0.03	0.15	0.06	0.04	0.10	0.05		
Line1234 x Line25-7-4		**0.45****	**0.03**	**0.11**	**0.08**	**-0.07***	**-0.13**	**-0.04**	**0.09***	**-0.03**	**-0.04**	**6.96***	D
	±	0.02	0.03	0.10	0.10	-0.03	0.14	0.05	0.04	0.09	0.05		
Line362 x Arka Vikas		**0.47****	**0.01**	**-0.12**	**-0.13**	**0.10****	**0.24**	**-0.16****	**0.04**	**0.01**	**0.06**	**10.78***	D
	±	0.02	0.03	0.10	0.09	0.03	0.14	0.06	0.03	0.08	0.05		
Line362 x Pusa Ruby		**0.58****	**-0.03**	**0.02**	**0.01**	**0.01**	**0.09**	**-0.05**	**-0.06**	**-0.12**	**-0.01**	**3.14***	C
	±	0.03	0.02	0.14	0.13	0.03	0.16	0.04	0.04	0.14	0.13		
Line362 x Line25-7-4		**0.48****	**0.06***	**-0.02**	**-0.33****	**0.05**	**0.01**	**-0.04**	**0.06**	**0.05**	**0.02**	**4.65***	D
	±	0.01	0.03	0.08	0.08	0.03	0.12	0.03	0.05	0.07	0.04		
Arka Vikas x Pusa Ruby		**0.47****	**0.02**	**0.21**	**0.09**	**0.10**	**0.05**	**0.03**	**-0.17**	**-0.24**	**-0.05**	**3.78***	C
	±	0.03	0.03	0.14	0.13	0.06	0.20	0.06	0.11	0.20	0.08		
Arka Vikas x Line25-7-4		**0.33****	**0.01**	**-0.05**	**-0.02**	**0.00**	**0.15**	**-0.07**	**0.06***	**-0.11**	**0.01**	**7.48***	D
	±	0.01	0.02	0.06	0.06	0.03	0.10	0.05	0.03	0.06	0.03		
Pusa Ruby x Line25-7-4		**0.51****	**0.06****	**0.35****	**0.23****	**0.04**	**0.54****	**0.11**	**0.19****	**0.07**	**-0.12****	**17.37***	C
	±	0.02	0.02	0.10	0.08	0.04	0.18	0.12	0.05	0.15	0.04		

*, ** significant at 5 % and 1 %, respectively

significant estimate was found in Pusa Ruby x Line25-7-4. Duplicate epistasis was observed in eight crosses due to the presence of opposite signs in *h* and *l*. Complementary epistasis was noted in six crosses whereas one cross, Pusa 120 x Pusa Ruby was found to be non interacting.

4.3.5. Total soluble solids (TSS)

The estimates of simple scaling test, gene effects and χ^2 values have been presented in Table 8. The results showed that all the crosses were interacting (χ^2 significant) and additive-dominance model would be inadequate to explain the gene action. Estimates of simple scale (A, B, C and D) were also significant. The main effect (*m*) was significant in all the crosses indicated substantial variability among the hybrids.

Additive gene effect (*d*) were significant in nine crosses with positive estimates in four crosses. The highest magnitude of positive estimate (0.48) was observed in Line1234 x Arka Vikas. The dominant gene effect (*h*) were significant in six crosses with positive estimates in two crosses. The highest magnitude (1.16) of positive estimate was recorded in Line362 x Pusa Ruby. In the remaining nine crosses *h* effects were non- significant.

Seven crosses showed significant additive x additive (*i*) gene effects with positive estimates in four crosses. The highest magnitude of significantly positive estimate (1.14) was observed in Line362 x Pusa Ruby. Additive x dominant gene effects (*j*) were significant in nine crosses with positive and significant estimates in five crosses. The highest magnitude (1.16) of significant positive estimate was found in Line1234 x Line25-7-4. Six crosses were found to be non- significant. Dominant x dominant gene effects (*l*) were

Table 8.Gene effects for total soluble solids (TSS) in a 6 x 6 diallel cross of tomato

Crosses		m	d	h	i	j	l	A	B	C	D	χ^2	Type(s) of gene action
Pusa 120 x Line1234		**4.19****	**-0.20****	**-0.28**	**-0.28**	**-0.11**	**3.24****	**-1.59****	**-1.40****	**-2.67****	**0.14**	**591.49****	D
	±	0.05	0.06	0.25	0.25	0.07	0.033	0.01	0.08	0.23	0.08		
Pusa 120 x Line362		**3.98****	**0.08**	**-0.12**	**-0.05**	**0.60****	**0.70***	**-0.87****	**0.23***	**-0.60****	**0.02**	**77.53****	D
	±	0.02	0.07	0.12	0.16	0.07	0.33	0.15	0.11	0.20	0.08		
Pusa 120 x Arka Vikas		**4.44****	**0.12**	**-0.02**	**-0.18**	**-0.45****	**2.85****	**-0.99****	**-0.10**	**0.67***	**0.88****	**54.90****	D
	±	0.08	0.08	0.36	0.40	0.09	0.50	0.14	0.11	0.33	0.18		
Pusa 120 x Pusa Ruby		**4.93****	**-0.63***	**-0.16**	**-0.06**	**-0.19**	**1.10**	**-0.73**	**-0.34****	**0.01**	**0.03**	**43.24****	D
	±	0.04	0.30	0.60	0.60	0.29	1.10	0.60	0.08	0.17	0.30		
Pusa 120 x Line25-7-4		**3.95**	**0.05**	**0.00**	**0.65***	**-0.09**	**0.28**	**0.56****	**-0.37****	**-1.59****	**-0.33***	**46.26****	C
	±	0.05	0.09	0.28	0.26	0.10	0.44	0.17	0.14	0.24	0.13		
Line1234 x Line362		**4.03****	**0.38****	**-0.68***	**-0.69***	**-0.32***	**2.20****	**-1.08****	**-0.44***	**-0.83****	**0.34***	**82.48****	D
	±	0.04	0.13	0.31	0.31	0.13	0.54	0.12	0.20	0.20	0.15		
Line1234 x Arka Vikas		**4.11****	**0.48****	**-1.91****	**-1.30****	**-0.16***	**2.07****	**-0.60****	**-0.24**	**0.50****	**0.64****	**27.74****	D
	±	0.06	0.08	0.31	0.30	0.08	0.40	0.14	0.15	0.30	0.15		
Line1234 x Pusa Ruby		**4.10****	**-0.15**	**-1.33****	**0.30**	**0.22***	**3.28****	**-1.28****	**-1.72****	**-2.72****	**0.14**	**522.46****	D
	±	0.03	0.09	0.22	0.21	0.09	0.40	0.17	0.11	0.14	0.11		
Line1234 x Line25-7-4		**4.21****	**0.20****	**0.30**	**0.34***	**1.16****	**1.33****	**-0.82****	**-0.85****	**-2.01****	**0.17***	**83.66****	C
	±	0.03	0.06	0.18	0.15	0.07	0.33	0.15	0.13	0.22	0.07		
Line362 x Arka Vikas		**3.25****	**0.01**	**0.41**	**0.55**	**0.08**	**0.02**	**-0.21**	**0.36****	**-1.11****	**0.27**	**12.74***	C
	±	0.07	0.08	0.33	0.31	0.09	0.50	0.19	0.12	0.33	0.15		
Line362 x Pusa Ruby		**4.12****	**-0.93****	**1.16****	**1.14****	**0.14****	**-0.31**	**-0.27****	**-0.56****	**-1.96****	**-0.57****	**112.25****	D
	±	0.04	0.04	0.20	0.18	0.05	0.26	0.10	0.07	0.20	0.09		
Line362 x Line25-7-4		**3.75****	**-0.60****	**-0.15**	**-0.13**	**-0.04**	**1.40****	**-0.66****	**-0.58****	**-1.11****	**0.07**	**127.59****	D
	±	0.06	0.04	0.30	0.30	0.05	0.30	0.10	0.06	0.06	0.13		
Arka Vikas x Pusa Ruby		**4.20****	**-0.18****	**-0.79****	**-0.86****	**-0.82****	**3.73****	**-0.61****	**-2.25****	**-2.01****	**0.43****	**375.96**	D
	±	0.03	0.05	0.18	0.17	0.07	0.30	0.10	0.12	0.20	0.08		
Arka Vikas x Line25-7-4		**3.95****	**0.03**	**0.44****	**0.42***	**0.47****	**-0.17**	**0.35****	**-0.60****	**-0.70****	**-0.21***	**75.60****	D
	±	0.05	0.05	0.20	0.20	0.06	0.30	0.10	0.10	0.10	0.23		
Pusa Ruby x Line25-7-4		**4.87**	**0.37****	**-0.41**	**-0.41**	**-0.19**	**1.81****	**-0.89****	**-0.51****	**-0.98****	**0.21**	**40.84****	D
	±	0.10	0.10	0.41	0.41	0.10	0.50	0.20	0.12	0.38	0.21		

*, ** significant at 5 % and 1 %, respectively

significant in ten crosses with positive estimates in all. The highest magnitude of significantly positive estimate (3.73) was found in Arka Vikas x Pusa Ruby. Genetic parameters *h* and *l* had opposite sign in twelve crosses there by indicating the predominance of duplicate epistasis whereas, three crosses exhibited complementary epistasis due to the presence of the same sign in *h* and *l*.

4.3.6. Locule number

The estimates for either of the simple scales (A, B, C and D) were significant and gene effects and χ^2 values were also significant for this trait, Table 9. All the crosses were found to be interacting (χ^2 significant) thereby suggested that additive-dominance model was inadequate to explain the gene action for the character concerned.

Ten out of the fifteen interacting crosses showed significant additive (*d*) gene effects of which three showed positive estimates and seven showed negative estimates, respectively. The highest magnitude (0.91) of significantly positive estimate was observed in Pusa 120 x Line1234. Five crosses were not significant. Dominance gene effects (*h*) were found to be significant in fourteen crosses whereas one cross was non significant. Four crosses showed significantly positive estimates. The highest magnitude (4.13) of significantly positive estimate was found in Arka Vikas x Line25-7-4. Ten crosses had significant estimates in negative direction. In general, the magnitude of dominant (*h*) effect were higher than additive (*d*) gene effects.

Among the epistatic effect, additive x additive (*i*) gene effects were significant in eleven crosses with positive estimates in five crosses and negative

Table 9 Gene effects for **locule number in a 6 x 6 diallel cross of tomato**

Crosses		m	d	H	i	j	l	A	B	C	D	χ^2	Type(s) of gene action
Pusa 120 x Line1234		**4.07****	**0.91****	**-1.69****	**-1.71****	**-0.67****	**3.56****	**-1.59****	**-0.25**	**-0.13**	**0.86**	**408.57****	D
	±	0.06	0.10	0.32	0.30	0.10	0.50	0.09	0.20	0.30	0.15		
Pusa 120 x Line362		**3.25****	**-0.44****	**0.62****	**2.11****	**-1.92****	**-4.26****	**-0.85****	**2.99****	**0.04**	**-1.06****	**225.21****	D
	±	0.30	0.11	0.30	0.26	0.16	0.50	0.20	0.22	0.27	0.13		
Pusa 120 x Arka Vikas		**4.35****	**-0.01**	**-3.21****	**-3.22****	**-1.76****	**9.07****	**-4.68****	**-1.16****	**-2.61****	**1.61****	**217.99****	D
	±	0.07	0.15	0.40	0.40	0.15	0.72	0.32	0.15	0.40	0.20		
Pusa 120 x Pusa Ruby		**5.48****	**0.10**	**-7.83****	**-6.70****	**0.10**	**11.12****	**-2.31****	**-2.11****	**2.29****	**3.35****	**115.41****	D
	±	0.11	0.22	0.67	0.64	0.23	1.07	0.40	0.30	0.60	0.30		
Pusa 120 x Line25-7-4		**3.88****	**0.27****	**1.97****	**1.89****	**-0.44****	**0.67**	**-1.72****	**-0.84****	**-4.46****	**-0.95****	**219.50****	C
	±	0.07	0.08	0.35	0.30	0.09	0.50	0.17	0.13	0.40	0.17		
Line1234 x Line362		**2.52****	**-0.15****	**-1.73****	**-0.14**	**-1.50****	**2.27****	**-0.56****	**-0.27****	**0.61***	**0.72****	**52.21****	D
	±	0.06	0.05	0.26	0.30	0.05	0.33	0.10	0.07	0.26	0.13		
Line1234 x Arka Vikas		**2.25****	**-0.42****	**3.48****	**3.11****	**0.49****	**-0.86**	**-0.64***	**-1.61****	**-5.36****	**-1.56****	**55.50****	D
	±	0.15	0.16	0.72	0.67	0.16	1.02	0.30	0.40	0.80	0.30		
Line1234 x Pusa Ruby		**3.89****	**-1.31****	**-1.94****	**-0.22**	**0.06**	**-3.04****	**1.69****	**1.57****	**3.48****	**0.11**	**1006.53****	C
	±	0.06	0.04	0.30	0.30	0.05	0.30	0.06	0.05	0.30	0.13		
Line1234 x Line25-7-4		**2.98****	**-1.00****	**-1.40****	**-1.36****	**-0.14**	**4.23****	**-1.57****	**-1.30****	**-1.51****	**0.68****	**185.94****	D
	±	0.07	0.09	0.30	0.30	0.09	0.50	0.16	0.12	0.30	0.16		
Line362 x Arka Vikas		**3.13****	**-0.23**	**-0.74***	**-0.68**	**0.67****	**2.38****	**-0.18**	**-1.52****	**-1.02****	**0.34**	**129.54****	D
	±	0.06	0.12	0.35	0.35	0.12	0.60	0.20	0.14	0.30	0.18		
Line362 x Pusa Ruby		**2.48****	**0.89****	**0.77**	**1.85****	**1.81****	**-2.06****	**1.92****	**-1.71**	**-1.64**	**-0.93****	**735.11****	D
	±	0.01	0.04	0.50	0.09	0.50	0.96	0.09	0.94	0.95	0.05		
Line362 x Line25-7-4		**2.69****	**-0.41****	**-1.09****	**0.09**	**0.46****	**0.15**	**0.33****	**-0.58****	**-0.34**	**0.05**	**46.80****	D
	±	0.09	0.07	-0.38	0.37	0.08	0.50	0.10	0.18	0.40	0.19		
Arka Vikas x Pusa Ruby		**4.07****	**-1.70****	**-4.09****	**-3.55****	**-1.23****	**8.89****	**-3.80****	**-1.45****	**-1.80****	**1.77****	**455.73****	D
	±	0.02	0.20	0.50	0.50	0.23	0.91	0.40	0.10	0.10	0.20		
Arka Vikas x Line25-7-4		**3.21****	**0.05**	**4.13****	**3.88****	**0.02**	**-2.98****	**-0.43****	**-0.46****	**-4.78****	**1.94****	**2120.80****	D
	±	0.02	0.04	0.12	0.11	0.05	0.20	0.07	0.09	0.12	0.05		
Pusa Ruby x Line25-7-4		**3.28**	**-0.11**	**-0.72****	**-0.46***	**-0.56****	**6.60****	**-3.60****	**-2.50****	**-5.67**	**0.23***	**2084.62****	D
	±	0.03	0.07	0.19	0.18	0.08	0.30	0.10	0.14	0.17	0.09		

*, ** significant at 5 % and 1 %, respectively

estimates in six crosses. The highest magnitude (3.88) of significantly positive estimate was observed in Arka Vikas x Line25-7-4. Four crosses were non-significant

Additive x dominant gene effect (*j*) were significant in eleven crosses, with significantly positive estimates in four crosses and significantly negative estimates in seven crosses. The highest magnitude(1.81) of significantly positive estimate was recorded in Line363 x Pusa Ruby. Four crosses wee not significant.

Significant dominant x dominant (*l*) gene effects were observed in twelve crosses with significantly positive estimates in eight crosses and significantly negative estimates in four crosses. The highest magnitude (11.12) of significantly positive estimate was observed in Pusa 120 x Pusa Ruby, followed by Pusa 120 x Arka Vikas (9.07). Three crosses were non- significant. Duplicate epistasis was observed in thirteen crosses due to the presence of opposite sign in *h* and *l*. Complementary epistasis was observed in two crosses which had the same sign in *h* and *l*.

4.3.7. Seediness

The estimates of simple scaling test, gene effects and $\chi 2$ values have been presented in Table 10. The estimates of either of the simple scales (A, B, C and D) were significant in all the crosses indicating additive -dominance model was not adequate for explaining the gene action involved in the inheritance of this trait.

Significant additive gene effects (d) were observed in six crosses with positive estimates in two crosses and negative estimates in four crosses. The

Table 10 Gene effects for seediness in a 6 x 6 diallel cross of tomato

Crosses	m	d	h	I	j	l	A	B	C	D	χ^2	Type(s) of gene action
Pusa 120 x Line1234	**1.20****	**-0.18****	**-0.91****	**-0.61****	**0.37****	**1.17****	**0.09**	**-0.65****	**0.05**	**0.31**	**54.84****	D
	± 0.03	0.05	0.17	0.16	0.05	0.30	0.08	0.09	0.15	0.08		
Pusa 120 x Line362	**0.67****	**0.06**	**-0.38****	**-0.38***	**-0.06**	**0.72****	**-0.23****	**-0.11**	**0.04**	**0.19***	**20.21****	D
	± 0.04	0.04	0.17	0.17	0.05	0.20	0.05	0.09	0.16	0.08		
Pusa 120 x Arka Vikas	**0.69****	**0.01**	**-0.05**	**0.00**	**-0.03**	**0.15**	**-0.10***	**-0.04**	**-0.15**	**0.00**	**9.93***	D
	± 0.01	0.02	0.09	0.08	0.03	0.12	0.04	0.04	0.08	0.04		
Pusa 120 x Pusa Ruby	**1.57****	**-0.03**	**0.14**	**0.11**	**0.77****	**-0.09**	**0.76****	**-0.78****	**-0.13**	**-0.05**	**644.58****	D
	± 0.06	0.03	0.30	0.26	0.03	0.30	0.06	0.07	0.27	0.13		
Pusa 120 x Line25-7-4	**1.85****	**-0.48****	**-0.18**	**-0.66**	**0.19***	**0.70**	**0.17**	**-0.21**	**0.62**	**0.33**	**8.51***	D
	± 0.09	0.09	0.41	0.41	0.09	0.50	0.17	0.20	0.38	0.20		
Line1234 x Line362	**0.97****	**0.23****	**-0.30**	**-0.13**	**-0.45****	**0.91****	**-0.84****	**0.06**	**-0.65****	**-0.06**	**90.17****	D
	± 0.04	0.05	0.19	0.19	0.05	0.26	0.09	0.06	0.19	0.09		
Line1234 x Arka Vikas	**1.03****	**0.03**	**-0.09**	**-0.05**	**-0.56**	**1.11****	**-1.08****	**0.03**	**-1.00****	**-0.03**	**126.02****	D
	± 0.05	0.06	0.26	0.22	0.06	0.39	0.13	0.16	0.31	0.11		
Line1234 x Pusa Ruby	**2.03****	**-0.08**	**-0.03**	**-0.05**	**0.17****	**0.71**	**-0.16**	**-0.50****	**-0.60****	**0.03**	**27.35****	D
	± 0.07	0.06	0.30	0.30	0.06	0.39	0.10	0.09	0.30	0.20		
Line1234 x Line25-7-4	**1.98****	**-0.09**	**-0.09**	**-0.13**	**0.02**	**0.44****	**-0.14***	**-0.17****	**-0.17***	**0.07**	**11.46***	D
	± 0.02	0.03	0.10	0.09	0.04	0.20	0.06	0.06	0.08	0.05		
Line362 x Arka Vikas	**0.59****	**-0.02**	**0.07**	**0.07**	**0.07**	**0.01**	**0.03**	**-0.11**	**-0.14**	**-0.03**	**6.20***	C
	± 0.02	0.03	0.10	0.10	0.04	0.20	0.06	0.06	0.09	0.05		
Line362 x Pusa Ruby	**1.50****	**0.07**	**1.87****	**-1.93****	**0.86****	**3.96****	**-0.16**	**-1.87****	**-0.11**	**0.96****	**843.82****	C
	± 0.04	0.04	0.19	0.18	0.05	0.26	0.09	0.07	0.19	0.09		
Line362 x Line25-7-4	**1.42****	**0.04**	**0.26**	**-0.18**	**0.84**	**0.88****	**0.50****	**-1.18****	**-0.50****	**0.09**	**388.11****	C
	± 0.04	0.05	0.20	0.19	0.53	0.30	0.08	0.06	0.18	0.09		
Arka Vikas x Pusa Ruby	**1.49****	**-0.42****	**-0.85****	**-0.85****	**0.42****	**0.02**	**-0.13***	**-0.97****	**-0.24**	**0.24****	**85.94****	D
	± 0.04	0.06	0.2	0.20	0.06	0.28	0.06	0.10	0.16	0.09		
Arka Vikas x Line25-7-4	**1.40****	**-0.20****	**-1.20****	**-1.05****	**0.56****	**2.12****	**0.03**	**-1.09****	**-0.01**	**0.53**	**100.38****	D
	± 0.03	0.04	0.20	0.14	0.08	0.25	0.07	0.15	0.19	0.72		
Pusa Ruby x Line25-7-4	**2.10****	**0.13****	**-0.08**	**-0.11**	**-0.01**	**0.90****	**-0.40****	**-0.39****	**-0.68****	**0.06**	**100.70****	D
	± 0.05	0.04	0.20	0.20	0.04	0.24	0.07	0.05	0.20	0.10		

*, ** significant at 5 % and 1 %, respectively

highest magnitude (0.23) of significantly positive estimate was found in Line1234 x Line362. Nine crosses were non-significant. Dominant gene effects (*h*) were significant in five crosses with positive estimate (1.87) in one cross, Line362 x Pusa Ruby. Four crosses had significantly negative estimates. Ten crosses were non- significant.

Among the interaction effects, additive x additive (*i*) gene effects were significant in five crosses with negative estimates in all and this was in the desirable direction. Ten crosses were non- significant. Highly significant and negative additive x dominant (*j*) gene effects (-0.45) in one cross, Line1234 x Line362 whereas significantly positive estimates were found in seven crosses. The highest magnitude of significantly positive estimate (0.86) was observed in Line362 x Pusa Ruby. Seven crosses were observed non-significant.

Nine crosses showed significant and positive estimates for dominant x dominant gene effects (*l*), but this was no in the desired direction. Six crosses were non- significant. Duplicate epistasis was noted in twelve crosses which had *h* and *l* estimates with opposite sings. Three crosses had complementary epistasis due to the presence of the same sign in *h* and *l* estimates.

4.3.8. Yield

The estimates of simple scaling tests, gene effects, and χ^2 values has been presented in 11. Significance of either of the scales (A, B, C and D) indicated the presence of epistasis. This was further confirmed by the significant χ^2 values, except in one cross. Additive -dominance model (three parameter) was found to be adequate in one cross, Pusa 120 x Pusa Ruby. In

Table 11 Gene effects for yield in a 6 x 6 diallel cross of tomato

Crosses		m	d	h	i	j	l	A	B	C	D	χ^2	Type(s) of gene action
Pusa 120 x Line1234		1.63**	0.14**	0.16	0.15	-0.40**	0.12	1.07**	-0.33**	1.54**	-0.07	181.09**	C
	±	0.04	0.04	0.20	0.20	0.05	0.25	0.08	0.07	0.20	0.10		
Pusa 120 x Line362		1.85**	0.14**	-0.46*	- 0.47**	-0.49**	1.11**	-0.81**	0.16	-0.18	0.23*	182.77**	D
	±	0.04	0.05	0.20	0.18	0.05	0.26	0.06	0.70	0.18	0.09		
Pusa 120 x Arka Vikas		2.96**	-0.06	0.02	0.70*	-0.30**	2.13**	0.50**	1.01**	0.83**	-0.32	37.93**	C
	±	0.07	0.09	0.40	0.30	0.10	0.50	0.15	0.20	0.30	0.17		
Pusa 120 x Pusa Ruby		2.37**	0.13	-0.10	--	--	--	-0.14	-0.07	-0.05	-0.08	0.69	-
	±	0.07	0.08	0.30				0.19	0.14	0.30	0.16		
Pusa 120 x Line25-7-4		2.33**	-0.05	0.05	0.03	-0.04	-0.78**	-0.44**	-0.40**	-0.84**	-0.02	49.41**	D
	±	0.05	0.04	0.20	0.20	0.05	0.30	0.08	0.08	0.20	0.11		
Line1234 x Line362		1.24**	-0.06*	-0.05	-0.73**	-0.18**	0.75**	-0.53**	-0.15**	-0.60**	0.04	126.82**	D
	±	0.01	0.03	0.10	0.09	0.04	0.16	0.05	0.05	0.09	0.04		
Line1234 x Arka Vikas		1.78**	-0.08**	0.00	-0.50*	0.22**	0.30	0.10	-0.34**	-0.19	0.02	50.49**	C
	±	0.05	0.02	0.22	0.22	0.03	0.28	0.08	0.09	0.27	0.11		
Line1234 x Pusa Ruby		1.81**	-0.14**	0.28*	0.27*	0.20**	-0.40	0.26**	-0.13	-0.14	-0.14*	96.29**	D
	±	0.02	0.05	0.13	0.12	0.06	0.23	0.03	0.12	0.10	0.06		
Line1234 x Line25-7-4		1.87**	-0.12**	0.07	0.07	0.40**	0.44*	0.14*	-0.66**	-0.58**	-0.03	101.95**	C
	±	0.01	0.04	0.10	0.10	0.05	0.20	0.06	0.10	0.10	0.05		
Line362 x Arka Vikas		1.78**	-0.32**	-0.22*	-0.27**	0.11**	0.64**	-0.08	-0.30**	-0.10	-0.13**	24.76**	D
	±	0.01	0.03	0.10	0.10	0.04	0.20	0.08	0.08	0.13	0.04		
Line362 x Pusa Ruby		1.68**	-0.13**	0.87**	0.77**	0.33**	-1.18**	0.54**	-0.13	-0.36**	-0.38**	139.47**	D
	±	0.02	0.04	0.12	0.10	0.05	0.20	0.07	0.10	0.10	0.05		
Line362 x Line25-7-4		1.90**	0.05	-0.62**	-0.69	0.69**	1.50**	0.30**	-1.09**	0.11	0.35	273.74**	D
	±	0.03	-0.04	0.15	0.14	0.05	0.20	0.08	0.08	0.73	0.07		
Arka Vikas x Pusa Ruby		1.90**	-0.27	-0.60	-0.50	-0.23	1.90	-0.93	-0.47**	-0.88	0.26	33.77**	D
	±	0.03	0.30	0.65	0.65	0.32	1.30	0.64	0.09	0.18	0.30		
Arka Vikas x Line25-7-4		2.18**	0.11*	-0.25	-0.28	0.33**	1.18**	-0.13	-0.78	-0.63**	0.14	104.30**	D
	±	0.04	0.05	0.20	0.20	0.06	0.27	0.09	0.07	0.19	0.10		
Pusa Ruby x Line25-7-4		2.28**	0.23**	0.37	0.35	0.41**	-0.33	0.40**	-0.42**	-0.36	-0.17	72.87**	D
	±	0.05	0.04	0.23	0.22	0.05	0.28	0.08	0.08	0.24	0.11		

*, ** significant at 5 % and 1 % respectively

this cross additive (*d*) gene effect was of higher magnitude than dominant (*h*) effect.

Among the interacting crosses, additive (*d*) gene effect were significant in ten crosses with positive estimates in four and negative estimates in six crosses, respectively. The highest magnitude of significantly positive estimate (0.23) was recorded in Pusa Ruby x Line25-7-4. Five crosses were non-significant. Dominance (*h*) gene effects were significant in five crosses, with positive estimates in two crosses and negative estimates in three crosses, respectively. The highest magnitude of significantly positive estimate (0.87) was observed in Line362 x Pusa Ruby. Ten crosses were recorded as non-significant.

Among the interaction effects, additive x additive (*i*) effects were significant in seven crosses, with positive estimates in three crosses and negative estimates in four crosses, respectively. The highest magnitude (0.77) of significantly positive estimate was recorded in Line363 x Pusa Ruby. Ten crosses were non- significant. Highly significant additive x dominant (*j*) gene effects were recorded in twelve crosses, out of which eight had positive estimates and four had negative estimates. The highest magnitude (0.69) of significantly positive estimate was observed in Line362 x Line25-7-4. Three crosses were non- significant for this trait.

Nine crosses showed significant dominant x dominant (*l*) gene effects. Of these, seven crosses showed positive and significant estimates. The highest magnitude (2.13) of significantly positive estimate was recorded in Pusa 120 x Arka Vikas. Six crosses were non- significant. Opposite sings in *h* and *l* effects

were exhibited by ten crosses, indicating duplicate epistasis. Four crosses showed complementary epistasis due to the presence of the same sign in *h* and *l* effects.

4.4. Correlations

Genotypic and phenotypic correlations (Al-Jibouri *et al.*, 1958) was worked out in 66 genotypes (treatments) on eight characters has been presented in Table 12. In general, the magnitude of correlations at genotypic level was higher than their corresponding values at phenotypic level.

Oxalates recorded significantly positive correlation with seediness (r=0.369). Oxalates showed positive but non-significant correlations with lycopene (r= 0.294), TSS (r= 0.137), locule number (r= 0.135). Correlations with ascorbic acid (r= -0.240) and acidity (r = -0.216) showed a negative trend.

Lycopene had positive and highly significant correlations with acidity (r= 0.538) and with ascorbic acid (r= 0.363). It showed positively non significant correlations with oxalates (r= 0.294), TSS (r= 0.315) and seediness (r=0.093). correlations with locule number (r=-0.118) observed to be negatively non-significant.

Ascorbic acid showed positive and significant correlations with lycopene (r=0.363), acidity (r=0.420) and TSS (r=0.370). Correlation with locule number (r=0.157) was positive but non-significant. Negatively non-significant correlations were recorded with oxalates (r= -0.240) and seediness (r= -0.200). Highly significant and positive correlations were indicated by acidity with lycopene (r= 0.538) whereas positively significant with ascrobic acid (r= 0.420) and TSS (r= 0.432). It had positive but not significant

Table 12 : Genotypic (below the diagonal) and phenotypic (above the diagonal) correlations for the characters studied in a 6x6 diallel cross of tomato

Characters	1	2	3	4	5	6	7	8
1	**1.000**	0.294	-0.240	-0.216	0.137	0.135	0.369*	0.313
2	0.318	**1.000**	0.363*	0.538**	0.315	-0.118	0.093	-0.184
3	-0.256	0.425*	**1.000**	0.420*	0.370*	0.157	-0.200	0.062
4	-0.234	0.632**	0.474*	**1.000**	0.432*	-0.095	0.131	-0.126
5	0.143	0.362*	0.406*	0.481*	**1.000**	0.315	0.508**	0.332
6	0.138	-0.125	0.169	-0.109	0.333	**1.000**	0.070	0.585**
7	0.399*	0.122	-0.219	0.178	0.556**	0.077	**1.000**	0.117
8	0.322	-0.200	0.064	-0.134	0.350*	0.611**	0.124	**1.000**

1. Oxalates
2. Lycopene
3. Ascorbic acid
4. Acidity
5. Total soluble solids
6. Locule number
7. Seediness
8. Yield

***, ** significant at 5% and 1% respectively**

correlation with seediness (r= 0.131). Correlation with oxalates (r= -0.216) was negative and non-significant.

Total soluble solids showed highly significant and positive correlations with seediness (r=0.508) and positively significant with ascorbic acid (r=0.370) and acidity (r=0.432). Positive but non-significant correlations were recorded with oxalates (r=0.137), lycopene (r=0.315), locule number (r=0.315).

Highly significant and positive correlations were showed by locule number with yield (r=0.585). Observed correlations with oxalates (r=0.135), ascorbic acid (r=0.157), TSS (r=0.135) and seediness (r=0.070) were positive but non-significant. With lycopene (r=-0.118) and acidity (r=0.095) correlations observed were negative but non significant.

Seediness recorded positive and significant correlations with oxalates (r=0.369) and T.S.S. (r= 0.508) With lycopene (r=0.093) acidity (r=0.131), locule number (r=0.070) observed correlations were positive and non significant. Correlation with ascorbic acid (r= -0.200) was negative but non-significant.

4.5. Path coefficient analysis

In the present study path coefficient analysis (Dewey and Lu, 1959) was worked out separately for two characters *viz.*, oxalates and lycopene content taking these two characters as dependent variable and other characters as independent variables. The path coefficient analysis was utilized to partition the correlation coefficients into measures of direct and indirect effects.

4.5.1. Oxalate content

Direct and indirect path coefficients of oxalates has been presented in the Table 13. Lycopene showed the highest (rg=0.686) direct positive effect on oxalates. Its indirect effects were positive through seediness (rg=0.030). Indirect effects were expressed negatively through ascorbic acid (rg=-0.083), acidity (rg = -0.239) and TSS (rg = -0.029). The direct effect (rg = -0.228) of ascorbic acid was negative. Indirectly and negatively it influenced through acidity (rg =-0.186), TSS (rg =-0.034) and seediness (rg = -0.064). It expressed its indirect and positive effect through lycopene (rg = 0.249). The direct and negative effect (rg –0.126) of acidity supported its negative correlation (r = -0.443) with oxalates. It influenced indirectly and negatively through ascorbic acid (rg = -0.096) and TSS (rg = -.040). Through lycopene (rg = 0.370) and seediness (rg = 0.042) it exhibited its indirect and positive effect. Total soluble solids recorded direct and negative effect (rg = -0.091), though it has positive correlation (r =0.137) with oxalates. Its negative direct effects were lessened due to its indirect and positive effect through lycopne (rg =0.216) and seediness (rg = 0.161). TSS exerted influence negatively and indirectly through ascorbic acid (rg = -0.084) and acidity (rg = -0.192).

As was evident from the significant positive correlation (r =0.369), seediness also recorded a positive and direct effect (rg=0.318) on oxalates. Its positive and indirect effects through lycopene (rg –0.064) and ascorbic acid (rg = 0.046), might have contributed to its direct effect. Seediness influenced indirectly and negatively through acidity (rg = -0.058) and TSS (rg = 0.046).

Table 13 : Direct and indirect path coefficients (Phenotypic) of different characters on oxalates in a 6x6 diallel cross of tomato

Characters	2	3	4	5	6	7	8	Correlation coefficient
2	**0.686**	-0.083	-0.239	-0.029	0.002	0.030	-0.074	0.294
3	0.249	**-0.228**	-0.186	-0.034	-0.003	-0.064	0.025	-0.240
4	0.370	-0.096	**-0.443**	-0.040	0.002	0.042	-0.057	-0.216
5	0.216	-0.084	-0.192	**-0.091**	-0.006	0.161	0.133	0.137
6	-0.081	-0.036	0.042	-0.029	**-0.019**	0.022	0.235	0.135
7	0.064	0.046	-0.058	-0.046	-0.001	**0.318**	0.047	0.369*
8	-0.127	-0.014	0.056	-0.030	-0.011	0.037	**0.402**	0.313

Residual effect = 0.4197

2. Lycopene
3. Ascorbic acid
4. Acidity
5. Total soluble solids
6. Locule number
7. Seediness
8. Yield

Bold letters are direct effects

High estimates of residual effect (r= 0.4917) showed that all factors contributing towards oxalates had not been taken care of in the present study.

4.5.2. Lycopne content

Direct and indirect path coefficeints of different characters on lycopene has been presented in the Table 14. Oxalates recorded highest (rg =0.614) positive direct effect on lycopene, it had positive indirect effect (rg =0.020) through TSS. Negative and indirect effects were expressed through ascorbic acid (rg = -0.059) acidity (rg = -0.105), and seediness (rg = -0.066). Ascorbic acid expressed positive and significant correlation (r =0.363) and direct and positive effect (rg =0.244) on lycopene. This significant correlation was achieved through its indirect and positive effects via acidity (rg =0.204), TSS (rg =0.053) and seediness (rg =0.036). Ascorbic acid exhibited its negative and indirect effects through oxalates (rg = -0.148).

As was evident from Table 14, acidity recorded positive and highly significant correlation (r =0.538) and direct and positive effect (rg =0.485) on lycopene. Significant and positive correlation was also due to the indirect and positive contribution through ascorbic acid (rg =0.102) and TSS (rg =0.062). It expressed, indirect and negative influence through oxalates (rg =-0.133) and seediness (rg =-0.023). Positive correlation (rg =0.315) and positive and direct effect (rg =0.143) was recorded in the case of TSS on lycopne. Its positive and indirect effects were expressed through oxalates (rg =0.084), ascorbic acid (rg = 0.090), and acidity (rg =0.210). Indirect and negative contributions were observed through seediness (rg = -0.091). It was interesting to observe that, though seediness had negative direct effect (rg = -0.179), it had positive

Table 14 : Direct and indirect path coefficients (Phenotypic) of different characters on lycopene in a 6x6 diallel cross of tomato

Characters	1	3	4	5	6	7	8	Correlation coefficient
1	**0.614**	-0.059	-0.105	0.020	-0.003	-0.066	-0.107	0.294
3	-0.148	**0.244**	0.204	0.053	-0.004	0.036	-0.021	0.363*
4	-0.133	0.102	**0.485**	0.062	0.002	-0.023	0.043	0.538*
5	0.084	0.090	0.210	**0.143**	-0.008	-0.091	-0.114	0.315
6	0.083	0.038	-0.046	0.045	**-0.026**	-0.013	-2.00	-0.118
7	0.226	-0.049	0.063	0.073	-0.002	**-0.179**	-0.040	0.093
8	0.192	0.015	-0.061	0.047	-0.015	-0.021	**-0.342**	-0.184

Residual effect = 0.3755

1. Oxalates
3. Ascorbic acid
4. Acidity
5. Total soluble solids
6. Locule number
7. Seediness
8. Yield

Bold letters are direct effects

5. DISCUSSION

An effective breeding programme for developing high yielding and improved quality varieties requires preliminary information on the nature and magnitude of variability present in the breeding material. Yield, of course, is the most vital varietal character. However, breeding for improved quality in tomato assumes greater importance since tomato tops the list of processed vegetables in the world. Hence, it becomes most important that the processed products of tomato should be of high quality. This could be ensured by improving the quality parameters concerned and by reducing the oxalates content an anti-nutritional compound present in tomato. Breeding efforts directed to improving the important quality achieved rather variable results. This was probably due to little attention paid to the correlation among plant-fruit characteristics and fruit composition. Therefore, it is very essential to get genetic information on major quantitative and qualitative characters associated with yield before embarking upon a plant improvement strategy.

Generation mean analysis comprising of six generations i.e., P_1, P_2, F_1, F_2, B_1 and B_2 generations offer greater scope for obtaining information on genetic control of various quantitative and qualitative traits. For a systematic improvement of yield along with qualitative traits, a precise knowledge on nature of gene action (mono factorial or epistasis) and association of different quality parameters with yield and among themselves became indispensable. The present investigation was undertaken to get an insight into the nature and

magnitude of gene effects, character association and their direction on yield, oxalates content and other quality traits concerned in tomato viz. lycopene, ascorbic acids acidity, total soluble solids, locule number and seediness. The results obtained are discussed hereunder.

5.1. Studies on gene effects

The information on type (s) of gene action governing the various qualitative and quantitative traits could be generated through different approaches like diallel analysis or line x tester analysis. Population as a whole but not the individual crosses could be assessed by the above approaches. But generation mean study enables to analyse the gene effects cross wise and provide precise information on the fixable (additive x additive, *i)* and non-fixable (additive x dominance *j* and dominance x dominance *l*) effects and their relative magnitude which should indicate the future breeding strategy. Therefore, generation mean analysis was used in the present study to detect the relative magnitude of additive and dominant compounds along with the digenic epistatic interactions.

Oxalates had wide distribution in the plant kingdom. Plant tissues has been found to contain soluble and total oxalates and high concentration of soluble oxalates may lead to calcium deficiency and oxalurea (Srivastava and Krishnan, 1959). Considering the fact that tomato is consumed in considerable quantity both in the fresh and processed form, it was worthwhile to investigate the oxalates content and their mode of inheritance in tomato. Generation mean analysis revealed that estimates of either of the scales (A, B, C and D) were significant which indicated the presence of interaction in the crosses. This was

further confirmed by the significant χ^2 (except in one cross; Line 1234 x Line 362). Main effect (*m*) was significant indicating considerable variability present among the hybrids. Additive gene effects was significant in the negative direction in nine crosses which indicated a reduced levels of oxalates, most desirable in this trait. This would mean that pure line selection would be helpful in getting reduced levels of oxalates from desirable parents. Dominant gene effects were significant in six crosses in the positive direction which meant that considerable dominance existed in the material and hybrid production would lead to increased levels of oxalates which was undesirable from the quality point of view. Additive x additive effects were significant in the positive direction in seven crosses, additive x dominance effects were significant and positive in eight crosses and dominant x dominant effect were significantly negative in nine crosses (Table 4.).

The results indicated that additive and non-additive effects were involved in the inheritance of this trait, with additive part significantly influencing the reduced levels of oxalates, while non-additive part contributed to increased levels of oxalates. None concerned had reported so far regarding the inheritance of oxalates. Duplicate epistasis was found to be of significant level in ten crosses. Duplicate epistasis coupled with negative and significant *i* effects indicated that segregants could be obtained for this trait in later generations. Duplicate epistasis coupled with positive and significant *i* effects indicated the possibility of recovering the recombinants in segregating generations. Complementary epistasis was observed in three crosses where selection could fix this trait in advanced generations.

Lycopene is the principal coloured carotenoid present in tomato. Red fruit colour typical of the cultivated tomato is due to the accumulation of lycopene as principal fruit carotenoid. Generation mean analysis revealed that in three crosses namely Pusa120 x line 25-7-4, Line 1234 x Arka Vikas and Arka Vikas x Line 25-7-4 additive dominance model was adequate to explain the inheritance of lycopene. All the three types of interactions (*i*, *j* and *l*) also played a greater role in the inheritance of this trait as indicated by their significance (Table 5). The results suggested that additive and non-additive gene action contributed to the inheritance of this trait, with the magnitude of non-additive gene action higher than those of additive gene action. Similar results obtained by Bhutani and Kalloo (1983), Raijadhav and Kale (1987) and Stommel and Haynes (1994), supported the present finding. Thus to get an increased level of lycopene a breeding method which would exploit the non-additive gene action was found to be appropriate.

In four crosses complementary epistasis was observed which suggested that selection could fix this traits in these crosses in advanced generation. Duplicate type of epistatis coupled with positive and significant *i* effects indicated the possibility of recovering recombinants in segregating generations. Duplicate epistasis coupled with negative and significant *i* effects suggested that desirable segregants could be obtained in later generations.

Among the quality components which are important for processing are total soluble solids (Stevans, 1979) acidity (Thompson *et al.*, 1964). Ascorbic acid, sugars and organic acids are also important constituents of flavour and edible quality of tomato (Lower and Thompson, 1967). Significant estimates of

scals and χ^2 test indicated the presence of non-allelie interactions for the ascorbic acid (Table 6). Additive gene effects (*d*) were positive and significant in three crosses, and significant positive dominant gene effects in three crosses were important for this trait. Among the interaction components, *i, j* and *l* were significant and positive in four, four and nine crosses, respectively. The results suggested that additive and non-additive gene effects contribute in the inheritance of this trait, with non-additive (epistasis) effects had higher magnitude than additive components of gene action. Similar reports by Arora *et al.* (1982), Dodd *et al.* (1995) all supported the present finding. The predominance of non-additive components suggested heterosis breeding using desirable parents could improve this trait. Epistasis was duplicate in thirteen crosses, which suggested selection could not improve this trait in these crosses. Two crosses had complementary epistasis where selection could be employed to fix this trait in later generations.

Bulk handling of tomatoes for processing industry requires fruits that are having adequate levels of acidity which is important for preventing the germination of spores of thermophilic organisms (e.g *Bacillus caogulans*) in the processed product (Thompson, *et al.*, 1964). An acidity of 4 to 4.5 (g/100g juice) is, therefore, desirable for safe processing. Generation mean analysis revealed that in one cross, Pusa120 x Arka Vikas, additive-dominance model was adequate to explain the inheritance of this character, with dominance gene effect more pronounced than additive effects (Table 7). Among the interacting crosses, additive (*d*) gene effects were positive and significant in four crosses and dominance (*h*) effect positive and significant in one crosses. The

interaction effects *i* was significant and positive in one cross, Pusa Ruby x Line 25-7-4. In the *j* effect the significance was in the negative direction. The *l* effects was positive and significant in two crosses namely, Pusa 120 x Arka Vikas and Pusa Ruby x Line 25-7-4. The results indicated that additive gene effects was more important compared to non-additive gene effects in the inheritance of this trait. Similar resutls Raijadhav and Kale (1987), Sonone *et al.* (1986), Singh *et al.* (1988) and Dhaliwal *et al.* (2001) all were in agreement with the present finding. Duplicate epistasis was recorded in eight crosses. Duplicate epistasis coupled with negative and significant *i* effects indicated that segregant could be obtained in later generation. Complementary epistasis was noticed in six crosses, where selection could fix this trait in advanced generation.

Total soluble solids (TSS) are important as the increase in the fruit TSS would results in the improved recovery of the processed products *viz.*, ketch-up, sauce, paste etc. and the acid: TSS ratio determine their flavour. Considering the significant χ^2 values and scaling tests for TSS it became quite obvious that additive-dominant effects were inadequate to explain the inheritance of this trait in all the fifteen crosses. In the interacting crosses, additive effects (*d*) were positive and highly significant in four crosses and dominant effect (*h*) was positive and highly significant two crosses, respectively. The *i*, *j* and *l* effects were positive and significant in four, five and ten crosses, respectively (Table 8). The results indicated additive gene effects and non-additive gene effects contributed to the inheritance of this trait with influence of non-additive (epistasis) effects more pronounced and significant in the desirable direction for

this trait. The present findings were in full agreement with the similar reports by Raijadhav and Kale (1987), Govindarasu *et al.* (1981) and Khalil *et al.* (1988), Peter and Rai (1980), Kumar *et al.* (1997) and Dhaliwal *et al.* (2001). With the predominance of epistatic effects upon the inheritance, heterosis breeding could be employed to exploit these effects. Majority of the crosses exhibited duplicate epistasis, where selection would not give the desired results. Duplicate epistasis coupled with positive and significant *i* effects as was the case in two crosses namely, Line 362 x Pusa Ruby and Arka Vikas x Line 25-7-4, desirable recombinants could be obtained from segregating generation. In three crosses complementary epistasis was noted where selection can be employed to fix this trait in later generation.

Locule number is a major component of the fruit size-shape-locule number complex in tomato (Dennet and Larson, 1953). It shows a continuous variation typical of a quantitative character (Ahuja, 1968). Locules present in tomato fruits plays an important role in governing its quality as it is positively correlated with fruit size and number of fruits (Bhutani and Kalloo, 1991). Regarding the locule number all the crosses were epistatic as indicated by the significance of χ^2 values and scaling tests (Table 9). Among the interacting crosses, additive effects (*d*) were positive and significant in three crosses and dominant effect (*h*) were positive and significant in four crosses. Among the interaction effects, *i, j,* and *l* were positive and significant in five, four and eight crosses, respectively. The results indicated the preponderance of non-additive (epistatic) effects over additive gene effect for this trait. Similar results obtained by Murthy *et al.* (1967), Ahuja (1968), Arora *et al.* (1982), Bhutani

and Kalloo (1991), Dodd *et al.* (1995) and Dhaliwal *et al.* (2001) supported the present finding. Majority of the crosses showed duplicate epistasis which would mean that selection have a reducing effect on this trait. Two crosses, namely Pusa-120 x Pusa Ruby and Line 1234 x Pusa Ruby showed complementary epistasis, where selection could fix this character in later generations.

Increased number of seeds in tomato fruit is an undesirable character from the point of view of its table value as well as its quality as it was found out from the present investigation that seediness was positively and directly correlated with oxalates – a character which is undesirable from the quality point of view. Hence, less number of seeds per fruit is preferred for both table and processing purposes. Generation mean analysis indicated that all the fifteen crosses were interacting suggesting the presence of epistasis for seediness (Table 10). Additive gene effects were significant in negative direction in four crosses, indicating that less seediness could be manifested by selection. Dominance gene effects were significant and negative in four crosses and magnitude of dominance gene effects were more pronounced than additive gene effects in the negative direction, which was desirable for this trait. However, the dominance x dominance (*l*) interactions were positive and significant in eight crosses coupled with duplicate type of epistasis might have resulted in the cancellation of the favourable negative heterotic effects in those crosses (Table 10). All the significant *i* effects were in the negative direction, but *j* effects were significant and positive in seven crosses. The results indicated that non-additive (epistasis) effect favourably influenced the seediness. Similar resutls

obtained by Mittal and Singh (1978), Dhoke (1990) and Bhutani and Kalloo (1991) were in agreement with the present finding. Duplicate epistasis was noted in majority of the crosses. Duplicate epistasis coupled with negative and significant *i* effects suggested the possibility of recovering recombinants in segregating generation. Three crosses had complementary epistasis, where selection could fix this trait in later generation.

Increased yield is the basic objective for all the crop improvement programmes. Unless, the new genotype has a potential for yield equal to or exceeding that of the commercially adapted cultivar, it will achieve little or no success. Generation mean analysis revealed that additive-dominance effect was adequate in one cross, namely Pusa 120 x Pusa Ruby. In the remaining crosses, χ^2 values were significant and also scaling test which indicated the presence of non-additive gene action (Table 11). Additive (*d*) effects were significant and positive in four crosses. Three crosses showed positive and significant *i* effects. These had practical significance on yield per plant since these components were fixable and yield could be improved by simple selection in these crosses. The results obtained by Swami and Mathai (1982) and Kanthaswamy *et al.* (1995) were in agreement with the above finding. Dominant gene effects were positive and significant in two crosses. In most cases dominance was partial or incomplete which suggested the predominance of recessive alleles in the parents. Additive x dominant (*j*) effects and dominant x dominant (*l*) were significant and positive in eight and seven crosses, respectively. This suggested that magnitude of non-additive (epistasis) effects were more than additive effects and heterosis breeding would results in the improvement of this

trait. Similar findings by Peter and Rai (1980), Anbu *et al.* (1981), Govindarasu *et al.* (1981) and Chandrasekhar and Rao (1984) were in agreement with the present finding. Complementary gene action was noticed in four crosses, where selection could fix this trait in advanced generations. Duplicate gene action was recorded in most cases where selection would be effective in the improvement of this trait.

5.2. Correlation studies

Very often it is found that change in one variable is accompanied by change in another variable. Such characters are said to be correlated. When an increase in one variable is accompanied by increase in another correlated variable the correlation is positive. On the other hand, when increase in one variable is accompanied by a decrease in another variable the correlation is negative. The coefficient of correlation express association between two variables but tell us nothing about the causal relations of variable i.e. which variable is independent and which is dependent. The correlation coefficient is not associated with the units of measurement.

In the present study genotypic and phenotypic correlations were worked out in 66 lines and hybrids of tomato (including parents) on eight characters. Generally, genotypic correlations were of higher magnitude than their corresponding phenotypic values (Table 12). It was argued that environment might influence the expression of inherent relationship (Thomson *et al.*, 1955). The correlations observed in the present study has been discussed here under.

Oxalate recorded positive and significant correlation with seediness (r = 0.369). With lycopene TSS and locule number it had non-significant positive

correlations. Observed correlations with ascorbic acid and acidity were negative and non-significant. The works on correlation of oxalates have not been reported so far. The results suggested that those characters which are positively correlated could be considered major contributing factor towards increased oxalates. In the present studies inverse correlations observed with ascorbic acid and acidity indicated that a simultaneous improvement of these characters would result in a decreased oxalate levels, which is desirable from the quality point of view. Thus, the present studies is clearly pointed out that a breeding programme which aims at the improvement of ascorbic and acidity would be helpful in obtaining a line with reduced oxalates, while a simultaneous improvement in lycopene, TSS and seediness would run the risk of increased oxalates.

In the present studies lycopene recorded highly significant positive correlations with acidity (r = 0.538) and ascorbic acid (r = 0.363). Positively non-significant correlations were observed with oxalates and seediness, while inverse and non-significant correlation was recorded with locule number. Earlier reports by Kurian and Peter (1997), Nair and Thamburaj (1995), Kumar and Tiwari (1999) and Wang-Yang Fei *et al.* (1999) all supported the present finding. From the results it was clear that a strong association of acidity and ascorbic acid with lycopene would make it not impossible to combine these characters simultaneously in an improvement programme. The above mentioned two characters also showed inverse correlations with oxalates which meant that an improvement of lycopene through acidity and ascorbic had the obvious advantage of reduced oxalate content. However, oxalates itself

recorded non-significant positive correlations with lycopene, TSS and seediness. Hence, from the quality point of view these two characters could not be selected in an improvement programme.

From the results it was clear that ascorbic acid had strong positive associations with acidity (r = 0.420), TSS (r = 0.370) and lycopene (r = 0.363). Positively non-significant association was observed with locule number. But non-significant inverse correlation trend was recorded with oxalates and seediness. Similar earlier reports by Bhutani and Kalloo (1999), Amaral *et al.* (1999) and Wang-Yong Fei *et al.* (1999) all lend credence to the present finding. From the strong positive *inter se* associations with acidity TSS and lycopene would make it useful to combine these characters in the improvement programme. Negative trend in correlations recorded with oxalates and seediness meant that an obvious way to improve the quality of tomato by reducing the oxalates and seediness would be to breed for improved ascorbic acid.

The results recorded for acidity revealed highly significant positive correlations with lycopene (r = 0.538), ascorbic acid (r = 0.420) and TSS (r = 0.432), non-significant positive correlations with seediness. However, an inverse trend was observed in correlation with oxalates. Earlier reports by Bhutani and Kalloo (1989) and Wang-Yong Fei *et al.* (1999) all supported the present finding. The results suggested that the inverse trend observed in correlations with oxalates was useful since an increase in acidity would mean a decrease in oxalates. Highly significant positive correlations were noted, in the present studies, with lycopene, ascorbic acid and TSS suggested that these traits

could be used as an indirect tools for breeding for higher acid content along with a simultaneous improvement in these traits. From the present studies it was clear that, of the correlations studied in all the present characters concerned, an obvious way to combine almost all the quality traits in a single improvement programme would be to breed for improved acidity.

Inter se associations of total soluble solids observed in the present studies with seediness (r = 0.508), acidity (r = 0.432) and ascorbic acid (r = 0.370) were highly significant and positive. Correlations with oxalates, lycopene showed a positive trend. Earlier reports by Kurian and Peter (1997) ; Patil and Bojappa (1987) all supported the present finding. Positive associations observed with all the characters suggested that, these traits except oxalates and seedienss could favourably be combined in a plant improvement programme to get an improved variety qualitywise.

In the present studies, highly significant positive correlation was showed by locule number with yield (r = 0.585). Observed correlations with oxalates, ascorbic acid TSS and seediness showed a positive trend. Reports by Takac *et al.* (1995), Amaral *et al.* (1999) earlier published all lend credence to the present finding. The results suggested that the positive association with these characters with the exception of oxalates and seediness could favourably be combined to increase the number of locule. Multilocular fruits (fresh market type) had high ascorbic acid and TSS than bilocular fruits which indicated that selection for higher number of locules could improve these characters (Amaral *et al.*, 1999).

Significant positive correlations were recorded in the present studies with TSS (r = 0.508), and oxalates (r = 0.369) by the trait seediness.

Correlations with lycopene, acidity and locule number showed a positive trend. However, ascorbic acid was inversely correlated with seediness. Earlier report by Burman *et al.* (1996) lends credence to the present finding. The results suggested that an obvious way to get decreased oxalates was to select for lesser seed content. Also it was evident that lesser the seed content the higher will be ascorbic acid content. From the point of quality in terms of TSS a low seed content cannot be favoured.

5.3. Path coefficient analysis

Coefficient of correlation indicates the relationship between two variables, however, it provides no information regarding the extent of change in one variable resulting from change in another variable. It is the regression coefficient which measures the rate of change in one variable per unit rate of change in another variable. The correlation between a number of independent variables which are the component characters and the dependent variable can be partitioned into the measures attributable to the direct effects and indirect effect.

In the present studies path coefficients were worked out separately for two characters, namely oxalates (Table 13) and lycopene (Table 14). In each cases, the two characters individually were taken as the dependent variable while other character as independent variables. The results obtained from the path coefficient analysis are discussed here under.

The component characters showed negative and positive effect on oxalates in the present study (Table 13). Lycopene (rg = 0.686) and seediness (r = 0.318) had positive direct effect and positive correlations with oxalates which

indicated that these characters showed true association with oxalates mainly due to their positive direct effect. But the positive direct effect of lycopene was somewhat lessened due to its negative indirect effects through ascorbic acid, acidity and TSS and hence it showed a positive correlation (r = 0.294) of lesser magnitude. The indirect effects through locule number and seediness was positive. The results showed that an attempt to select for increased lycopene would result in increased oxalates also. However, the negative indirect effect expressed through the other traits would reduce the direct effect in a combined selection programme.

Seediness showed significant correlation (r = 0.369) and positive direct effect (rg = 0.318) on oxalates. The results showed that the observed correlation was true and an increase in the content of seed would result in increased oxalate levels. This positive direct effect got magnified by its indirect positive effect through lycopene, ascorbic and yield. However, its indirect effects were negative through acidity, TSS and locule number. The results suggested that a selection programme which will combine lesser seed content with higher levels of acidity, TSS and locule number may result in reduced levels of oxalates.

Ascorbic acid, acidity, TSS and locule number showed negative direct effect on oxalates. Ascorbic acid was inversely correlated with oxalates. The path coefficient analysis confirmed that the observed correlation was true and mainly due to its negative direct effect. It also had indirect negative effects through acidity, TSS, locule number and seediness, however, positive indirect effect was through lycopene. The results suggested that the trait ascorbic acid

along with acidity, TSS, locule number and seediness can be favourably combined in a breeding programme to get low content of oxalates.

Acidity also in the present studies recorded negative direct effect (rg = -0.443) and inverse correlation (r = -0.216) with oxalates. However, its negative direct effect did get lessened due to its positive indirect effects through lycopene, locule number and seediness. Thus the path coefficient analysis confirmed that even though it had negative direct effect on oxalates, this trait could not be taken as an indirect selection tool along with the characters studied in the present investigation.

In the present studies it was interesting to observe that the TSS and locule number recorded positive correlations notwithstanding their negative direct effects. Path coefficient analysis revealed that observed correlations were not true and not due to their respective direct effects. The indirect positive effect through lycopene, seediness, and yield contributed to its positive correlation case of TSS. Locule number revealed its positive indirect effect through acidity, seediness and yield. The result clearly confirmed that in case of TSS and locule number, a consideration for their individual direct effect alone are not the sufficient criteria to combine them in a breeding programme to get reduced level of oxalates.

Path coefficient analysis for lycopene (Table 14) in the present studies revealed that oxalates (rg = 0.614), ascorbic acid (rg = 0.244), acidity (rg = 0.485) and TSS (rg = 0.143) recorded positive direct effect and positive correaltion with lycopene. Thus, path analysis confirmed that observed correlations were true. Similar results reported by Kurian and Peter (1997);

Kumar and Tiwari (1999) and Wang-Yong-Fei *et al.* (1999) where they observed correlation of lycopene with TSS and lycopene with ascorbic acid, respectively supported the present finding. Thus from the present study it was clear that the positive correlation of lycopene with these character could be due to their direct positive effects. Hence, from the quality point of view combining these characters except oxalates together in a selection seems not impossible.

However, locule number recorded negative direct effects (rg = -0.026) and negative correlation (r = -0.118) with lycopene in the present study. Earlier report by Amaral *et al.,* (1999) supported the present finding which confirmed that number of fruit locules were inversely correlated with lycopene mainly due to its negative direct effect. Seediness had negative direct effect, though it recorded positive correlation, where its negative direct effect did get lessen because of its positive indirect effects through acidity, TSS and oxalates. In the present studies path co-efficient analysis of lycopene revealed that higher levels of lycopene could be brought about by a simultaneous improvement in ascorbic acid, acidity, TSS along with lycopene. This had the obvious advantage of reduction in oxalates as ascorbic acid and acidity had negative correlation and negative indirect effects on oxalates.

SUMMARY AND CONCLUSION

The present investigation entitled **"Breeding tomato for improved nutritive value by reducing oxalate content"** was carried out in the Division of Vegetable Crops, IARI, New Delhi-110012, during 1997-2001. The studies were mainly centered on the mechanisms of inheritance, character association, and path coefficient analysis for yield and quality parameters.

The experimental materials for the present investigation comprised of six parents, 15 F_1'S, 15 F_2'S, 15 B_1'S and 15 B_2'S. The materials other than parents were generated by making crosses in the parents in all possible combinations following a diallel mating design. During the spring summer season of the year 1999, 15F_1'S were generated. Further the F_1'S, were selfed and backcrossed with both the parents (P1 and P2). Thus the 15 F_2'S, 15 B_1'S, and 15 B_2'S were generated in the spring summer season of the year 2000. The final trial comprising of six generations was laid out in a Randomised Block Design with three replication during the spring summer season of 2000-2001.

The observations were recorded on eight parameters viz., oxalates, lycopene, ascorbic acid, acidity, total soluble solids, locule number, seediness and yield.

The means over the three replications were subjected to statistical analysis. The generation mean analysis was done to determine the additive, dominant and epistatic components as per Hayman (1958), correlation by Al-Jibouri *et al.* (1958) and path co-efficient analysis by Dewey and Lu (1959).

The salient findings of the present investigation are summarized below:

- Analysis of variance revealed that mean sum of squares due to treatments were found to be significant in all characters except lycopene and acidity which indicated considerable variability in the experimental material.
- Generation mean analysis showed that majority of the crosses of each traits were found to be interacting thereby indicated the presence of digenic interaction (non-allelie).
- Additive (*d*), dominant (*h*) and epistatic (*i, j* and *l*) effects played a major role in the inheritance of all the eight characters.
- In general, dominant x dominant (*l*) interactions were significant and positive coupled with duplicate epistasis suggested that selection would have an increasing effect on the respective characters in advanced generations.
- Three crosses in each of oxalates, TSS, ascorbic acid and seediness exhibited complementary epistatis. Four crosses, each in lycopene and yield, two crosses in locule number and six crosses in acidity showed complementary epistasis. These crosses can be improved by simple selection in later generation.
- Correlation analysis revealed that oxalate was positively and significantly correlated with seedienss (r = 0.369). Positive correlations were also observed with lycopene, TSS and locule number. Inversely correlated with ascorbic acid and acidity. Lycopene was significantly and positively correlated with ascorbic acid (r = 0.363) and acidity (r = 0.538). It indicated for improving lycopene content along with reduced oxalates, acidity and ascorbic acid should be combined in a improvement programme.

- Path co-efficient analysis for oxalates and lycopene showed that, most of the observed corelations were true in both the cases. Ascorbic acid, acidity, TSS and locule number had direct negative effects on oxalates, while ascorbic acid, acidity and TSS had positive direct effect on lycopene. Between oxalates and lycopene they had positive direct effect on each other. The results opened up the way for improved quality by reducing oxalates by combining the characters ascorbic acid, acidity and TSS along with lycopene, in an improvement programme.

Conclusions / Future strategies

It is concluded from the present studies that simultaneous exploitation of additive and non-additive components (including epistasis) would be rewarding through the adoption of biparental intermating system followed by selection in majority of the crosses for the improvement of yield and quality characters. Future strategies may be as follows:

- To formulate a breeding programme to get a line/variety of low oxalates with higher content of other quality traits viz., lycopene, ascorbic acid, acidity, total soluble solids, locule number.
- A judicious selection programme in advanced generations for simultaneous improvement of quality parameters along with yield should be adopted.
- To break undesirable associations between characters of interest the selective biparental matings approach should be followed in the cyclic manner till the desired level of trait(s) is achieved.

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* Originals not seen.