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FOCUS

Guava improvement in India and future needs

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ABSTRACT

Guava (*Psidium guajava* L; Myrtaceae) is an important fruit crop of India. High heterozygosity and frequent cross pollination resulted in the present day variability in seedling populations from which promising genotypes have been selected. As of now, there are about 160 cultivars available in India, among which 'Allahabad Safeda' and 'Sardar' varieties are widely cultivated. Crop improvement work attempted in India resulted in release of several superior selections / hybrids. Also, interspecific hybrids resistant to guava wilt were developed at CISH, Lucknow which are graft compatible with commercial varieties of *P. guajava*. The use of new biotechnological tools like DNA fingerprinting to study the extent of genetic variation among cultivars, rapid multiplication through in vitro shoot-tip culture needs to be employed extensively. Attempts need to be made to spot genetic markers for wilt resistance to improve efficiency in developing wilt resistant clones and rootstocks. Survey to identify superior genotypes with Allahabad Safeda traits and high density planting characters like early bearing, compact plant type, favourable response to pruning, good branch angle to minimize branch breakage even under heavy bearing, and, with a high fruit : shoot ratio need to be paid due attention. Work on aneuploidy breeding, development of autotetraploids and in vitro genetic manipulation of somatic cells needs to be intensified.

Key words: Guava, improvement, varieties/hybrids, *Psidium* sp.

INTRODUCTION

Guava (*Psidium guajava* L.) is an important fruit crop of India. It has gained considerable prominence on account of its high nutritive value, availability at moderate prices, pleasant aroma and good flavour. It is one of the commonest fruits liked by the rich and the poor alike and is popularly known as 'apple of the tropics'. It is one of the hardiest fruit trees, adaptable to a variety of soil and climatic conditions.

It grows well even under neglected conditions and, in fact, is even sometimes considered of a weed in Fiji and Hawaii. It is the fifth most widely grown fruit crop of India. The area under guava is about 0.178 million hectares, producing 1.83 MT of fruit. Popular varieties of guava in India are Allahabad Safeda, Lucknow-49, Nagpur Seedless, Dharwar, etc. Bihar is the leading state in guava production, with 0.26 MT, followed by Maharashtra, Uttar Pradesh, Karnataka, West Bengal, Punjab, Andhra Pradesh, Gujarat, Orissa and Tamil Nadu. At present, it is grown throughout the length and breadth of the country night from sea level to 1300m altitude, and is so acclimatized that it seems like a native of India. Guava is a rich source of vitamin C and pectin. Guava fruit contains 82.5% water, 2.45% acids, 4.45% reducing sugars, 5.23% non-reducing sugars, has 9.73 % TSS, 0.48% ash and 260 mg vitamin C/100g fruit (which differ with cultivar, stage of maturity and season). Guava fruit is relished when mature or ripe, or, when freshly plucked from the tree. It is also used in making many commercial products like jelly, fruit butter, juice, etc.

ORIGIN AND DISTRIBUTION

The guava is said to have originated in tropical America (Hayes, 1953). De Candolle (1904) stated that it originated in Mexico, while Purseglove (1968) opined that it originated in Brazil. It is widely distributed over equatorial regions growing in tropical and sub-tropical climates. It was introduced in to India during the 17th Century. In Spanish, the tree is known as *guayabo* or *guayavo*, the fruit *guayaba* or *guyava*. The French call it *goyave* or *goyavier*; the Dutch, *guyaba*, *goeajaaba*; the Surinamese, *guave* or *goejaba;* and the Portuguese, *goiaba* or *goaibeira.* Hawaiians call it guava or *kuawa*. In Guam, it is *abas*. In Malaya, it is generally known either as guava or

jambu batu, but has also numerous dialectal names as it does in India, tropical Africa and the Philippines where, the name *bayabas*, is often applied. Various tribal names – *pichi, posh, enandi, etc*., are employed among Indians of Mexico and Central & South America.

SPECIES STATUS

The genus *Psidium* belongs to the family Myrtaceae and has a basic chromosome number of x=11. All the cultivars of Indian guava belong to a single species, *Psidium guajava* L. Hayes (1953) reported the genus to contain about 150 species, though only a few have been studied in detail. Bailey (1919) reported that the two species, *pyriferum* and *pomiferum* mentioned by Linnaeus are nothing but trees with pear shaped and round shaped fruits. Subsequently, other species were recognized and documented. The wild species of guava are of considerable importance in breeding programmes.

P. Cattleianum var.cattleianum (Sabine) *syn: P.littorale* (Raddi) *var. longipes (Berg.)*

It is a wild subtropical species closely related to guava. It can adapt to many soil types and is quite cold resistant. It is a small tree or shrub with a smooth bark. Leaves are obovate elliptic and glabrous. Fruits are round, about 2.5 cm in diameter and very fragrant. The skin is thin, pulp is soft with numerous seeds. It has a sweet flavour and good aroma. It is also known as 'Strawberry guava' because of the sweet aroma reminiscent of strawberry. Since this lacks muskiness of the common guava, it is preferred among certain tribals (Normand, 1994).

P. Cattleianum (Sabine) *var. lucidum syn: P. littorale* (Raddi) *var. littorale (Berg).*

It is a relatively hardy subtropical species. The fruits are small, globose, juicy, acidic and sulphur yellow in colour. It is also called 'lemon guava'.

P. guineense (Sw). Syn: *P. molle* (Bertol), *P. araca* (Raddi), *P. Schiedeanum* Berg.

It is also called Brazilian or Castilian guava. It is a slow growing shrub, about 1 to 3m long and withstands short periods of drought. The leaves are oblong, scantily hairy on the upper side but coated beneath with pale or rusty hairs and distinctly dotted with glands. The fruits are round with yellow skin, pale yellow pulp surrounding the white central pulp. It contains numerous hard seeds (Mortan 1987).

P. friedrichsthalianum (Niedenzu)

It is a tall tree about 7-10m high. The branches are slender and smooth. Leaves are oval or oblong/oval, smooth, almost glossy above and pubescent below. Fruits are globose, small and sour. The fruits are good for jelly making because of their high acidity. Reported to be wilt and nematode (*M. incognita*) resistant, it is also called Chinese guava or Costa Rican guava.

P. montanum (Swartz)

It is generally found in the mountains of Jamaica. The branchlets are four angled, leaves oblong to oval, glabrous, fruits are round, pulp white with more number of seeds. It produces fruits of poor quality.

P. araucanum (Soares-Silva and *Proenca)*

A large tree with membranous leaves, brochidodromous venation, long petioles and peduncles, flowers solitary, axillary or ramiflorous or in short racemes, with two pairs of flowers. Fruits globose or pear shaped, thin pericarp, fruits yellowish green when mature, seeds angular or lenticulate.

P. acutangulum DC

The shrub or tree ranges in height from 26 to 40 ft. Its branchlets are quadrangular and winged near the leaf base and the new growth is finely hairy. Leaves are elliptical with very short petioles. Fruits are round to pear shaped, pale yellow to yellowish white acidic pulp but well flavored pulp containing few hard, triangular seeds. The fruits are mixed with honey and eaten or, made into acid drinks or preserves.

CYTOLOGY

In guava, most of the commercial varieties are reported to be diploids, the chromosome number being 2n = 22, except the seedless types which are triploids (Kumar and Ranade, 1952). Cytological studies made on structure and behavior in different varieties of *P. guajava* by several workers indicated that meiosis was normal with formation of 11 bivalents at diakinesis, and normal distribution of chromosomes at later stages (Raman *et al*., 1969). The chromosome number of *P. friedrichsthalianum* Niedenzu was reported to be 2n = 22 (Srivastava, 1977). A natural triploid with somatic chromosome number of 2n = 33 was reported by Kumar and Ranade (1952). The same chromosome number was reported by Raman *et al* (1971) in a seedless variety of *P. guajava* suggesting that triploidy is the cause of seedlessness in guava. Shafaat Mohammed

(1975) studied breeding behaviour of the aneuploids in guava (*Psidium guajava* L.) such as trisomic, tetrasomic and higher aneuploids. He observed that reciprocal crosses between aneuploids and diploids indicated less than 100% crossability. The aneuploids, when used as the male parent, crossed less frequently than as female parents and some aneuploids crossed more readily than others. Differences were observed in fruit size, fruit weight, and seed number in reciprocal crosses. The extra chromosome was found to be transmitted through both the egg cell and the pollen. However, frequency of transmission was greater through the egg cell than the pollen. As high as 26% transmission of extra chromosomes were obtained through the egg cell. There was no clear cut difference between trisomics and higher aneuploids with regard to frequency of transmission of the extra chromosomes. In guava, where large number of seeds is a disadvantage, aneuploidy breeding appears to be beneficial.

FLORAL BIOLOGY

The knowledge of flower bud development, time of anther dehiscence and anthesis, extent of fruit set and degree of cross pollination are a pre-requisite for planned hybridization for crop improvement.

In guava, flower buds are borne in leaf axil on current season's growth, either singly or in cymose of two or three (Braganza, 1990). Guava is reported to require about 30 days in Northern India from flower bud differentiation to complete development upto the calyx cracking stage (Singh and Sehgal, 1968). However, under Bangalore conditions, Braganza (1990) reported that the period varied from 45 to 51 days. The flowers consist of a superior calyx with five lobes and the corolla consists of 6 to 10 petals arranged in one or two whorls. The androecium consists of 160 to 400 thin filaments carrying bilobed anthers, closely packed together. The gynoecium consists of an inferior ovary, syncarpous, with axillary placentation and subulate style. The style is smooth and bearded at the summit. Three flowering seasons, *viz.*, 'Ambe bahar', 'Mrig bahar' and 'Hatti or Hasta bahar' have been reported in the peninsular regions of India (Cheema *et al* 1954). However, some workers reported only two flowering seasons (Sehgal and Singh, 1967; Sachan *et al*, 1969; Srivastava, 1974; Syamal *et al*, 1980; Ojha *et al*, 1986). In guava, it has been observed that the flowering season does vary between regions. Generally, three flowering seasons are recognized in the tropical South India and only two seasons in the subtropical North India.

In guava, peak anthesis was found to be between 6 and 7.30 A.M. under North Indian conditions (Singh and Sehgal, 1968). Dehiscence of anthers was observed to take place 15 to 30 minutes after anthesis and continued upto 2hrs (Balasubramanyam, 1959). Pollen fertility has been generally found to be high in guava (78 to 91%) in diploid varieties. Balasubramanyam (1959) found 4% sucrose solution to be the best medium for artificial germination of pollen. The pollen is reported as round with large grains (Srivastava, 1974). Stigmatic receptivity, as studied by fruit set following controlled pollination, was observed to be maximum on the same day as anthesis. Stigma was found to be receptive two days before dehiscence, extending upto 4 days (Singh and Sehgal, 1968).

VARIETIES

Varietal description and nomenclature of different guava varieties grown in India are greatly confusing. Some varieties were named according to shape of the fruit, skin colour and pulp colour, while, several other varieties were named after in the place of origin. Pandey (1968) made detailed studies in different cultivars of guava and classified them into the white pulp group and the red pulp group.

Guava is largely a self-pollinated crop, but cross-pollination also does occur. This results in a large variability in the seedling population from which promising genotypes have been selected in different agro-climatic regions of the country. Promising cultivars of different Indian states are given below:

State	Cultivars
Andhra Pradesh	Allahabad Safeda, Anakapalli, Banarasi, Chittidar, Hafsi, Sardar, Smooth Green and Smooth White
Assam	Amsophri, Madhuriam, Safrior Payele
Bihar	Allahabad Safeda, Chittidar, Hafsi (Red Fleshed), Harijha, Seedless
Gujarat	Nasik, Seedless, Sindh
Karnataka	Allahabad Safeda, Arka Mridula, Sardar, Navalur
Maharashtra	Dharward, Dholka, Kothrud, Lucknow-24, Sardar
Tamil Nadu	Anakapalli, Banarasi, Bangalore, Chittidar, Hafsi, Nagpur Seedless and Allahabad Safeda
Uttar Pradesh	Allahabad Safeda, Apple Colour, Chittidar, Red Fleshed, Banarasi Surkha, Sardar, Mirzapur Seedless
West Bengal	Bariampur and cvs. of Uttar Pradesh

About 160 genotypes, including some *Psidum* spp., are available in Indian collections and are maintained at several centres within the country in field gene banks. Nomenclature of the cultivars of guava grown in India is not yet well established. Some of the varieties have been

named according to shape, colour, and smoothness of skin or by the place of their origin. Characters like plant growth, yield and physico-chemical composition of different guava varieties were reported by several workers. Varietal evaluation was carried out by many workers who reported performance of these varieties under different agro-climatic conditions (Golberg and Levy, 1941; Teaotia *et al*, 1962; Srivastava and Srivastava, 1965; Singh *et al*, 1979; Chadha *et al*, 1981; Dinesh and Reddy, 2001). Characteristic features of some of the important guava cultivars grown in India are given below:

Allahabad Safeda : It is the most popular variety in India and has acquired large variations due to seed propagation. This is the progenitor of many Indian varieties and occupies the largest area under cultivation. Fruits are round, large in size, skin with smooth, light yellow on ripening, pulp white, firm, excellent in quality with high TSS and Vitamin C, pleasant flavour and a few, soft seeds.

Anakapalli: Fruits are medium sized with red pulp. Seeds are soft and plenty. Fruits are slightly oval.

Apple Colour: The trees are medium in vigour and are moderate yieldes. Fruits are medium sized, with apple coloured skin; cool temperature is required for good colour development. The pulp is white and firm, sweet to taste.

Bangalore: Fruits are medium to large in size, pulp is white with good taste and flavour.

Chittidar: This variety is very popular in Western Uttar Pradesh. The fruits are characterized by numerous, red dots on skin. Fruits are sub globose, with white pulp, high TSS and Vitamin C content of 240 mg /100g pulp.

Hafsi: Fruits are spherical in shape with thin skin and medium size. The pulp is red with good taste and flavour. Seeds are comparatively less in number, but hard.

Red Fleshed: Fruits are medium sized with red pulp, round, smooth skinned, seeds are plenty and medium soft. Fruits possess sweet flavour, are rich in Vitamin C (386 mg /100g pulp).

Sardar (Lucknow 49): It is a selection from Allahabad Safeda made at Poona during 1927. The plant has a spreading nature. The tree is dwarf with open, rounded crown. The fruits are medium to large and contain a crisp, soft and creamy pulp; it is a heavy bearing variety. The fruit has a slightly acidic flavour, attractive aroma, with many seeds, and good keeping quality.

Smooth Green: Fruits are round and medium sized. Skin is glossy and greenish yellow when mature. Pulp is white, good in taste and flavour.

Nasik: Fruits are medium sized, round, with white pulp, sweet with good flavour.

Banarsi Surkha : Trees are medium sized (5.1m) with a broad crown, fruit shape is round and surface smooth, skin colour golden yellow, pulp colour pink, seed number very high, seed texture very hard.

Seedless: The plants are very vigorous. There are different varieties, like, Saharanpur Seedless, Nagpur Seedless, Sringeri Seedless, etc., which are nearly identical. Two types of fruits, *viz.*, long, big sized with warty surface, and yellow, thin skin with swollen calyx end and round; small, with very few seeds. The pulp is white, good to taste and has aroma, contains moderate to high levels of Vitamin C (240 mg / 100g pulp).

Navalur: It is a variety grown in Dharwad district of Karnataka. It is hardy in nature, drought tolerant and resistant to canker. The important cultivars are: CIW-2 (Channappa Itigatti White), CIW-3, CIW-4, CIW-5, GR 1 (Ghatage's Red number one), GR 3, GW-1 (Ghatage's white number), GW-4, SR-1 (Shivammanavar red number one), SR-2, SW-2 (Shivammanavar white), SWY-1 (Shivammanavar white yalakki).

Apart from these prominent commercial cultivars, other cultivars grown in localized areas are: Pear Shaped, Apple Colour, Banarasi Surkha, Sangam, Seedless, Dholka, Sindh, Karela, Mirzapuri Seedling, Superior, Pourtgal, Spear Acid, Superior Sour Licidium, White Fleshed, Behat Coconut, Smooth white, Amsophri, Madhuriam, Bariampur, Harijha,

Dharwar, Safri or Payera, Soh-Pryiam, Am-Sophri, Kaffree, Supreme, White Supreme, Bangalore, Bhavnagar, Gwalior-27, Kafri (Pear shape), Kafri (Round shape), Rewa-72, Hazi sahib, Kohir, etc.

CROP IMPROVEMENT

In India, during the early days, guava plants were generally propagated by seeds from limited varieties available with nurserymen and pomologists. The seedling population obtained by open pollination gave rise to considerable variation in the form and size of fruit, the nature and flavour of pulp, seediness and other morphological characters such as spreading or erect growth habit of trees (Naik, 1949). Cheema *et al*., (1954) observed all the cultivars of guava to be highly heterozygous. Commercial producers utilized the variation thus obtained for selection of desirable genotypes and propagated them vegetatively. Assessment of genetic diversity and relationship among *Psidium* spp was carried out by Sharma *et al* (2007). They observed a high genetic similarity between Chinese guavas grouped with *Psidium guajava* cultivars.

It has been observed that only a few named varieties are under cultivation. Most of these varieties suffer from one defect or the other. Hence, guava improvement by breeding was started mainly with the following objectives for developing new cultivars:

i) dwarf plant habit suitable for high density planting

ii) fruits with uniform shape, size, good colour, firm and thick pulp, good aroma, few and soft seeds, high TSS and high pectin

iii) long shelf life

iv) resistance to *Fusarium* wilt

Plant introduction

Most of the guava varieties have evolved as selections from seedling variants. Variability has come about because of open pollination from highly heterozygous parents. Several introductions of promising genotypes have been made in guava growing countries. In India, many introductions made from Hawaii, Brazil, Thailand, etc. are being cultivated and used in breeding programmes. Similarly, introductions of Indian cultivars like Allahabad Safeda and Sardar have given excellent results in other parts of the world (Gonzaga *et al*, 1999).

Although introduction is a potential tool in any crop improvement programme as it considerably saves time, there is also the danger of new diseases getting introduced. It has been our observation that some of the introduced exotic acidic types like Beaumont were prone to 'Stylar End Rot' caused by *Phomopsis psidii*. This character was inherited even by hybrids. Hence, utmost care needs to be taken while introducing varieties. Unless these are observed under plant quarantine, further multiplication or usage on field scale should not be made.

Selection

At Ganeshkhind Fruit Experimental Station, Pune, India, guava improvement work was initiated in1907, primarily with collection of seeds of varieties grown in different places, to isolate superior strains. One strain from open pollinated seedlings of 'Allahabad Safeda' collected from Lucknow was selected and released as 'Lucknow-49' (Cheema *et al*, 1954) which became very popular and has now been renamed as 'Sardar' (Phadnis, 1970) after trials at Saharanpur (Singh,1953) and Kodur (Rangacharlu, 1954). The plant has a spreading nature. The tree is vigorous, dwarf with open rounded crown. Fruits are medium to large and contain a crisp, soft and creamy pulp. It is a heavy bearing variety. Fruits have a slightly acidic flavour, attractive aroma, with many seeds and good keeping quality.

At the Fruit Research Station, Saharanpur, one superior selection, *viz.*, S-1, with good fruit shape and quality, few seeds, sweet taste and high yield was isolated (Singh, 1959).

At Faizabad, seedling selections were made from 'Allahabad Safeda' and many selections were made under 'Faizabad Selection' (Pathak and Dwivedi, 1988).

At CISH, Lucknow, four seedling selections of guava, namely, CISH-G-1, CISH-G-2, CISH-G-3 (Lalit), CISH-G-4 (Swetha) have been released and their performance was studied by Marak and Mukunda (2007).

CISH-G-1: It is a selection from local red fleshed type, with attractive fruits having deep red skin, firm pulp with high TSS, soft seeds.

CISH-G-2: Selection from local red fleshed type, crimson colored attractive fruit, stripes in groove, seeds soft.

CISH-G-3 (Lalit): It is a selection from a high yielding variety, responsive to primary and high density planting. Fruits are round, weighing 150g, pink pulp suitable for both table and processing purposes.

CISH-G-4 (Swetha): Plants are semi vigorous, medium in height and are prolific bearers. Fruits are round, weighing 225g, with white pulp with good keeping quality.

At the Indian Institute of Horticultural Research, Bangalore, out of 200 open pollinated seedlings of the variety 'Allahabad Safeda' (collected from Uttar Pradesh), one seedling selection, 'Selection-8', was found to be promising and was released as 'Arka Mridula'. This variety has been reported to have also performed well with respect to yield and quality under rainfed conditions of Bihar (Ramkumar, 1998). The plants are semi-vigorous and spreading in nature. Fruits are round in shape and weigh about 180g. Fruit are yellow in colour with smooth skin.The pulp is white, firm, sweet with few soft seeds. The TSS is 12.0°B, 100 seed weight is 1.6g. Keeping quality is good. Pectin content is 1.04 %. The variety is good for jelly making.

At Allahabad Agricultural Institute, Allahabad, a selection from the local red pulp type has been released as 'Allahabad Surkha'. The plans are vigorous, dome shaped and compact. Trees are high yielding, producing upto 120kg per plant. The fruits are round with uniform, pink skin and deep pink pulp, sweet, strongly flavoured and with few seeds.

At Bulakihar (Malihabad), Lucknow, a selection has been made as **'**G. Vilas Pasand'. The trees are vigorous, wide spreading with bushy, low growing habit. Fruits are round to ovoid, skin texture is course to smooth, fruit skin pale yellow to golden, colour of flesh is creamy white texture creamy soft, very large (400g to 800g) fruit, less seeds, very productive throughout the year. High content of Vitamin C makes it stand out among guava varieties.

At Aurangabad and Bihir districts of Marathwada, three promising selections, *viz*., ABD3, BHR3 and BHR5 were made out of the 12 strains collected (Thonte and Chakrawar,1981).

At Narendra Dev University of Agriculture and Technology, Faizabad (UP), of the 23 strains collected from a survey of guava growing regions, 3 seedlings of Allahabad Safeda (AS1, AS2 and AS3) and 2 of Faizabad selection (FS 1 and FS 2) were found to be promising with respect of fruit quality and yield (Pathak and Dwivedi, 1988).

At GBPUA&T, Pantnagar (Uttaranchal), A selection was made as 'Pant Prabhat' for commercial cultivation. Plant growth in this line is upright; with broad leaves, the tree is highly productive (100 -125kg). Fruit skin is smooth and light yellow in colour, fruits medium sized with average fruit weight of 150-172g , pulp is white, seeds are small and medium soft, the fruit has a sweet taste with pleasant flavour, ascorbic acid content varies from 125mg (rainy season) to 300mg/ 100g fruit weight (winter season). TSS varies from 10.5 to 13.5^{0}B.

At the Fruit Research Station, Kuthulia, Rewa, a selection from an old, seedling orchard was made as 'Dhareedar'. The trees are vigorous, medium tall with erect and upright branching and a flat crown. Fruits are medium to large sized, roundish ovate in shape with 5-7 raised lines on the surface of mature fruits, the peel in greenish yellow, the pulp soft and sweet (TSS 11.7^0 Brix).

Hybridization technique

In guava, flowers that are chosen for crossing are emasculated when at the 'calyx break stage', a day before opening. Pollen from the pollen parent is brought from an unopened flower, at preferrably at calyx break stage. The stigmatic surface is gently smeared with the pollen and flowers are bagged. Under Bangalore condition pollination carried out during the morning hours between 10 AM to 12 noon has given better results.

Intervarietal Hybridization

In general, intervarietal crosses in guava are successful, having no crossability barriers. However, varietal cross incompatibility in guava is reported in crosses made between 'Behat Coconut' and 'Sardar', 'Behat Coconut' and 'Apple Colour'. In India, breeding work for guava improvement has been going on at several research institutions. At HETC, Basti, a number of cross combinations of 'Seedless' x 'Allahabad Safeda', 'Seedless' x 'L-49', 'Allahabad Safeda' x 'Patillo', 'Apple Colour' x 'Red Fleshed' and 'Apple colour' x 'Kothrud' were made. None of the 55 hybrids obtained from these crosses were found to be promising (Chadha, 1998).

At the Fruit Research Station, Sangareddy, A.P., two hybrids, 'Safed Jam' and 'Kohir Safeda' were selected out of crosses of 'Allahabad Safeda' x 'Kohir' and 'Kohir' x 'Allahabad Safeda', respectively, and released. These hybrids are particularly recommended for semi arid tropical areas. These have also been found to be suitable for the preparation guava juice (Mitra and Bose, 1985; Shanmugavelu *et al*, 1987).

At the Indian Institute of Horticultural Research, Bangalore, 'Arka Amulya' a hybrid was released through intervarietal hybridization involving 'Allahabad Safeda' and 'Triploid' (Subramanyam and Iyer, 1998; Anon., 1996).

At the Fruit Research Station, Anantharajupet, Andhra Pradesh, out of 6 hybirds, two (H1 and H6) were

found promising with regard to fruit quality and precocious bearing (Rama Rao and Dayanand, 1977).

At Rajendra Agricultural University, Sabour, Bihar, 210 F_1 hybrid seedlings were raised from various intervarietal crosses. A hybrid from the cross 'Apple Colour' x 'Sardar' had maximum fruit weight, Vitamin C and pectin content (Singh and Hoda, 1994).

Chaudhary Charan Singh Haryana Agricultural University, Hisar, released two guava hybrids, namely, Hisar Safeda (Allahabad Safeda x Seedless) and Hisar Surkha (Apple Colour x Banarasi Surkha).

Traits of some of the guava hybrids released recently are given below:

Safed Jam: This is a hybrid between the cross 'Allahabad Safeda' X 'Kohir' developed at FRS, Sangareddy. The tree is medium in height and a heavy yielder. Fruits are round in shape, large in size with a thin peel, good taste and few, soft seeds.

Kohir Safeda: It is a cross between a selected, heavy yielding line of Kohir X Allahabad Safeda. The tree is vigorous, fairly large in size and dome shaped. Fruits are large, with few, soft seeds and white pulp.

Arka Amulya: As stated above, this is from the cross 'Allahabad Safeda' X 'Triploid' developed at the Indian Institute of Horticultural Research, Bangalore. Plants are semi-vigorous and spreading type. Fruits are medium sized (180-200g), weight of 100 seed is 1.8g, pulp is white, with high TSS (12.5°B), fruits have good keeping quality.

Arka Kiran: It is from the cross 'Kamsari' X 'Purple Local'. Plants are semi vigorous, amenable to high density planting. The fruits are sub globose, weighing about 200-230g .The pulp is deep pink, thick and has good flavour. The seeds are medium soft (9.0 kg cm^{-2}), with high lycopene content (7.45 mg /100g) and TSS of 12.0 to 12.5°B.

Hisar Safeda: It is from the cross 'Allahabad Safeda' X 'Seedless', developed at CCSHAU, Hisar. Plants are upright, trees have a compact crown. Fruits are round, with a smooth surface, creamy yellow skin; average fruit weight is 92g, creamy white pulp, few soft seeds high TSS (13.4%).

Hisar Surkha: It is from the cross 'Apple Color' X 'Banarasi Surkha'. The tree crown is broad to compact. Fruits are round, skin yellow with red dots, average fruit weight 86g, pulp pink, seed count medium, TSS high (13.6%).

Autopolypoloidy: From several parts of our country, seedless varieties have been reported. At Poona, Kumar and Ranade (1952) reported a triploid guava variety with 33 chromosomes, and suggested it to be autotriploid. The chromosome status of seedless varieties available at IARI and Saharanpur was studied by Majumder and Singh (1964) and were found to be autotriploids. Iyer and Subramanyam (1971) were of the opinion the production of any more triploids was futile since fruit shape in triploids is highly irregular with mis-shapen fruits because of differential seed size. A natural autotetraploid in *P. guajava* was reported by Naithani and Srivastava (1966). Tetraploidy in guava has been induced too with colchicine treatment (Janaki Ammal, 1951; Ram Kumar, 1975).

Aneuploidy: At the Indian Agricultural Research Institute, New Delhi, with a view to evole a variety with fewer seeds and high yield, crosses were made between seedless (triploid) and seeded (diploid) 'Allahabad Safeda'. Of the 73 F_1 hybrid seedlings raised, 26 were diploids, 9 trisomics (2n+1), 5 double trisomics (2n+1+1) and 14 tetrasomics (2n+2). They showed distinct variation in tree growth habit and, leaf and fruit characters. Three tetrasomic plants had dwarf habit and, normal shape and size of fruits, with less number of seeds (Majumder and Mukherjee, 1972a,b; Mukherjee, 1977). In the progeny of open pollinated triploid, and triploid with diploid (Mohammad, 1974), 30 trisomics, 2 double trisomics, 1 tetrasomic and higher aneuploids were obtained. Reduction in growth and size of leaf distinguished aneuploids from diploids. Aneuploids, particularly trisomics, had promising qualities and may prove useful in developing plants with reduced seediness and, possibly, in providing dwarfing rootstocks.

Sharma (1982) identified a promising tetrasomic dwarfing rootstock (Aneuploid No. 82), through selection, out of 48 aneuploid seedlings at IARI, New Delhi. Studies conducted on the effect of aneuploid No. 82 rootstock on growth and yield of 'Allahabad Safeda' showed that the aneuploid induced substantial dwarfing in Allahabad Safeda in terms of plant height, plant spread and tree volume. Overall yield/unit volume of the plant was highest in aneuploid

No. 82, which indicated its strong potential for use as dwarfing rootstock on a commercial scale, for increasing production and profitability of guava orchards (Sharma *et al*, 1992).

Mutation: According to Cheema and Deshmukh (1927), naturally occurring mutations are not rare in guava. Brar and Bal (2003) investigated the effect of gamma rays (1,2,3,4 and 5 kR) on buds of guava cv. Sardar. After the treatment, these were budded onto Lucknow-49 rootstock. Variability for plant height, internodal length and stem diameter was maximum in 2 kR treatment; while, for number of branches, number of leaves and breadth of leaves, maximum variability was noted in 4, 1 and 3 kR treatments, respectively. Mutagenic treatments had no significant effect on stomatal size.

In vitro mutagenesis, followed by micropropagation *via* axillary bud proliferation of shoot tips in guava, was carried out by Zamir *et al* (2003). Shoot tips irradiated with gamma rays at 15-90 Gy and cultured in Murashige and Skoor's (MS) medium containing 3% sucrose, 6-benzylaminopurine (benzyladenine) (BAP) and L-glutamine. Optimum shoot proliferation was recorded in MS medium supplemented with 1.0mg BAP and 250mg L-glutamine/litre. Rooting of cultured shoots was observed in half-strength MS medium supplemented with IAA and IBA. LD_{50} was observed at 45 Gy. Rates of more than 75 Gy were lethal to explants.

Biotechnological techniques

Biotechnological techniques can be useful chiefly in breeding for disease resistance and in germplasm storage using tissue culture techniques. Use of tissue culture and micropropagation of superior guava cultivars has been discussed by several researchers (Amin and Jaiswal, 1988; Jaiswal and Amin, 1987; Loh and Rao, 1989; Papadatou *et al*, 1990). Jaiswal and Amin (1992) felt that somatic cell genetics could be useful in guava breeding for specific objectives. A technique for successful *in vitro* propagation of guava germplasm using shoot-tip explants from mature trees was reported by Jaiswal and Amin (1987). These workers also demonstrated that adding activated charcoal to the medium enhanced rooting of explants and vegetative growth of established plantlets. Risterucci *et al*, (2005) constructed a library of microsatellite-enriched (GA)n and (GT)n and, 23 nuclear simple sequence repeat (SSR) loci were characterized in the guava species *Psidium guajava* L.). All the SSR loci were found to be polymorphic after screening for diversity in different cultivars, and across-taxa amplification tests showed potential transferability of most SSR markers in three other *Psidium* species. First to be published for *P. guajava*, this new SSR resource will be a powerful tool for genetic studies in guava, including cultivar identification and linkage mapping, as well as potentially, for, interspecific genetic studies within the genus *Psidium*. Rapid multiplication of seedling plants of guava through *in vitro* shoot-tip culture and subsequent plant establishment also has been successful (Papadatou *et al*, 1990).

Somaclonal variation, which normally occurs in several tissue cultures (Larkin *et al*, 1985; Evans and Sharp, 1988; Lee and Philips, 1988) could be useful for selecting guava plants resistant to the wilt disease. An efficient protocol for plant regeneration from callus culture would also be helpful in selecting plants resistant to disease or environmental stresses. Recovery of plants of haploid origin from anther/pollen culture of guava could offer advantages in breeding (Jaiswal and Amin, 1992).

Chandra *et al* (2004) attempted embryogenesis and plant regeneration from mesocarp of *Psidium guajava* L. (guava) and developed a protocol for induction, maturation and germination of somatic embryos from this tissue. Explants were cultured on modified MS medium fortified with 2,4-D (2.0 mg/l), ascorbic acid (100 mg/l), L-glutamine (400 mg/l) and sucrose (6%). Embryogenic proliferating tissue was induced, which was found to be translucent, mucilaginous and it differentiated into many, small somatic embryos. The somatic embryos were retained in the same medium, where simultaneously differentiation of new somatic embryos and their conversion into plantlets was observed. Thus, embryogenesis in guava can be perpetuated and could be used in the future for carrying out cellular selection against wilt causing organism.

Phylogenetic affinity, usefulness of wild species and interspecific hybridization

Utilization of wild species for crop improvement has been one of the ways to introduce certain gene(s) for specific purposes like hardiness, disease and pest resistance, etc. However, in perennial crops, because of the long time gap, efforts have not been made to their full potential. Exploitation of wild species requires extensive knowledge of taxonomy, reproductive biology & cytogenetics, genetics, crossability barriers and fertility of the hybrids. Although success obtained in fruit crops is low, many desirable traits with great potential for crop improvement are found in the

wild species. Interspecific crosses in many fruit crops, between cultivars and species, have resulted in hybrids that are partially sterile due to ploidy level differences genomic incompatibilities and cytoplasmic imbalances. In order to develop a rootstock tolerant/resistant to guava wilt and to test the possible role of different species, studies have been initiated on interspecific hybridization, in the genus *Psidium*. Phylogenetic studies carried out in *Psidium* species utilizing differences in flavonoid patterns showed a close affinity between *P. guajava* and *P. molle*. Two species, *P. molle* and P. *guineense* were found to be morphologically similar with minute differences in their chromatographic pattern (Das and Prakash, 1981). These workers also found a close affinity between *P. guineense*, *P. pumilum* and *P. chinensis*. It was observed that *P. guajava* and *P. chinensis* were crossable. However, *P. guajava* and *P. molle* are cross incompatible when *P. guajava* is used as the female parent (Subramanyam and Iyer, 1982). Leslie *et al* (1995) and Edward & Shankar (1964) reported that *Psidium friedrichsthalianum* Niedenzu to be resistant to guava wilt. The other species reported to be resistant to the wilt are *P. cumuni*, *P. cattleianum* var. *lucidum*, *P. molle*, and *P. guineense*. However, Singh et al (1977) reported that *P. cattleianum* var *lucidum, P. corecium, P. cajuvalis, P. guineense* and *P. friedrichsthalianum* developed wilt infection. Hence, intensive work is needed to develop useful interspecific hybrids resistant to wilt using the resistant species in breeding programmes.

The contribution of wild species to crop improvement and management programmes mainly involves their utilization as rootstocks for regulation of vigour, yield, fruit quality and, disease and pest resistance. Pathak and Ojha (1993) enumerated their potential uses: *P. cujavalis, P. molle, P. cattleianum* and *P. guineense* can be used as rootstock. Chinese guava (*P. friedrichsthalianum)* and Philippine guava are compatible rootstocks and have been reported to be resistant to the wilt disease. 'Allahabad Safeda' trees grafted on to *P. pumilum* had a dwarfing influence. *P. cujavallis* produced the largest trees but with non-uniform and rough skinned fruits. Singh *et al* (1976) observed that fruits of 'Allahabad Safeda' contained higher sugar content on to *P. pumilum* while, higher ascorbic acid content was recorded in these grafted on *P. cujavallis*. High yields were obtained using *P. cattleianum* rootstock. Other species reported to be resistant to the wilt are: *P. cumunii, P. cattleianum var. lucidum, P. molle* and *P. guineense*. However, Singh *et al* (1977) reported that *P. araca, P. cattleianum var lucidum, P. corecium, P. cujavalis, P. guineense* and *P. friedrichsthalianum* developed infection. At the Central Institute for Subtropical Horticulture, Lucknow, Uttar Pradesh, interspecific hybridization was carried out between *P. molle* and *P. guajava*. The interspecific hybrids have been found resistant to guava wilt and are graft compatible with commercial varieties of *P. guajava* (Anon., 2003-04).

Inheritance studies

Genetic studies conducted in guava at IIHR, Bangalore, indicated that red pulp colour was dominant over white and that this character was governed monogenically. Many cultivated red fleshed varieties were found to be heterozygous for this character. Bold seeds were found to be dominant over soft seeds and this was also found to be determined monogenically. Linkage was also found between flesh colour and seed size, i.e., red flesh with bold seeds (Subramanyam and Iyer, 1982). Mitra and Bose (1985) have reported heterosis in guava. Studies conducted at Coimbatore by Raman *et al*, (1969 and 1971), have shown that triploidy and genetic factor(s) are responsible for female sterility and, that; variation among triploids is due to their independent origin from a distinct diploid variety. Iyer and Subramanyam (1971) opined that seedless varieties of guava were triploids, grew vigorously and bore fruits that were irregular in shape with ridges, because of irregular distribution of seeds of various sizes. Dinesh and Yadav (1998) carried out half-sib analysis in progenies of the variety 'Apple Colour'. They observed that genotypic variance was lower than the phenotypic variance, and heritability was moderately high for all the characters implying, that, selection may be practiced for improvement of fruit characters. Hence, hybridization among less seeded diploids can be adopted in an improvement programme. It is our observation on inheritance pattern using 'Purple guava' and 'Arka Mridula' as parents that hybrids segregate in a ratio of 3:1 for green leaf types and purple leaf types.

Characterization and evaluation

Cluster analysis was carried out using fifteen morphological characters in 29 varieties and 5 species. The cluster diagram showed four main clusters (Fig. 1). In the first cluster, the species *P. cattleianum, P. friedrichsthalianum* and *P.molle* are placed. The second cluster consists of 8 varieties and one species, viz., Bangalore Local, Benaras, Dharwad, Karela, Kamsari, Spear acid, Surka Chitti, Surka Chitti Neputani and *P. quadrangularis*.

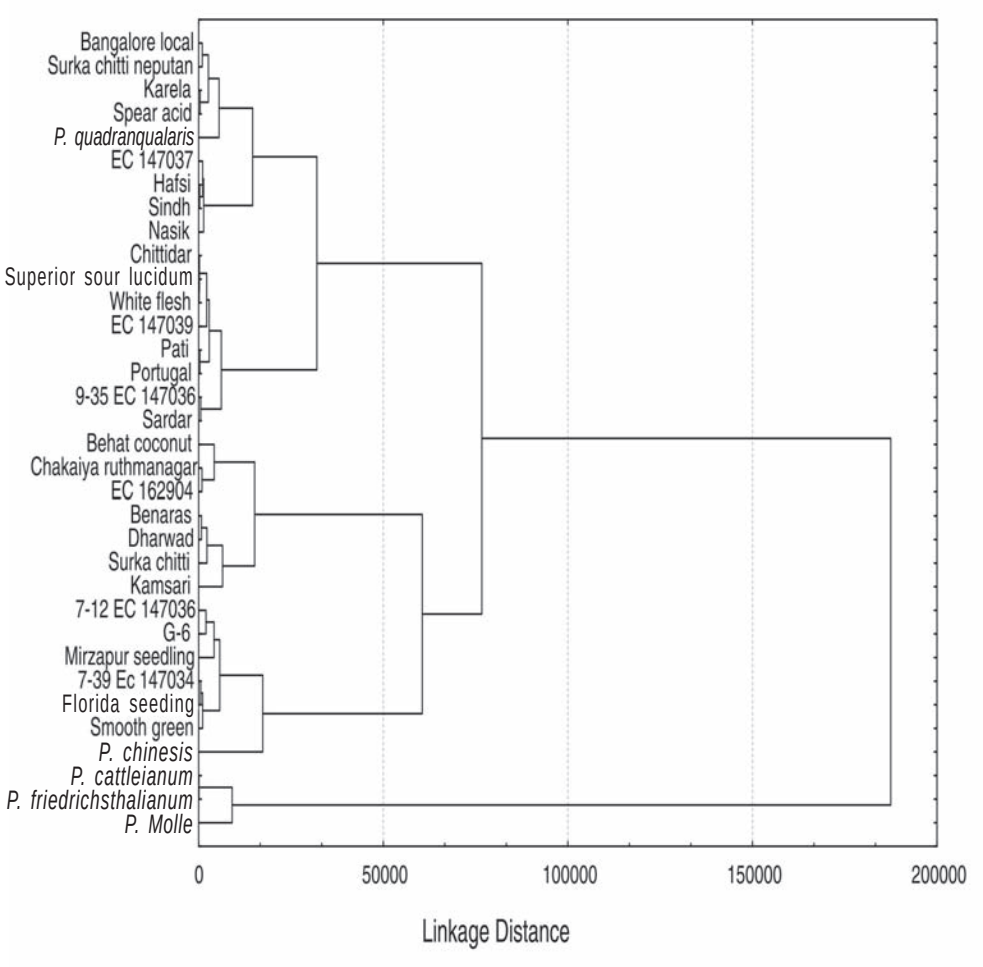

Fig 1. Tree diagram for 29 varieties and 5 species

In the third cluster, 10 varieties are grouped, viz., Chittidar, EC 147039, 147037, Hafsi, Nasik, Pati, Portugal, Sindh, Superior sour lucidum and White flesh. In the fourth cluster, Behat Coconut, Chakaiya Ruthmanagar, EC 147306, EC 147036, EC 147034, EC 162904, Florida seedling, G-6, L-49, Mirzapur seedling, *P.chinensis* and Smooth Green are grouped together.

The cluster means indicate that fruit weight, fruit volume, fruit length and width are greater more in Cluster II and low in Cluster I. Members of cluster I are mainly species that usually bear small sized fruits, except *P. quadrangularis*. The mean Vitamin 'C' content and fruit / seed ratio was maximum in cluster IV, which indicates that hybridization involving these accessions would be expected to result in maximum hybrid vigour. Mean acidity ranged over 1.00 to 1.65 % and total sugar was about 7.23 to 7.86g among different clusters. Crosses between Cluster I and Cluster II crosses may result in desirable combinations leading to development of varieties with good processing traits.

Principal component (Fig. 2) analysis shows that the species *P.molle, P. friedrichsthalianum* and *P. cattleianum* var. *lucidum* are closely related and are away from varieties of *P. guajava* and the species, *P. chinensis*. Due to the edible nature of *P. chinensis*, it is closely related to *P. guajava. Although P. quadrangularis* is not placed with the species group,it is different from *P. guajava* varieties as well. Fruits of *P. quadrangularis* are not edible, but because of fruit size, it is placed with the *P. guajava* varieties. Seeds of *P. quadrangularis* are unusually large compared to *Psidium guajava* varieties or any other species. The cluster analysis clearly shows that the species are different from cultivated *Psidium guajava* varieties and considerable diversity is present for various characters within the species of *P. guajava* for breeding varieties with good fruit size, fewer number of seeds or for dwarfness.

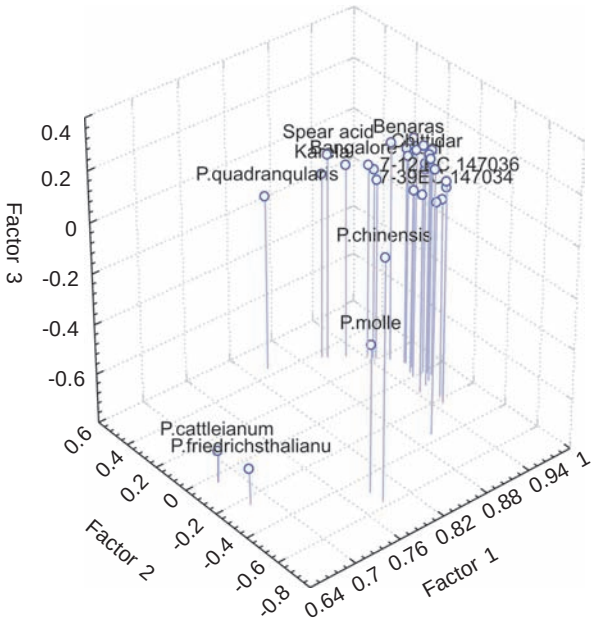

Fig 2. Principal component analysis

Guava varieties based on shape, colour and weight

Classification of guava varieties

Based on fruit shape

Variety : Lalit

Globose: Allahabad Safeda, Apple Colour, Arka Amulya, Arka Mridula, Benaras, Behat Coconut, Chittidar, Dharwad, EC 147037, Hafsi, Local 2, Mirzapur seedling, Nasik, *P. cattleianum var. lucidum, P. chinensis, P. friedrichsthallianum, P. molle, P. quadrangularis,* Phili (pink), Philippine guava, Red flesh, Sindh, Smooth green, Surka Chitti, Superior Sour Lucidum, Dhareedar, Aneuploid 2, Lalit

Subglobose: Chakaiya Ruthmanagar, 7-12 EC 147036, 9-35 EC 147036, EC 14089, EC 162904, kamsari, Karela, Local 1, Lucknow 42, Pati, Portugal, Sardar, GR-1, Spear acid, Abu Ishakwala

Pyriform: Bangalore Local, G-6, White flesh

Ovate: Florida seedling, Surka Chitti Neputani

Oblong: Oblong, Aneuploid-1, 7-39 EC 147034, Nagpur Seedless, Seedless triploid, Thailand 2, Lucknow 42

Based on fruit weight

Small (16-100g)

Aneuploid 1, Apple colour, EC 14039, EC 147037, G-6, Hafsi, Local 1, Local 2, Nagpur seedless, *Psidium cattleianum var. Lucidum, P. chinensis, P. friedrichsthalianum, P. molle*, Pati, Philippine guava, Portugal, Seedless (triploid), Sindh, GR1

Medium (100-140g)

Allahabad safeda, Arka Amulya, Arka Mridula, Bangalore Local, Chittidar, 7-39, EC 147034, 7-12 IC 147036, 9-35 EC 147036, EC 162904, Florida seedling, Lucknow 42, Mirzapur seedling, Nasik, Phili (pink), Red Flesh, Sardar, Smooth Green, Spear acid, Surka chitti, Surka Chitti Neputani, White Flesh

Large (>140g)

Abu Ishakwala, Benaras, Behat Coconut, Chakaiya Ruthmanagar, Dharwad, Kamsari, Karela, *P. quadrangularis*, Superior Sour lucidum

Based on skin colour

White: Abu Ishakwala, Allahabad safeda, Aneupoloid 2, Apple colour, Arka amulya, Arka Mrudiula, Behat coconut, Benaras, Chakaiya Ruthmanagar, Chittidar, Dharwad, Florida seedling, Hafsi, Karela, Local 1, Llocal 2, Lucknow 42, Mirzapur seedling, Nagpur Seedless, Nasik, *P. chinensis*, Sardar, Seedless (triploid), Singh, Smooth Green, Superior Sour lucidum, Surka Chitti, Surka Chitti Neputani, White Flesh

Shades of red: Aneuploid 1, 7-39, EC 147034, 7-12 EC 147036, 9-35 EC 147036, EC 147039, EC 163904, EC 147037, GR-6, Kamsari, *P. chinensis*, Pati, Phili (pink), Portugal, Red Flesh, GR1

Variety: Kamsari

Shades of yellow: Spear acid, Bangalore Local, *P. cattleianum var. lucidum*, *P. quadrangularis*

Purple: Purple Local

Variety: Purple Local

Probable Gene donors

Probable donor parents were identified for various horticultural traits as follows:

Character	Accession Name
Dwarfness	Apple Colour, Aneuploid, *Psidium molle, P. chinensis, P. friedrichsthalianum*
Seedless	Seedless
Good yielder	Benaras, 7-39 EC147034, EC 162904, Behat Coconut,
Globose fruit shape	Smooth Green, Allahabad Safeda, Apple Colour, Arka Amulya, Arka Mridula, Benaras, Behat Coconut, Hafsi, Sindh, Mirzapur seedling, Dharwad
Purple pericap	Phillippine guava
Processing	7-12, EC 147036, 7-39 EC 147034
Big sized fruit	One kg guava, Behat Coconut, Benaras, Kamsari, Dharwad, Chaikaiya Ruthmanagar
High TSS	Dhareedar, Allahabad Safeda, Arka Mridula, Seedless, Sindh, Hafsi, Bangalore Local, Surka Chitti, Behat Coconut
High Vitamin C	Mirzapur seedling, *P. chinensis*, EC 162904, G-6, Chakaiya Ruthmanagar, Dhareedar
Suckering habit	*P. chinensis*

The accessions were screened for their variable reactions to insect pests and the least susceptible sources were identified:

Pest	Least susceptible varieties
Fruitfly	EC 147037, EC147039, Kamsari, Red Flesh, Superior Sour lucidum
Tea mosquito bug	EC 147036, EC 147039, Hafsi, Superior Sour lucidum
Spiralling whitefly	Arka Amulya, Benaras, Spear acid, *Psidium chinensis*, *P . friedrichsthalianum* ,EC 147039

Utilization of germplasm

The accessions Allahabad Safeda and Seedless were used in our breeding programme for developing varieties like Arka Amulya (Allahabad Safeda x Seedless) and Arka Mridula (selection from Allahabad Safeda). Interspecific hybridization was carried out using the wild species *Psidium chinensis* with *P. guajava* cv. Beaumont to produce rootstocks resistant to wilt disease. 'Apple Colour' and 'Sardar' were also used in various combinations. 'Red Flesh' and 'Philippine guava' are under use in the breeding programme for imparting red/purple colour to the progenies.

FUTURE NEEDS

Priority needs to be given to developing good fruit quality, since, there is little merit in improving yield and disease resistance if not accompanied by high quality. High quality should include high TSS, good sugar-acid blend, good aroma, attractive skin pulp colour and soft seeds; processing quality, which includes juice colour, high Vitamin C content, higher lycopene content, good pectin content and good flavour. While selecting new varieties, keeping quality may be accorded adequate importance. In this connection, flavour and firmness of the pulp, (that could contribute towards better keeping quality) of the 'Apple Colour' guava as the gene donor could be attempted to improve other commercial cultivars. Hence, attempts to hybridize these genotypes with 'Allahabad Safeda' and other commercial cultivars should be intensified and selections may be made of progenies without apple colour, provided they have all the other desirable characteristics.

In the recent past, efforts have been intensified to develop apple coloured cultivars to make them attractive for local as well as export markets. However, deep red colour has been found to be a very unstable character, the skin colour changing from deep red to yellowish white from season to season, as well as within the same tree. Hence, 'stable' types need to be identified and great care should be taken while selecting hybrids from a large population.

The cultivar 'Allahabad Safeda' possibly represents a population of guava trees grown extensively in Uttar Pradesh (India) rather than being descendent from a single clone. Hence, enormous variation has been observed in this so-called cultivar. It is for horticulturists to make rigorous screening of the population to identify superior genotypes, keeping specific objectives in mind. A survey to locate such genotypes is certainly required, especially in Uttar Pradesh.

While breeding or selecting superior types suitable for high density planting characters like early bearing, compact plant type, favourable response to pruning, good branch angle to minimize branch breakage even under heavy bearing, and with a high fruit-shoot ratio need to be given

due attention. Aneuploidy breeding should be intensified to develop high yielding, high quality varieties with fewer and soft seeds, and to develop dwarfing rootstocks. Autotetraploids of less-seeded, superior diploid varieties may be developed. Induction of mutation by physical and chemical mutagens may be attempted where improvement in a specific character is required in an otherwise acceptable variety.

Since guava cultivation in many locations is threatened by wilt (*Fusarium* spp), work on interspecific hybridization to develop wilt resistant rootstocks should be intensified. Efforts should also be made to develop wilt resistant scion varieties, of which, self-rooted plants could be used for commercial cultivation. The Philippine Guava (Purple type) has shown some promise as a wilt-resistant rootstock but needs extensive experimentation. As this species segregates into the purple and white types on crossing with *P. guajava* cultivars, there is a need to look for possible linkages between purple leaf types and resistance to wilt. Extensive screening of other related *Psidium* species needs to be made for assessing their resistance to wilt. In this connection, reliable pathological screening techniques need to be standardized to hasten the process of disease resistance breeding in guava.

Varietal introduction, though, becomes an essential part of any crop improvement programme and needs to be made with great caution and with strict, customary plant quarantine measures. To quote some examples of caution, the 'Beaumont' variety of guava, when introduced in to India, was found to be severely infected with 'Stylar End Rot' (*Phomopsis psidii)* although it is not a severe problem in its original habitat. Similarly, the 'Giant Thailand Guava' when introduced in to Bangladesh, was found to be highly susceptible to several insect pests. Such examples are many and should be borne in mind.

Molecular characterization of germplasm needs to be accelerated with a view to work out genetical distance so that good recombinants can be arrived at by crossing suitable parents. Biotechnological tools need to be employed extensively. DNA fingerprinting and similar tools may be used to study extent of variation, even with in 'Allahabad Safeda' cultivar. Attempts to spot genetic markers for wilt resistance may be made to improve efficiency for developing wilt resistant clones and rootstocks.

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