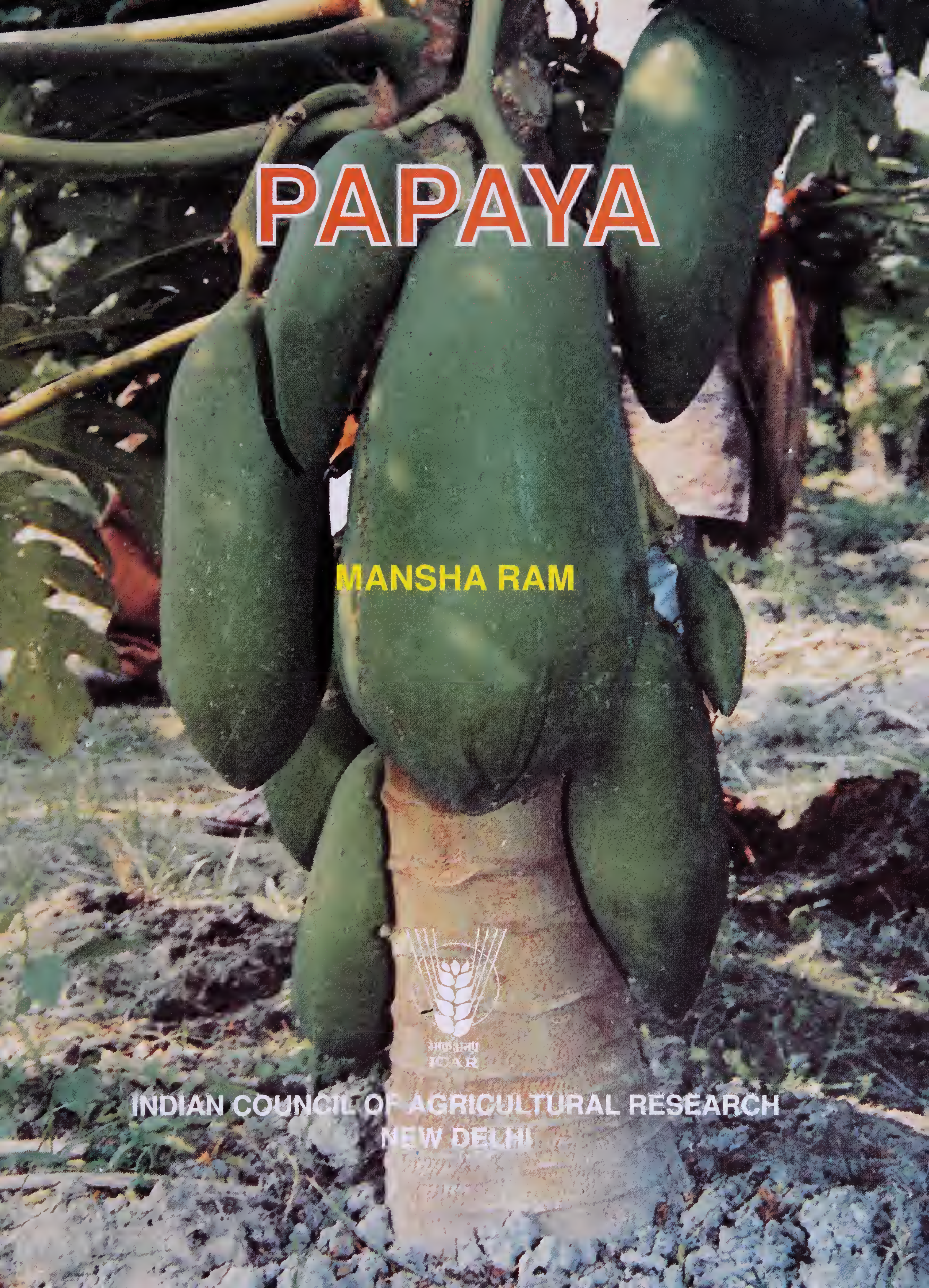
PAPAYA

MANSHA RAM



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INDIAN COUNCIL OF AGRICULTURAL RESEARCH
NEW DELHI

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Dr Mansha Ram
(Ex) Principal Scientist

Division of Fruits and Horticultural Technology
Indian Agricultural Research Institute, New Delhi 110 012

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Foreword

THE importance of papaya to agriculture and the world's economy is demon strated by its wide distribution and substantial production in the tropical countries. It has long been known and cultivated in the home gardens by the people of tropics because it is one of the few fruit crops that fruits throughout the year, gives quick return and adapts itself to diverse soil and climatic conditions. Papaya is now grown commercially for its delicious fruit, and extraction of papain – a digestive enzyme. If organised properly, the cultivation of papaya can bring about economic independence and employment to millions in our country.

Dr Mansha Ram has been associated life long with the research and development of papaya in India. I am very happy to commend this monograph on papaya by him which attempts to bring together the complete view of the germplasm collection, botany, genetics, cytogenetics, breeding, development of varieties, production technology; diseases and pests controls, post-harvest technology and industrialization for papain, pectine and various food products and processing in the country. The information given in this book would be very useful to the students, teachers, scholars, research institutions, extension workers, industrialists and others interested in papaya development and research programme in the country.

Dr R. B. Singh
Director, IARI Delhi

New Delhi

Preface

PAPAYA, a major fruit crop of the tropical world, is easy in cultivation and gives quick return. In tropical countries the research and development activities are being conducted to improve the production of papaya and diversify its multipurpose uses.

The information on papaya production, industrial development, and botany viz genetics, cytogenetics, plant physiology, plant-protection, biochemistry, and food technology is scattered in various horticultural, botanical, agricultural and food technological publications and journals. There is need to gather all information and bring out it in a single spine. Therefore this monograph, papaya is prepared. This has 3 major parts and 27 chapters. The first part deals with the knowledge of botany, genetics, cytogenetics and breeding alongwith genetic resources which can be useful to students, scientists and all those working in research organizations. The second part includes papaya production technology which can be specially useful to growers and extension workers. The third part is related to post-harvest technology which can be useful to industrialists and businessmen engaged in papaya-based ventures in the country.

It is a pleasure to acknowledge his dues to Dr S R Singh (Sr. Geneticist), Dr Baldeo Singh (Professor, Division of Extension) and Dr R K Rai (Senior Agronomist) all from IARI, New Delhi for their advice and healthy criticism. My thanks are also due to Mr Gurudass for typing and copying this manuscript as well as to my wife Vidya Devi Maurya for her best efforts during the preparation of this monograph.

I shall be thankful to have suggestions for the improvement of this book in the coming years to further improve upon.

Dr Mansha Ram
Principal Scientist

New Delhi

Contents

1. Introduction

PAPAYA (*Carica papaya* Linn.) has long been known as a wonder fruit of the tropics and grown primarily for its delicious fruits and for extraction of its digestive constituent papain. Papaya gives one of the highest production of fruits per hectare and an income next to banana.

Papaya provides cheap source of vitamins and minerals in the daily diet of the people. It is an abundant source of carotene, precursor of vitamin 'A' which removes blindness. The carotene content is 2020 IU/100 g.

Papaya fruit are used for the treatment of piles, dyspepsia of spleen and liver, digestive disorders deptheria and skin blemishes.

Both ripe and raw fruits of papaya are used in the preparation of various products and preserves like tuti-fruity, *petha*, jam, jelly, marmalade, syrups, wines, nectar, pickles, toffee, dehydrated flakes and baby foods. Several types of medicine, dental paste and face cream prepared from papain are now available in the market.

Papaya is grown in all tropical and sub-tropical countries of the world covering 32'N and 32°S on the globe (Fig. 1). Papaya is mainly grown in Australia, Brazil, Columbia, Coasta Rica, Ecuador, Hawaii, India, Mexico, Nigeria, Malaysia, Peru, Phillipines, Thailand, Venezuela, South Africa, Srilanka, Indoenesia, Taiwan, Zaire,

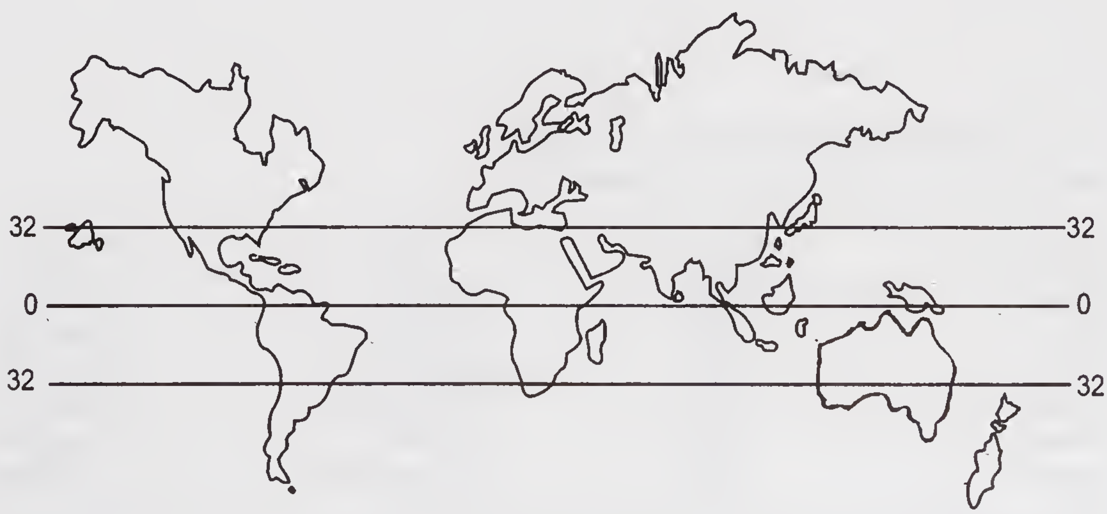


Fig.1. Papaya in the world distribution zone.

Fig.2. Papaya is grown in different states of India.

Table 1. Composition and food value of papaya fruit.

Nutrients	Composition	Vitamins	Composition
Moisture	89.6%	Vitamin A	2020 IU/100 g
Protein	0.5%	Vitamin B_2	0.04 mg/100 g
Fat	0.1%	Vitamin C	40 mg/100 g
Carbohydrate	9.5%	Nicotinic acid	0.2 mg/100 g
Calcium	0.01%	Riboflavin	250 mg/100 g
Phosphorus	0.01%	Calorific value	40/100 g
Iron	0.4%		

Source: *Health Bulletin*. **23** 1991.

Mozambique, Cuba, Jamaica and Bangladesh.

Papaya is grown in India mainly in Maharashtra, a leading state which produces papaya mainly for papain production. Other states are Karnataka, Madhya Pradesh, Uttar Pradesh, Bihar, Gujarat, West Bengal, Tamil Nadu, Kerala, Andhra Pradesh, Assam and Rajasthan (Fig. 2). The present area under papaya cultivation is about 0.07 million ha and production is around 1.5 million tonnes. Thus there has been 11.6-fold-increase in area and 4.5-fold in production of papaya when compared with 0.006 million ha area and 0.33 million tonnes production in 1961–62. It occurred because of development of high-yielding good quality cultivars through breeding, improved production technology and efficient management of pests and diseases. Thus our India emerged largest producer of papaya in the world.

2. Origin and history

PAPAYA, a cross between two species of the genus *Carica* native to Mexico is cultivated in the tropical and sub-tropical countries of the world. The first record of papaya in India was made by the Dutch traveller Linschoten in 1576 who observed that papaya plant had been taken from the West Indies to Malaysia and transported to India. Spanish and Portuguese are credited for disseminating papaya to other tropical and sub-tropical countries. Papaya spread widely in the Pacific Islands in 1800 AD. After the discovery of the western hemisphere by Europeans, it spread rapidly throughout the world with suitable climatic conditions. It might have spread to the islands of the pacific at an earlier time as is indicated by the presence of two Hawaiian names which were not ordinarily given to plants introduced by the Europeans. As has been seen it reached India before Van Linschoten who began his voyage in 1576 (Hays, 1944). The time of papaya introduction to the Hawaiian islands is not known. Some authorities say that it might have been brought in between 1800 and 1823 by Don Moris, the Spanish horticulturist who settled in Hawaii. Others believe that it came to the islands via Asia and the South Sea islands before the Europeans appeared here. There are hardly any archaeological studies available in the literature about papaya. However, the family *Caricaceae* as a whole was practically reported to be restricted to continental America before her discovery, though it was known in the West Indies namely Jamaica atleast in 1756. An account by Oviedo in his report to Charles V. of Spain in 1526 reports for the first time about papaya from the Caribbean coast of Panama and Portuguese. Evidence leads to the belief that it was introduced on the coast of Africa and Asia after the discovery of America. Seeds were taken from India to Nepal, Italy in 1626.

De Candolle believes it to be a native of the shore of the Gulf of Mexico and of the West Indies and doubtfully of Brazil. All the other species of the genus *Carica* are unquestionably proved by its not having been known before the discovery of America.

The first papaya introduced to Hawaiian islands was the large fruited types. Introduction of 'Solo' papaya from Barbados and Jamaica on 7 October 1911 by Gerritt P. Wilder resulted in a complete transformation of the Hawaiian papaya industry. This small papaya which was named Solo in 1919 replaced the earlier large fruited forms and by 1936 the Solo was the only variety grown commercially in Hawaii. Even at the turn of the century the papaya was the universal breakfast fruit in Hawaii and was considered as one of the most wholesome fruit. Early horticulturist predicted a strong economic future. Today it ranks third after pineapple and macadamia in acreage and value in Hawaii.

In India, papaya was introduced from Malacca in the 16th century, (Kumar and Abraham, 1943). Papaya was introduced in China as an Indian plant as early as 1565, Fairchild, 1913). Presently the papaya is one of the most important fruit crops of Hawaii, Malaysia, Burma, Srilanka, India, Queensland, South Africa, Tanjania, Kenya and other tropical and sub-tropical countries of the world.

In India papaya research is being conducted on evaluation of varieties, production technology and papain production (Ram, 1997 a) at Fruit Research Station, Saharanpur (Uttar Pradesh); Agriculture College and Research Institute, Coimbatore; Indian Institute of Horticultural Research, Hessaraghatta, Bangalore (Karnataka). Indian Agricultural Research Institute Regional Station, Pusa (Bihar); Govind Ballabh Pant University of Agriculture and Technology, Pantnagar (Uttar Pradesh); Punjab Agriculture University, Ludhiana (Punjab); Rajendra Prasad Agriculture University, Binauli (Bihar); and Central Horticultural Experiment Station, Ranchi (Bihar). In 1971 papaya was included as one of the 8 fruits under the All-India Co-ordinated Research Project on tropical fruits and inter-disciplinary research was started with various centres in the country. At present work on papaya covers crop improvement, production technology, and pest and disease management.

3. Botany and classification species and their relationship

PAPAYA, (*Carica papaya* Linn.), a member of *Caricaceae* has 4 genera, *Carica* with about 21 species, *Jacartia* with 6 species, *Jarilla* (*Moccina*) with 1 species and *Cylocomorpha* with 2 species (Badillo, 1967).

BOTANY

Caricaceae is a polygamous family. Both unisexual and bisexual flowers occur among the species. Most species are dioecious, some are monoecious and others are polygamous. The flowers are radially symmetrical with 5 sepals, 5 petals, 5 or 10 stamens, 5 carpels, 5 stigmatic rays and a 5 caspellate pistil that is parietal in placentation. The ovary may have a large single central cavity or it may have 5 spurious locule separated by false septa. The fruits are berries which vary greatly in size among the various species.

Species having edible fruits of papaya are found only in Genus *Carica*. Besides *Carica papaya*, they are *C. chilensis, C. goudotiana, C. monoica* and *C. pubescens*. The fruit is eaten cooked as a vegetable or candied by cooking in sugar syrup to make dulce rather than eaten raw. In Peru, the leaves of *C. monica* are cooked and eaten as greens.

Plants of *C. papaya* are small, herbaceous, evergreen dicotyledonous fragile tree with a hollow, soft wooded 1 to 10 m high perennial which may produce fruits for more than 20 years but economical life is not more than 3 years. Papaya plant has a tap root system. Stem is simple, thick, spongy with no lateral branches but sometimes dividing into several erect stems bearing heads of leaves, leafy at apex, marked with scars to falling of leaves, reaching up to a height of 10 m or more specially when grown in fertile, well-drained soils with sufficient moisture.

The large deeply lobed leaves sometimes reaching across are arranged in alternate whorls, palmately lobed, mostly long-petioled, stipulate, each is further pinnately lobed, petioles long, hollow, 60 cm or more in length venation-reticulate, multicostate.

Since papaya is a polygumous species, many forms of inflorescence have been reported. However, Oschae *et al.* (1975) classified flowers and its plants into following groups viz.

Type I: Typical pistillate.

Type II: pentandria like I except having 5 stemens attached to the ovary.

Type III: intermediate which is mostly unstable in nature.

Type IV: hermaphrodite or elongate which produces long fruits.

Type V: staminate flowers hanging on the long peduncles.

According to above flower types, plants are also categorized into four groups:

Group A: pistillate or female plant producing Type I flower.

Group B: hermaphrodite or bisexual may bear flowers of Type II, III, IV or V. Mostly it has Type II in summer, Type IV in winter, Type III during transition periods, and rarely Type V.

Group C: Summer sterile hermaphrodite produces Type IV in winter and pseudo-type IV in summer (an aberrant of group B).

Group D: Staminate or male producing Type V flowers which are usually born but occasionally Type IV flowers appear.

MORPHOLOGICAL DESCRIPTION OF PAPAYA FLOWERS

Staminate (♂)-bracteolate, sessible in cluster or raceme, incomplete, actinomorphic, bracts-leafy or scaly, hypogynous, funnel-shaped 2.5 to 3.2 cm long.

Calyx-Sepals 5, gamosepalous (fused), small, light green, lobed 5.

Corolla-petal-5, gamopetalous, tube-like, elongated, yellow.

Androecium-stamens-10, in two whorls, interones are smaller, epipetalous (joined with petals), anthers-bilocular, introse.

Floral formula: ♂ K(5) C(5) A5 + 5Go

Pistillate (♀): Born on a raceme, corymb, sub-sessible, bracteolate.

Calyx: Sepals 5, gamosepalous, light-green.

Corolla: Petals 5, linear, deciduous, polypetalous, twisted aestivation.

Androecium: absent.

Gynoecium: Sessile, style very short, stigma-5, dilated or linear, simple or lobed, ovary-superior, monocarpellary, parietal placentation, many seeded.

Fruit: A berry (pulpy in nature).

Seeds: Blackish to brownish, straight embryo, fleshy endosperm, cotyledons oblong and flat.

Floral formula: %♀ K(5) C(5) Ao G1

Hermaphrodite: Long-fruited type plants, flowers similar to pistillate type but the inflorescence is multiflowered (5–6 flower corymb), corollo gamo, stamens 19 (5 + 5), sessile at base of petals, ovary usually functional.

Floral formula: %⚥ K(5) C(5) A 5 + 5 G.1.

Fig.3. Male *Carica cauliflora*. It is dioecious plant.

Species of papaya

Carica papaya Linn.: This is a smali tree evergreen with a hollow softwooded, erect and unbranched trunk, bearing at the top a crown of large, long-stalked palm-like leaves. The fruits are edible and produced from leaf axils and are generally spherical to oblong in shape having central cavity where numerous seeds are attached to placenta. On ripening the flesh colour turns yellow, deep orange, pinkish or deep-red depending upon cultivar.

C. candamarcensis Hook: It is the mountaineous papaya and is small tree with cordate, palmately 5-lobed leaves and small yellow 5-angled 7.5–12.5 cm long fruit. The fruits are too acid to be used as desert but can be stewed or made into jam.

C. erythrocarpa Lindenet Andre: This is similar to *C. papaya* Linn. but the fruit has thin red flesh.

C. quercifolia Bant and Hook: The plant height reaches up to 2 m maximum and has oak-like leaves and cluster of small ellipsoid fruit 2.5 to 5 cm long with longitudinal strips that change from white to yellow when it ripens. It is hardier than *C. candamarcensis* and the fruits though small are reported to contain a greater percentage of papain than *C. papaya*.

C. gracilis: It is a small slender ornamental species. It has compound leaves of 5 digital, each leaflet having wavy indentations, the middles leaflet being 3.

Until now the following species appears to be utilized in breeding programme for different objectives with special reference to disease resistance.

C. monoica (Desf): Monoecious plant, susceptible to virus.
C. microcarpa (Jacq): Dioecious plant, susceptible to virus.
C. cauliflora (Jacq): Dioecious plant, resistance to virus (Fig.3).
C. goudotiana (Solms-Lauback): Dioecious plant, susceptible to virus.
C. parviflora (Solms): Dioecious plant, susceptible to virus.
C. pennata (Heilborn, Siensk): Dioecious plant, resistant to frost.
C. pubescens (Lenne et Koch): Dioecious plant, resistant to distortion ringspot virus.
C. stipulata (Badillo): Dioecious plant, resistant to distortion ringspot virus.
C. horovitziana (Badillo): Dioecious plant, susceptible to virus.
C. candicans (Gray): Dioecious plant, resistant to distortion ringspot virus.
C. pentagona (Heilorn): Dioecious plant resistant to frost.

INTER-SPECIFIC HYBRIDIZATION

The brief account of crossing relationship in the genus *Carica* given by Sawant (1957) summarises nicely all the information on the topic. The inherent resistance of *C. monoica* to virus disease viz. bunchy top has involved an intensive search of some of the other species to seek breeding stock which might carry immunity a higher resistance and to attempt the incorporation of such immunity into the ordinary papaya which is highly susceptible. A wide range of interspecific and reciprocal combination has been made by Sawant (1957) utilizing some of the lesser known species viz. *C. goudotiana*, *C. monoica*, *C. candamarensis*, *C. cauliflora*, *C. grandis* and *C. erythiocarpa*. It appear possible to induce hybridization between many of the species but that well-demonstrated barrier, may exist in some cases. The natural barrier operates at different times in respect to fruit development, hence indicates in part the degree of incompatibility between the species. For example, fruit of *C. goudotiana* × *C. papaya* will drop 75 days with a 90% set at the beginning. The same species *C. gondotiana* × *C. monoica* pollen holds its fruit 30–45 days with 15% set and when crossed with *C. cauliflora* holds the fruit 21 to 28 days with 5–6% set. Crosses between 6 species of *Carica* were tried by Ziminez and Horovitz (1958).

According to their crossability these species can be arranged in 3 groups.

(*i*) *C. monoica, C. cauliflora, C. microcarpa* and *Candamarcensis;* (*ii*) *C. papaya*, and (*iii*) *C. goudotiana.*

Crosses between species of group I and II do not form mature seed but in most cases the immature embryos can be cultivated. Crosses between group II (papaya) and III (goudotiana) gives always negative results.

Iyer and Subramanyam (1984) found fertile hybrids in an interspecific hybridization by bridging technique between the species in group (*i*) and (*ii*), although *Carica cauliflora* and *C. monoica* are incompatible with *C. papaya*, but their studies showed that the interspecific hybrids of *C. cauliflora* × *C. monoica* is compatible with *C. papaya*. Iyer *et al.* (1987) further reported that interspecific hybridization between *C. papaya* and *C. cauliflora* easily produced F_1 plants. After backcrossing with *C. papaya*, they evolved a line 21–19 showing resistance to mosaic virus with normal fruit quality. However, this important finding needs further confirmation in different climatic conditions of the country where virus is a vexing problem.

A cross between dioecious *C. goudotiana* and monoecious *C. monoica* was found to be successful (Warmke *et al.*, 1954). F_1 hybrids were intermediate in most of the vegetative characters but were monoecious in sex expression and has large seed set. F_2 showed considerable segregation for both characters.

C. cauliflora was found to be a better rootstock than other species in a grafting experiment when different species of the *Caricaceae* were compared (Ricelli, 1963). But *C. cauliflora* has been found to be more susceptible to root rot than *C. papaya*. High affinity was shown in reciprocal grafts between papaya and *Jacartia dodecaphylla*, but both combinations were susceptible to root-rot.

A cross between *C. candamarensis* and *C. monoica* initiated by Seaney of the Department of Horticulture, California University resulted in an F_1 hybrid of considerable interest. It appears likely than upon extended investigation and concerted efforts all species within this group will eventually be utilized widely in hybridization possibly with each other or perhaps with *C. papaya* as one parent. The evidence concerning the stability of these interspecific hybrids is meagre at present and experience with them does not warrant conclusive statements at this time.

POLLINATION, FRUIT SET AND ABNORMALITY

The season of flowering depends on the planting and is influenced by the environmental factors. October plant papaya flowers from May to October–November in north Bihar condition (Mansha Ram and Ray, 1992 b). The flowering and fruiting succession in Pusa dwarf papaya showed that a sporadic flowering started in some plants (3.3%) after 7 months of planting under subtropical climate of north Bihar. But these flowers rarely developed into fruits.

Fruit setting started 10 months after planting when 23.33% plants were flowering. Peak fruit setting months were July, August and September when the entire plant population was producing abundant flowers. From October onwards, there was a gradual decline in the population of flower producing plants. The flowering ceases completely during winter between December and January. The second flowering and fruiting cycle began in March and continued till November.

Subramanyam and Iyer (1986) studied different aspects of floral biology, one cultivar of *C. papaya* and four other species viz. *C. monoica, C. cauliflora, C. goudotiana* and *C. quereifolia* were used. They observed that all these species except *C. quercifolia* flowered throughout the year. In *C. quercifolia* periodically the plant remained dormant. With regard to flowering habit in *C. cauliflora* the flowers were produced straight from the stem. A study of bud development in different species showed that the number of days required from bud emergence to anthesis was the least in *C. querciflora* (36 days). Peak anthesis was found to be between 5 and 6 AM in all the species except in the pistillate flowers of *C. cauliflora* and staminate flowers of *C. goudotiana.* Their studies also showed that difference exist with regard to anthesis of the flowers belonging to different sex. Though pollen of *Carica* germinated in distilled water, it was observed that 5% sucrose solution gave maximum germination. Stigma susceptibility in all species was found to be maximum on the day of anthesis.

The extent of genetic variability among some cultivars of *C. papaya* viz. Pink Flesh Sweet, Thailand, Coorg Honey Dew and Washington by partitioning the overall variability into its heritable and non-heritable components with suitable genetic parameters like genetic coefficient of variation, heritability estimates and genetic advance showed that there is immense variability available among genetic stock and that by mere selection alone considerable advance could be made for economic traits (Subramanyam and Iyer, 1981). The yield and yield components showed high standardized range and also gave high genetic variation which was not much influenced by environment. High heritability values for yield indicated that improvement in yield could be obtained through direct selection.

The setting of fruits in papaya besides varietal variation is governed by many factors viz. scarcity of male tree, drought, low temperature, nutrient deficiency and fungal attack.

The inflorescence in variety ‘Washington’ emerged 45–48 days after transplanting under Maharashtra condition, (Khuspe and Ugale, 1977). Male flowers appeared in the axil of 24th leaf whereas the female in that of 18 to 20 leaf axil. Flower developed within 32 days in female while 42 days in male after the bud initiation. Opening of the flower was observed between 8.00 and 11.00 AM in the both male and female. Dehiscence of the anther was completed within 18 to 36 hr before opening of the flower while stigma become receptive a day before

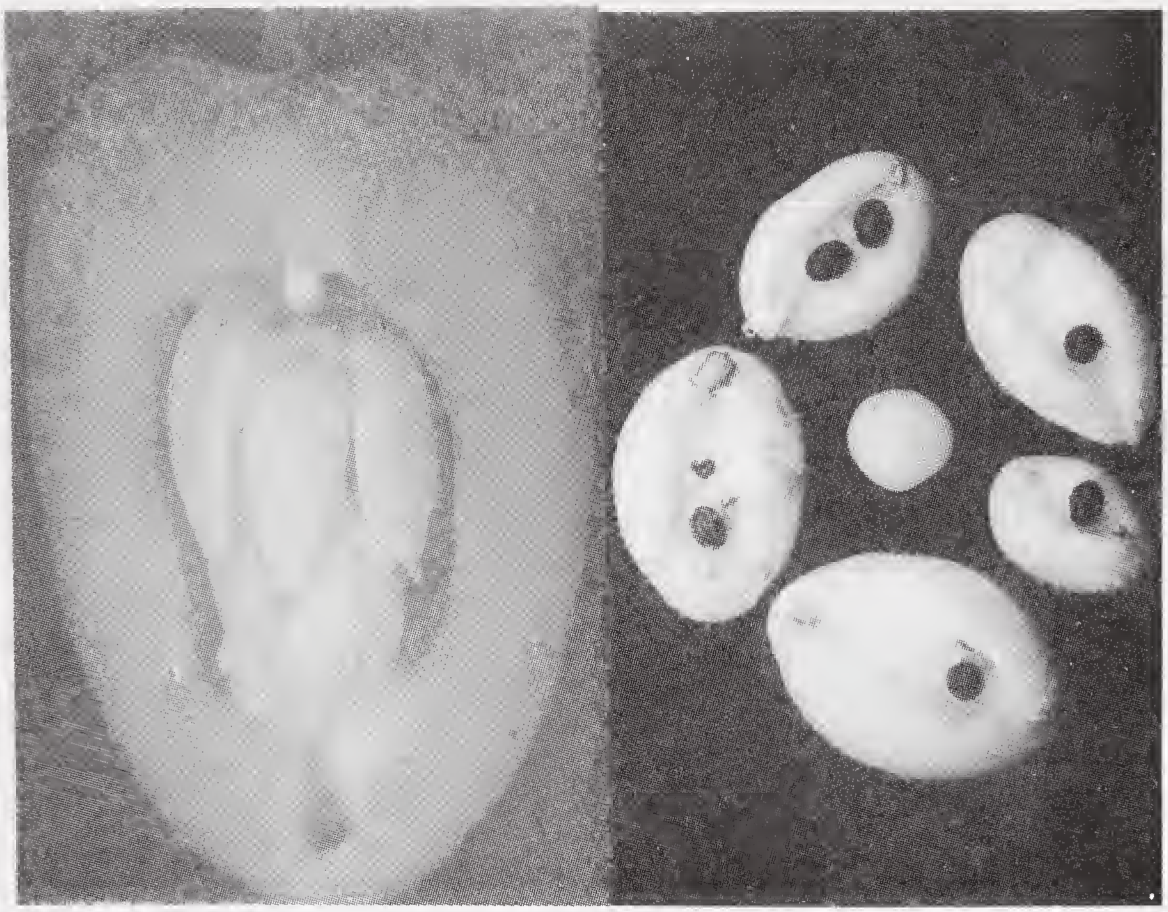


Fig.4. Development of intra-ovarian ovary *(left)*. Development of intra-ovarian ovary *(right)*.

opening of the flower and remained receptive for 6 days. Pollens were found to be spherical in shape and maximum germination of the pollen grain was found in 5% sugar-agar medium.

The anthesis and dehiscence of anthers was seen in pollen, morphology and viability and receptivity of stigma in Coorg Honey Dew (Sharma and Bajpai, 1969). Anthesis was found in the evening (5 PM to 8 PM) in all types of flowers. The maximum flower opened between 6 PM and 7 PM during both seasons. Dehiscence of anthers commenced about 6 hr before anthesis which completed within 6 hr (10 PM to 3 PM). Pollen fertility was higher in the beginning of the season. Sucrose solution (5%) was found most suitable media for the pollen germination. Fertility of pollen stored at room temperature in petri-dishes and desiccator with 10 to 50% relative humidity lasted for 24 days, 40 days and 48 days, respectively.

The pollen grains in papaya flowers remain viable from 2 to 3 days before to 2 days after anthesis with maximum being on the day of anthesis between 7

AM and 10 PM. The pollen production by different varieties of papaya which ranged from 8 950 to 12 465 per anther (Rao and Khader, 1962), 14 000 pollen grain per anther (Allen, 1963) and 500 to 23 750 pollen grain per anther (Singh and Sirohi,1981) showed genotypic variation among different varieties.

The stigma in female and hermaphrodite flower remain receptive from 2 days before 2 to 3 days after anthesis. The receptivity is maximum on the day of anthesis between 8 AM to 12 MOON followed by a day after during the same period. Although the trend of stigma receptivity in female and hermaphrodite flowers is similar, but the female flowers have slightly higher percentage of stigma receptivity than hermaphrodite.

Pollination problems occur where dioecious cultivars are grown without an adequate number of staminate trees. Flower type and season of flowering also determines the pollination and the fruit produced. Pollination in papaya is normally carried out by wind. Bees are found frequent visitors to papaya flowers and keeping of bee hives enhances yield.

The fruit sets within a week of pollination. Drop of fertile flowers and young fruits occurs under extreme temperature and moisture conditions.

Development of intra-ovarian ovaries

The occurrence of intra-overian overies in certain strains of papaya is not uncommon (Fig.4 a,b). Mostly the hermaphrodite fruits contains internal overies in stages of development ranging from thread like appendages to round or elongated pistils of various sizes and shapes. A few of them may be large enough to fill the entire cavity of seed of the primary fruit and possess their own cavities with seeds. This internal overies originate either from stimulated growth of rudimentry pistillate structure extending from the central axis of the receptacle or from placenta in position normally occupied by ovules. The placenta may be in its normal parietal position or a single strand may become free, extended from the base of the primary ovary and supporting a malshaped secondary ovary as well as ovules. A few of the hypertrophy as an intra-overian overies are as follows:

1. Rudimentary pistil like structure at the base of fruit cavity.
2. Excised internal pistils of various shapes and sizes in female fruits.
3. Vestigial pistil like structure from the central axis with a pair of distinct overies attached to the terminal stigmatic area.
4. Ovule development on structure extending from the central axis.
5. Well developed internal overies adnate to free central placenta.
6. Internal overies in female fruit attached either to the base of the primary fruit cavity or the placenta.

Thus internal overies in various stages of development can originate either from rudimentary pistillate structure extending from the central axis of the receptacle or from placenta in positions normally occupied by ovules.

The presence of rudimentary pistillate structure in the primary fruit of papaya can be explained by theory (Storey, 1967) based on evolutionary changes that took place in the ancestral bisexual flower and on derivation of the pistillate flower by a sequence of transformation of stamens into carpelloid structures with the loss of the ancestral gynoecium.

Adventitious apetalous female flowers formed inside a fruit in place of some of the ovules in papaya were reported by Srinivasan and Bose (1963) whereas Dutta (1963) reported a tendency of apocarpy in syncarpous ovary of papaya.

FRUIT GROWTH AND DEVELOPMENT

Amongst the three sex or tree types, generally hermaphrodite and female trees bears fruits having different shapes and sizes. The fruit is five carpellate, grooved and has a large cavity containing numerous seeds attached to the innerlining of the ovary walls. It has a smooth, thin skin or pericarp which is green when immature and yellow to orange-yellow when ripe. The mesocarp or flesh, about 2–3 cm thick is found next to the skin. The immature fruit produce milky sap latex which contains a proteolytic enzyme called papain.

After fruit setting on plants of either sex the fruit undergoes anatomical changes during its development. During the earlier stage of development the tissues are predominantly composed of meristematic cells. Later, the outer layer of the epidermal cells increases in size while the sub-epidermal layer remains meristematic. In the advanced stage, the sub-epidermal cells enlarge and their oval shape create intercellular spaces. Increase in fruit diameter follows and later, the placenta develops throughout the inner wall of the ovary. When the fruit reaches maturity, the epidermal cells become small, 5 to 10 layers of cells with chloroplast develop under it. The sub-epidermal layers become indistinct and the inner portion of the pericarp is composed of spongy tissues and intercellular spaces. (Pauziah *et al., 1994).*

The pericarp of the fruit is composed of laticifers which develop close to the vascular bundles. The laticifers are ramified throughout the fruit. They secrete latex which contains papain.

The fruit rapidly develops owing to rapid cell division and cell elongation. The growth of the papaya fruit exhibits a simple sigmoid curve showing increase in dimensions, weight and volume. Initial fruit growth is slow, followed by a rapid increase in length, diameter, size, volume and weight. As the fruit matures, these growth parameters either level off or decline slightly.

Physico-chemical changes during growth and maturation

The changes in physical properties during maturation occur simultaneously with changes in the chemical composition of the fruit especially in skin, flesh and seed colours after 15 weeks of anthesis. Before this the flesh and the seeds are white. As fruit matures, the skin colour changes from green to yellow. The flesh colour becomes orange and the seed changes to black towards the completion of the maturation process.

Papaya took 137 days from anthesis to fruit maturity. Fruit growth in respect of weight, volume, length and breadth showed a single sigmoid pattern. The cavity length and breadth in respect of developmental growth of fruit tended to express double sigmoid curve. The growth of pulp increased at the early stage and became static between 90 and 120 days. Total sugar content and reducing sugar fractions increased with advancing maturity. Acidity decreased with the maturity of fruits. In organic acids viz. tartaric, citsicmalic, molanic, succinic and fumaric acid were identified. The flesh contained 36.67 mg/100g of ascorbic acid at the eating ripe stage. Highest carotenoid content was found at the eating ripe stage. Maximum papain would be obtained from 90-day-old fruits owing to peak proteolytic enzme activity.

Production of latex changes to 1.6 g during fruit development after 5 days of fruit set. Maximum production occurs in 70-to 110-day-old fruit. The amount reduces to about 6g in 125-day-old fruit.

During fruit development and maturation changes also occur in the texture and firmness of the flesh. As the fruit matures the firmness decreases followed by softening of the tissues. The fruit pulp contains water 87–94%, carbohydrate 2–12%, sucrose, glucose and fructose formed 7–50%, 14–78%, and 13–50% respectively of total sugars. The dry matter content increased 7% from 15 days after anthesis to 13% at harvest (Selvaraj *et al.* 1982). There was a steady decline in alcohol, insoluble solids, starch, several minerals and an increase in total sugars. Vitamin A and proteins increased during colour break.

One of the most important biochemical changes during maturation and ripening of papaya is the substantial increase in sugar. The total sugar content gradually increases during the first 100 days and peaks at about 135 days after anthesis.

A similar trend is observed for sucrose which remains low at 110 days after anthesis and increases rapidly during further fruit development to constitute about 80% of the total sugar content (Chan, 1979). In contrast, glucose content drops from an initial 65% of the total sugar content to only about 20% at 135 days after anthesis. This trend turns around during the ripe stage in which the decrease in sucrose is rapidly accompanied by an increase in fructose and glucose. Total sugar decreases with senescence.

Changes also occur in the vitamin content of the fruit. In the young fruit the β carontene content is very low and increases gradually as the fruit matures. Vitamin C content decreases during the early stages of development but increases at the mature green stage. This is exhibited in Pakchong I cultivar (Kulwithit, 1993). In 10-day-old fruit the vitamin C content is 43.9 mg/100 g. It decrease to 19.8 mg/100 g when the fruit is 50-day-old. Thereafter, the value gradually increases and at the 25% yellow stage the vitamin C content has increased to about 134 mg/100 i.e. 2.7 times when compared with the mature green fruit.

Post-harvest behaviour and quality

Climatic factors: Climatic conditions include the effect of rainfall, temperature, relative humidity and typhoons on flowering, fruiting disease incidence and fruit maturation which have a pronounced effect on papaya growth and productivity. The overall perfoımance of the papaya was observed in tropical regions owing to high temperatures, humidity and rainfall (Agnew, 1968).

Papaya grows well in regions with even rainfall distribution throughtout the year without flash floods and waterlogging conditions. Prolonged droughts, associated with high temperature, adversely afftect fruit production by inducing abortion of floral and fruit structures, leading to sterile phases or fruiting skips along the stem. But at low temperatures and wet conditions, there may be a tendency for hermaphrodite flowers to revert to femaleness (carpellody of stamens). This leads to formation of misshapen fruits which are not marketable (Awada, 1958). Papaya plants are easily damaged or suffer lodging when exposed to strong winds Owing to shallow-rooted crop, strong typhoons lead to uprooting, blowdown, breakdown, leaf tearing or flower abscission. Leaf tearing reduces the supply of organic materials to the fruit. This can affect the quality of the fruit especially, if they are in the process of development during a typhoon. Slow recovery of affected plants results in the production of undersized fruit which are not suitbale to fetch good price.

Nutritional factors: The papaya, being a fast and continuously growing tree, has the potential of producing fruit throughout the year under good management. Therefore it needs an abundant supply of nutrients at regular intervals for good growth and prodction of good quality fruit.

It is a good practice to lime soils before growing papaya since a soil pH of 6.0 to 6.5 is universally considered as optimum for papaya growth and yield performance. For most tropical soils, this requires 3 to 4 tonnes/ha of lime. Well-limed papaya trees come to bearing earlier with higher yields of marketable fruit (Raveendranathan, 1986).

An adequate supply of nitrogen and phosphorus should be provided during the early stages to ensure good vetgetative growth. However, at fruiting, the levels of potassium should be raised considerably because it is very important for improving the quality of fruit i.e. flesh colour will be richer, fruit will be sweeter and more firm. But the levels of phosphorus should be reduced at the fruiting stage because high levels will reduce fruit size. The levels of nitrogen required do not change throughout the juvenile and fruiting stages. However, one should avoid excessive application of nitrogenous fertilizers, especially organic fertilizers,since it promotes sex reversal of the hermaphrodite flowers to females resulting in the development of unmarketable carpelloid fruit (Masri and Tengku Ab. Malik, 1992).

The importance of boron in papaya nutrition is not known (Wang and Ko, 1975). Papaya plants suffering from boron deficiency exhibits symptoms viz. in young non-fruiting trees, the symptoms appear on young leaves which are brittle in texture and claw-like; in fruiting trees, the symptoms are confirmed to the fruit which appear malformed with rough or 'bumpy' surface. Affected plants are dwarfed, and fruit set is severely reduced. Most seeds in affected fruit are either abortive, poorly developed or absence. Fruit from boron deficient plants often ripen unevenly and have low sugar content (Chapman *et al.*, 1978).

Cultural operations

Besides, climatic and fertilizer influences, significance improvements in yield from a low as a few tonnes to as high as 60 tonnes of marketable fruit depending on variety and culture management practices and papaya fruit quality can be obtained by proper cultural management practices.

Irrigation

Water is required for papaya during the early stages of growth and during periods of prolonged drought. Lack of moisture generally retards palnt growth and causes abortion of flowers and fruitle leading to sterile phases or fruiting skips along the trunk. Generally, irrigation increases both the number and size of marketable papaya fruit. But excessive soil moisture can lead to high incidence of soil born diseases particularly the phythophthora root rot.

Mulching

Mulching maintains soil-temperature, prevents losses of soil moisture, and controls weeds. Studies by Hamilton (1954) showed that organic mulch did not affect the growth of papaya. In Hawaii, trash mulch plus lime and fumigation was the most productive cropping practice for exceeding the performance of papaya under clean culture. Using black polyethylene plastic mulch, Lange (1961 a) showed that mulching could lead to larger trees and larger and higher number of fruits. It could also shade out weeds especially grasses.

Fruit thinning

Healthy papaya trees can be expected to flower about 4–6 months from the time of transplanting in the field. Fruit thinning in an important practice that will regulate production and improve the percentage of uniform size marketable fruit.

After fruit set, the initial stages of fruit development are very rapid. Therefore, any fruitlets that remain under-developed after a week or so from setting is unlikely to develop into marketable fruit. The poor development is normally due to poor pollination and fertilization of the ovules. Such fruit are normally seedless and very small and should be picked off by hand at the early stage.

In some instance, particularly during very wet and cool conditions, the papaya develops carpelloid fruits. The malformation is evident even at the flower stage and detection and elimination of such fruitlets can be done very early. Other fruitlets which should be discarded are those that have apparent damage due to thrips, mites and diseases.

The improved varieties of papaya set a single fruit. It is also recommended that a single fruit per node should be retained. On occasions when some nodes carry two or more fruitlets, only the largest one should be retained. Fruit thinning will results in high percentage of well formed, uniform size fruit because very early in their development all parasitic malformed fruit which do not have economic importance have been removed.

Growth regulators

Chemical growth regulators affect yield and fruit quality through their effects on sex expression and fruit development. Certain growth regulators can regulate sex expression. The application of ethylene continuously at 15-day-interval until flower bud emergence could induce femaleness (Singh and Sharma, 1976). Spraying hermaphrodite plants entering female sterility with 4 to 6 g/1,3-dichloroisobutyrate resulted in the production of fertile hermaphrodite flowers (Lange, 1961b). The flowering behaviour of papaya can also be controlled by growth regulators. The ethephon and triiodobenzoic acid can enhance flowering (Jindal and Singh, 1976).

Gibberellic acid increased vegetative growth of papaya and promoted higher fruit set (Guha and Chatuverdi, 1972) but caused reduction in fruit size (Shanmugavelu *et al.*, 1973). The use of gibberellic acid increased total soluble solids, fruit acidity and ascorbic acid content of papaya (Shanmugavelu *et al.*, 1973).

Pests and diseases. Developing papaya fruits are quite susceptible to insect infestation and diseases which if unattended result in loss of yield and fruit quality.

4. Genetic resources and their conservation

GENETIC diversity has played a significant role in the development of cultivars suitable for growing under different agro-ecological regions for fruit as well as papain extraction. There is a renewed interest in collection, characterization, evaluation and utilization of gene pool.

The papaya germplasm ranges from very primitive types to major commercial varieties. There are numerous local mixture everywhere in all parts of papaya growing belt. Similarly a number of lines exist in Australia, Brazil, Columbia, Costa Rica, Cuba, Ecuador, Hawaii, Maxico, Nigeria, Malaysia, Peru, Phillippines, Thailand, Venezuela and elsewhere. Although a wide range of genetic variability of papaya and different *Carica* species exist all over the tropical and subtropical countries of the world but their extensive and systematic collection and conservation has not been done at a particular place. Collection conservation, documentation, evaluation and utilization of papaya germplasm and thereby to contribute to develop varieties are pre-requisite for future advancement (Ram, 1992d).

Kulsekaran (1984) reported collection of 104 lines and *Carica* species at Tamil Nadu Agricultural University, Coimbatore. Some of these collections also appear to be duplicates at Indian Institute of Horticultural Research, Bangalore, along with their own collection total being 28. Similarly Punjab Agriculture University, Ludhiana, Govind Ballabh Pant University of Agriculture and Technology Pantnagar, Marathwada Agricultural University, Parbhani, collected 21, 30 and 15 germplasm. The author along with his colleagues (Ram and Majumder, 1984 and Ram *et al.*, 1985 a) collected more than 125 genotypes of papaya and *Carica* species at Pusa Bihar.

The main cultivars, a number of other germplasm, were found due to cross-pollination and put in category to which they resembled or reported to have been originally obtained.

Ranchi: This cultivar is found in Ranchi area of Jharkhand. It is chiefly characterized by high yield with good size of fruits. The fruit has sweet taste with good flavour. It is well acclimatized in specific zone. A large number of segregating populations are found in Northern India from this cultivar.

Washington: This cultivar is mostly found in Maharashtra. This is characterized by purplish colour of stem and leaf petiole. The flesh of fruit is orange with sweet taste and free from musky odour.

Honey Dew: This cultivar is grown in Karnataka and Maharashtra. The fruit size is medium with oval round shape having good taste. Most of the germplasm is now mixture and it is very difficult to get true to the type.

Barwani: This cultivar is centralized in Madhya Pradesh. It is chiefly characterized by good yield with elongated oblong fruit shape. The colours of flesh are distinctly red or yellow and are called *Barwani yellow* and *Barwani red*.

Haflong: This is grown in Assam. The fruits are medium, small, and moderately sweet. Most of the North-East Hill regions are occupied with this type of papaya.

Nongpoh: This is similar to Haflong distinguished by conical fruit-shape and the plants are slender tall. Most of the population is centralized in Nongpoh area of Assam.

Ceylon: This is original cultivar from Sri Lanka and was introduced to India long time ago. The fruit size is big with elongated oblong shape. This is an old variety suited for papain production.

Gujarat: This is an adopted variety in Gujarat and originated from Ceylon variety. The size and shape of fruit resembles the Ceylon variety and is used for papain extraction.

Coorg Honey: This cultivar is a chance seedling from Honey Dew identified at Chethalli (Karnataka). This is a gynodioecious variety. It performs well in Karnataka.

Co_1: This improved dwarf variety with round fruits from a cv. Ranchi, was released from Coimbatore after 7 generation of inbreeding.

Co_2: This variety, a selection from Peradeniya variety of Sri Lanka, with oblong fruits was released from Coimbatore. It is suitable for papain extraction.

Besides indigenous collections, different exotic varieties and *Carica* species were also collected from foreign countries by Plant Introduction Division of Indian Agricultural Research Institute, New Delhi (now National Bureau of Plant Genetic Resources) and other sources.

The cultivated species exhibited variability with respect to plant height (1–2.5 m), plant vigour (stunted to vigorous), stem and leaf petiole colour (purple to yellow and green), flower colour (yellow to white), sex types (unisexual to hermaphrodite), flower types (staminate to pistillate), fruit shape (long to round), fruit size (tomato to pumpkin i.e. 5 to 30 cm diameter), fruit weight (0.090 to 13.000 kg), fruit number (10–80), fruit skin colour (golden yellow to dark green), flesh colour (pale yellow to blood red), taste (bitter to very sweet), flavour (objectionable odour to pleasant), seediness (seedless to numerous seeded), and seed colour from whitish brown to black (Ram, 1992). The component characters viz. earliness, fruit yield, fruiting, height, single, fruit weight and the height of plant were found to be important for the expression of genetic and in the selection of parents for improvement programme (Ram and Majumder, 1992). Utilizing the diversity in gene pool, 5 improved cultivars viz. Pusa Delicious, Pusa Majesty, Pusa Giant, Pusa Dwarf and Pusa Nanha were developed. Realizing the facts, there is an urgent need of systematic collection, conservation, evaluation and utilization of germplasm so that disease and stress tolerant lines of papaya may be evolved. To achieve this goal and to maintain genetic wealth in papaya, gene sanctuaries should be established or genetic cryopreservation through tissue culture technique may be developed. The papaya improvement programme in Hawaii (U.S.A.) consists of several projects involving collaboration between researchers at the University of Hawaii, the USDA and mainland institutions. The programme aims to collect and evaluate papaya germplasm from Central and South America (166 papaya accessions collected to date) as well as address-specific breeding objectives. Some 75 accessions encompassing 11 other *Carica* species have also been collected (Manshardt and Zee, 1994).

GENETIC DIVERSITY OF INDIAN PAPAYA

India is famous for its high quality of papaya as Ranchi, Barwani, Washington, Ceylon and Coorg Honey Dew etc. The per plant yield of Ranchi papaya is regarded by epicures to be highest in the world.

Considering the utility, papaya has great potential as commercial crop by itself as this is highly esteemed and is in great demand in foreign countries for papain and confectionary production besides table use.

Not much variation has been found in vegetative characters than side branches and fruiting pattern at each node. These, however, are the indications of the variety although the number of branches and fruits are also variable from plant to plant. The leaf shape and size of lamina do not seem to be variable except for short petiole of advance cultivar.

The reason for having such a great genetic diversity in Indian papaya are probably due to their long history under domestication and the ease in producing new forms through indiscriminate cross-pollination and monoembryonic nature of their seed formation. Thus characterization becomes very difficult task. There are numerous local mixtures everywhere in the country but the relationship of these manifold mixtures among one another has been left unexplained. It is primarily because of high degree of wind and insect pollination up to a distance of several kilometres (Prest, 1955).

Sources of germplasm

A wide range of papaya germplasm viz. from the very primitive type up to the level of major commercial varieties exist in India. It is difficult to fix up any standard nomenclature of known varieties in its case. The germplasm categories are enumerated here.

Primitive cultigens: The plants grown intentionally or unintentionally from seedlings in some areas are characteristically tall and bear poor quality of fruits with numerous seeds. The fruits are used for culinary or medicinal purpose. They are seldom grown as backyard trees. They are invariably called wild types, eg *Carica candamarcensis* in Nilgiri Hills of South India (Ram *et al.,* 1985a).

Traditional cultivars: These are artificial and natural selection of cultivated papaya still grown in certain areas. The names are derived from the places where they are originally recognised. The fruits of papaya viz. Nongpoh, Halflong, Bangalore, Gujarat, Ceylon, Australia, Blue Jawa, Madagascar, New Zealand, Peradenya, Singapore and South African are sometimes sold in local market at low price mainly as dessert or to be used for culinary purpose.

Minor varieties: The Ranchi, Barwani, Honey Dew, Dehra Dun and Saharanpur are grown from selected fruits available in the locality from the second group which are known to produce good quality fruits and these fruits are sold in the local markets.

Local adaptive varieties: The Washington, Ranchi-Mammoth, Ranchi-Giant, Ranchi-Dwarf, Barwani-Red, Barwani-yellow, Pant papaya, Chianki local and Ramnagar local are phenotypic selections over minor varieties in having better plant type, quality and productivity. They are grown commercially in the area of adaptability. Consequently a multiplicity of varietal name has been assigned. The table fruits are of reasonably good quality and are marketable sometimes in big quantity in the local markets.

Principal varieties: These are the most advanced group of papaya in which fruits are dioecious or gynodiecious. They mostly attain the commercial standard in fruit quality and productivity. The trees are categorical tall, medium and dwarf i.e. Coorg Honey, Pink Flesh Sweet, Surya Co1, Co2, Co3, Co4, Co5, Co6, Co7. Solo and Sunrise Solo etc. (Aiyappa and Nanjappa (1959); Rao (1974); Shanmugevelue *et al.*(1988); Sulikari *et al.* (1977, 1998); and Hamilton and Ito (1968). Pusa Delicious, Pusa Majesty, Pusa Giant, Pusa Dwarf and Pusa Nanha (Ram, 1982, 1983b and 1984).

Genetic erosion and germplasm conservation

Realising the fact that papaya germplasm is threatened, there is urgent need of systematic collection, conservation, evaluation and utilization of germplasm to save from fast eroding. New sources of disease and stress tolerant lines have to be identified and more superior varieties should be evolved. Appropriate number of gene sanctuaries should be established where no new material should be introduced. The Nongpoh and Halflong area of Assam, Nilgiri Hills of South India, Lucca dweep, Andaman and Nicobar Islands of Indian ocean are suitable places for such sanctuaries (Ram, 1992).

FUTHER RESEARCH

Having a diversified wealth of papaya in India, there is still much scope to evolve more varieties for various objective suited for different agro-climatic regions of the country. There is need for more centres in the country in different zones especially one in North-Eastern Hills Region (Assam) and another in western India (Gujarat). Systematic collection should be suitably supported by National Bureau of Plant Genetic Resources with 2 to 3 maintenance centres. The centres already engaged in papaya improvement should be strengthened so that fundamental and applied research may be advanced. There is strong need for interspecific hybridization, genetical studies of different traits, incorporating resistance to virus diseases, screening for water-logging and cold resistance and mutation breeding (Chadha, 1992).

5. Genetics and cytogenetics

Some knowledge of papaya genetics has been gained in recent years specially as regards tree forms and sex determination from studies carried on principally in Hawaii, South Africa and India.

Tree (sex) forms

Papaya is a polygamous plant and have 3 basic sex types, staminate (male), hermaphroclite (bisexual) and pistillate (female), Fig.5. Out of these only female is stable whereas flowers of male and hermaphrodite vary in sex expression under

Fig.5. Typical flower of male (*left*) hermophrodite (*middle*) and female (*right*) plants.

different climatic conditions. According to the classification of Storey (1958), papaya flowers is in 8 categories on the basis of different sex forms and flowers types (i) staminate, (ii) teratological staminate, (iii) reduced elongata, (iv) elongata, (v) carpelloid elongata, (vi) pentandria, (vii) carpelloid pentandria, and (viii) pistillate (Fig.6). This clasification of flowers has simplified numerous overlaping and confusion prevailing since long and now it is widely acceptable to the workers.

Staminate flowers is produced by male plant whereas the teratological staminate flower is produced by sex reversing male plants. Types (iii) to (vii) i.e. reduced elongata, elongata, carpelloid elongata, pentandria and carpelloid pentardria are produced normally by hermaphrodite plants and type, and (viii) i.e. pistillate

Fig.6. Different types of flowers and fruits.

flower is produced by female plants. Since sex expression of male and hermaphrodite plants varies depending on environmental conditions, the male (sex reversing) plants can produce all 8 types of flowers during extreme sex reversal, while hermaphrodite plants can produce 6 types except staminate and teratological staminate flower. Female plant produce only pistillate type but in a very rare case produces bisexual flower. Generally the change of sex of male plant is in the direction of hermaphrodite and female. This is interesting to know that neither hermaphrodite plant produces male flower nor female plant produces flower of hermaphrodite and male plants. Except in two cases reported by Hofmeyr (1939) and Kumar (1952) female is quite stable and produces pistillate flowers only. In all 15 classes of sex variation have been proposed by Storey (1958) for hermaphrodite plants on the basis of seasonal shift in female sterility or carpellody of stamens or in both. Likewise 15 comparable classes are found in male plants. Thus according to him there are in all 32 heritable sex forms in papaya out of which the author observed 31 sex forms except female changing its sex at Pusa (Bihar) from 1966 to 1992.

Genetics of sex

Hofmeyr (1938), and Storey and Jones (1941) suggested that sex in papaya is controlled by 1 gene with 3 alleles. Accordingly, male and hermaphrodite are heterozygous for sex and female in homozygous. The sex determination in papaya is elucidated by Hofmeyr (1939) forwarding the genic balance hypothesis. The sex in papaya is determined not by single gene but rather a complex of genes which lie closely linked in differential segements occupying identical region on sex chromosomes (Storey, 1953). The sex determining segments behave in heredity as if they were unit factors. There are two independent sets of factors which modify sex expression in male and hermaphrodite under certain environmental conditions. One set is responsible for seasonal shift from female fertility to sterility and *vice-versa*. The other set causes stamens to become carpelloid usually with the fusion to pistil. The sets of factors either singly or in combination differentiate 15 sex forms in papaya (Storey, 1958). The occurence of sexual variability is dependent on the presence of allele F or Fh which are indispensable for the anther formation (Horovitz, 1954). Sex determination is attributed to a series of allelic genes. Within a given genotype, temperature is the decessive factor for the types of flower produced at a given moment. The existence of specific male and female florigenic substances has been postulated by him. Thus according to him the degree of sexuality of a given flower depends on the relative proportion of male and female forming substances present in the initial primordia.

From the foregoing informations it would thus appear that yet no clear picture emerges regarding the genetic basis of sex. However, the scheme for sex determination in papaya as adopted by Storey and Jones (1941) using the Mendelian symbol first proposed by Hofmeyr (1938) and further added by Mansha Ram (1983) is given below:

Genes

M_1^{RR}, Dominant factor for homozygous sex reversing maleness
M_1^{Rr}, Dominant factor for heterozygous sex reversing maleness
M_1^{rr}, Dominant factor for pure maleness
M_2, Dominant factors for hermaphroditism
m, Recessive factor for femaleness

Genetic constitution

$M_1^{RR}m$, Sex reversing homozygous male plant
$M_1^{Rr}m$, Sex reversing heterozygous male plant
$M_1^{rr}m$, Pure male plant
M_2m, Hermaphrodite plant
mm, Pistillate plant

Based on this invariably for sex inheritance and interpretation of data is used during cross combination in between different sexes.

Sex inheritance

Obviously sex in papaya cannot be identified in seed or in juvenile vegetative character before flowering. But different sex ratio can be predicted in the progenies raised thtough controlled pollination (Tables 1,2).

Table 1. The sex inheritance in different sex cross combination.

Cross and self	♀ plants (%)	♂ plants (%)	♂ plants (%)	Non-viable (lethal) (%)
mm × M_1m	50mm	–	50 M_1m	–
mm × M_2m	50mm	50M_2m	–	–
M_2m × M_2m	25mm	50M_2m	–	25 M_2M_2
M_1m × M_1m	25mm	–	50M_1m	25M_1M_1
M_2m × M_1m	25mm	25M_2m	25M_1m	25M_2M_1

M_1m, mm lethality in early stages of development

Table 2. Sex inheritance in different sex reversing male cross combination.

Cross or self	♀ plants (%)	⚥ plants (%)	♂ plants (%)		Non-viable (Lethal)
			Sex reversing	Pure male	
M_1^{Rr} × $M_1^{rr}m$	25mm	–	25$M_1^{Rr}m$	25$M_1^{rr}m$	25$M_1^{Rr}M_1^{rr}$
$M_1^{Rr}m$× $M_1^{Rr}m$	25mm	–	37.5$M_1^{R/-}m$	12.5$M_1^{rr}m$	25$M_1^{R\ R}M_1^{Rr}$
$M_1^{RR}m$× $M_1^{Rr}m$	25mm	–	50$M_1^{R/-}m$	-	25$M_1^{RR}M_1^{Rr}$
$M_1^{RR}m$× $M_1^{RR}m$	25mm	–	50$M_1^{RR}m$	-	25$M_1^{RR}M_1^{RR}$
$M_1^{RR}m$× $M_1^{rr}m$	25mm	–	25$M_1^{R/-}m$	25$M_1^{rr}m$	25$M_1^{RR}M_1^{rr}$

M_1m, mm lethality in early stages of development

The theoretical plant types shown as non-viable above failed to apper because of lethality in early stages of development of M_1M_1, M_1M_2, m_2 m_2, $M_1^{Rr}M_1^{rr}$, $M_1^{RR}M_1^{Rr}$, $M_1^{RR}M_1^{RR}$ and $M_2^{RR}M_1^{rr}$. Comprehensive studies of sex inheritance in inter-and intra-varietial crosses of papaya at Pusa (Bihar) attempted in several hundreds of progenies in a protacted period (1966–92) gave a satisfactory fit (χ^2 test) to the expected sex ratio Mansha Ram (1994). But in most of the cases male and hermaphrodite population were on the higher side. A significant deviation of male and hermaphrodite from the expected ratio of female to male (1:1) female to hermaphrodite (1:1), hermaphrodite to hermaprodite and hermaphrodite self (2:1) and hermaphrodite to male and male (sex reversing) to hermaphrodite (1:1:1) was observed in the total progeny. It gives reason to believe that some unknown factors may have been operative in reducing the number of m gamete or the viability of mm zygote in early stages of development. This is also in support of the finding of Hamilton (1954) in the self progenies of hermaphrodite in Solo variety. The sex determination in papaya is determined not by a single gene but rather a complex of genes or a series of allelic genes Storey, (1953); Horovitz 1954).

Hofmeyr (1938) and Storey and Jones (1941) assumed that M_1, M_2 and m represent differential sectors on the sex determining chromosomes. However, the respective hypothesis differed in certain aspects. Storey's (1953) hypothesis represents respective differential segements as linked-genes. But according to Hofmeyr

(1938) M_1 and M_2 represent inactivated or inert region of the sex chromosome in which vital genes are missing. It can be explained by assuming that X chromosome carries a viatality gene (V) which is absent in Y chromosome (v). The combination (vv) being, therefore, lethal. However, Westergaard (1958) postulated order of the genes in the sex determining segment on the basis of hypothesis of Hofmeyr (1938) explaining the lethality of M_1M_1 M_1M_2 and M_2M_2 genotypes. The author has partially modified the above chromosomal structure in the sex determining segment for better understanding the different sex types (Ram, 1993). Further it is postulated that male sex falls under two broad categories on the basis of multile allelic gene alongwith presence of a gene SuF/suF as below:

Female (♀) = $\frac{mp}{mp} = \frac{m}{m} = \frac{V}{v} = \frac{suF}{suF} = \frac{x}{x}$

Hermaphrodite (⚥) = $\frac{mp}{mp} = \frac{m}{M2} = \frac{V}{v} = \frac{s}{suF} = \frac{x}{z}$

Male (♂) = $\frac{mp}{mp} = \frac{m}{m_1^{\pi}} = \frac{V}{v} = \frac{suF}{suF} \quad \frac{x}{y}$

Sex reversing male (♂) = $\frac{mp}{Mp} = \frac{m}{M_1^{R/-}} = \frac{V}{v} = \frac{suF}{suF} \quad \frac{x}{y}$

Fig.7. Chromosome of *Camera lucida* papaya.

The presence of gene Mp or mp is the principal distinguishing factor between male and hermaphrodite respectively. An exception was observed one as Mp gene in female plant in a papaya groove in Bihar near Dholi in which fruit was born on longer stalk (Mansha Ram, 1992). This type of plant is usually not met in nature. The presence of lethal gene (v) present in both, males and hermaphrodites brings heterozygosity on the sex form. The dominant gene SuF present only in pure male plant suppresses the female organs hence plant becomes unproductive.

However, this dominant gene (SuF) is absent (suF) in sex reversing male as a result of this plant also produces fruit.

Sex identification

A sex-linked character in seed or seedling which might be useful in early detection of sexes is not yet discovered. The precocious separation of one pair of chromosome is discovered at anaphase I of meiosis in male and hermaphrodite (Kumar *et al.,* 1945). They did not observe such a separation in anaphase I of the female. The precocious sepration of one pair of chromosome with complete 9:9 chromosomal separation is also found in male. The karyological analysis showed that there is a satellited chromosome in the male plant. This satellited chromosome determines the male sex in papaya. The homologue chromosome is not satellited (Mansha Ram, 1982c). Whether this can be feasible to identify sex at nursery stage needs investigation. The leaves of male plants are richer in total carbohydrate, phosphorus and chlorophyll a and chlorophyll b when compared with the female plants which are rich in nitrogen and potash (Choudhary *et al.*, 1957). The amino acids were found (Kashinatan *et al.*, 1965) in male and female flowers of papaya. Female flowers are found to contain significantly more asparigin, arginine and histidine and less alamine and asparatic acid than the male flowers. The prediction of sex of nursery seedlings by colorimetric test for leaf extracts was true up to 88% in female, and 67% in male (Singh *et al.,* 1961a).

CYTOGENETICS

Chromosome number

In 1921 Heilborn reported 2n = 18 chromosome for *Carica chrysopetala, C. pentandria, C. candamarcensis* and *C.papaya* and same number was found for *C. quercifolia* by Storey (1941) and for *C. pubescens* and *C. dodecaphylla* by Kumar and Abraham (1942). Kumar *et al.* (1945) observed that all the sex types of *C. papaya* have n=9. Zerpa (1959) also observed 2n = 18 chromosomes in *C. monoica, C. goudotiana, C.cauliflora* and *C. microcarpa.* Hence it is found that all the species have the same number 2n = 18.

Sex chromosome: Meurman (1925) showed presence of 9 genome in the pollen mother cells of *C. papaya* and the absence of any sex chromosomes. Suguira (1927), Lindsay (1930), Hofmeyr (1938) and Storey (1941) also could not find any heteromorphism in the somatic chromosomes of different sex types. The one pair of chromosome separate precociously at anaphase I of meiosis in male and hermaphrodites (Kumar *et al.*, 1945). The precocious anaphasic separation in meiosis in the females was observed with the argument that the difference in behaviour is similar to the other plants with heteromorphic pair of sex chromosomes between the disjoining homologus. Storey (1953) and Mansha Ram (1982c) also confirmed precocious separation in anaphase I.

Karyotype analysis: The karyotype-morphological studies in *Carica* could not detect much differences among somatic complements of *C. dodecaphylla, C. pubescens* and *C. papaya* and the analysis showed that the chromosomes of 12 varieties have no distinct morphological differences in the chromosome (Kumar and Srinivasan, 1945). All the chromosomes have median or submedian constriction. There is a satellite chromosome in the male plant which determines the male sex in papaya (Fig. 6). The homologue chromosome is not satellited (Mansha Ram, 1982c).

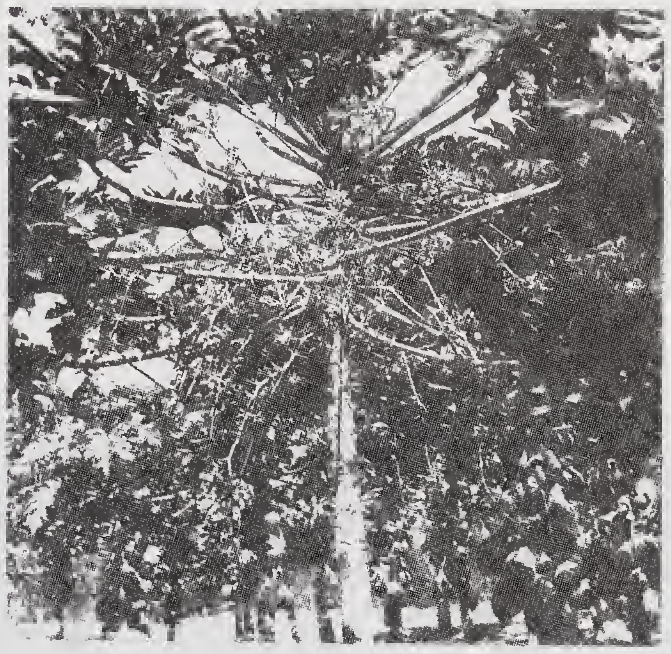
Meiosis

Meiosis is almost found in all the species (Heilborn, 1921; Storey, 1941; Kumar and Abraham, 1942; Kumar and Srinivasan, 1945; and Zerpa, 1959). Suguira (1927) however, observed the occurrence of multipolar and tripolar spindles in *Carica papaya*.

Meiosis in interspecific hybrids: The interspecific hybrids of *C. cauliflora* × *C. microcarpa, C. monoica* × *C. cauliflora, C. monoica* × *C. candamarcensis, C. goudotiana* × *C. monoica*, F_1 (*C. monoica* × *C. cauliflora*) × *C. candamarcensis*, and *C. cauliflora* × *C. candamarcensis* formed bivalent at anaphase I, indicating a high interspecific genetic affinity but the last mentioned hybrid tended to form polyvalent. In all hybrids, a certain number of hexads and pentas were produced causing 30–50% sterility in the pollen grain. Very large pollen grains were found in 2 hybrids viz. *C. monoica* × *C. candamarcensis* and *C. cauliflora* × *C. monoica*.

Sex reversal

The sex reversal in papaya is owing to the interaction of certain genetic and environmental factors (Hofmeyr, 1938, 1953) and (Singh *et al*., 1963). Two types of male plants were observed i.e. the pure males and the sex reversing males (Fig. 7). The sex reversing male and hermaphrodite readily change sex as a result of seasonal changes in temperature whereas pure male and the pistillate do not (Singh *et al.*, 1963). But under warmer conditions, there is a trend towards masculinity (Horovitz, 1954), Storey, 1958 and Lange, 1961c). The higher temperature favours femaleness and lower temperature masculinity (Singh *et al.,* 1961, 1963). Mansha Ram *et al.* (1994 a) observed higher female fertility (8.17%) in March when the maximum temperature was 29.5°C whereas lowest fertility (0.22%) in December when the minimum temperature was 12.2°C in sex reversing male plant. Singh *et al.* (1963) pointed out that there was indication that the genetic make up of sex reversing male and pure male trees might be entirely different with each other. The genetic make up of sex reversing male is entirely different than pure male (Mansha Ram *et al.*, 1985). The multiple allelism at M_1 locus itself followed the same as on this locus there are two different forms.



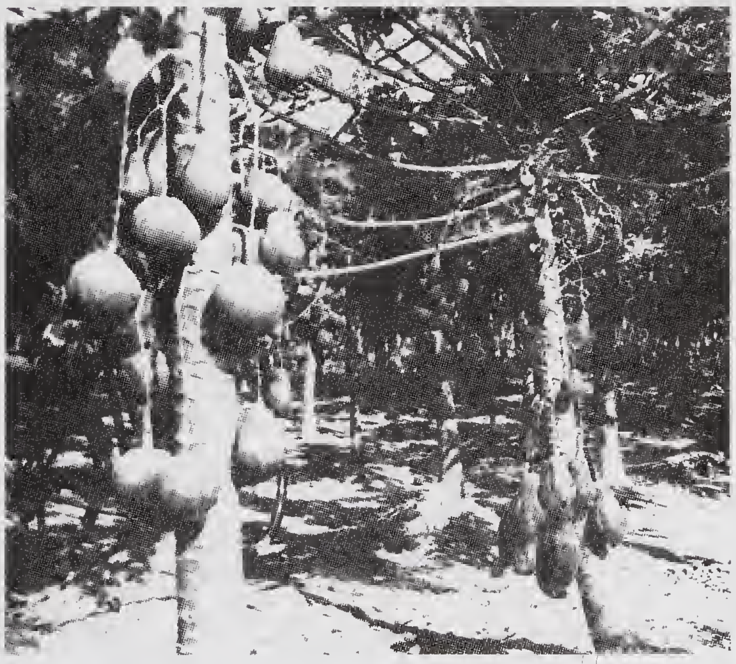


Fig.8. Pure male *(Top)*. Sex reversing male *(Bottom)*.

There are certain limitations that do not justify the universal application of the hypothesis of Storey and Jones (1941).

The inheritance pattern in sex reversing male showed that when the sex reversing male was selfed, it gave progenies of sex reversing males and pure males in the ratio of 3:1 whereas in the event of sex reversing males being crossed with pure male, the segregation of sex reversing males and pure males was 1:1 (Mansha Ram *et al.*, 1983 a, 1994). The sex reversing male is

Fig.9. Sex reversing male in homozygous condition.

heterozygous for one pair of allel, whereas pure male is homozygous recessive for the locus M_1 in question. Hence, symbolically gene symbol may be as Rr for sex-reversing male and rr for pure male.

The occurrence of few fruited plants is assigned to the possible presence of gene modifiers in hermaphrodite plants, (Storey, 1958). The RR type gave 100% fruiting in sex reversing male. This type of plant is not usually met in nature except in one case where it was found to have a male papaya with all female flower changing to male during winter. Using this type of technique of inbreeding in hermaphrodite plant, it has been possible to develop the Solo type of papaya

Fig. 10. Fruiting hermaphrodite.

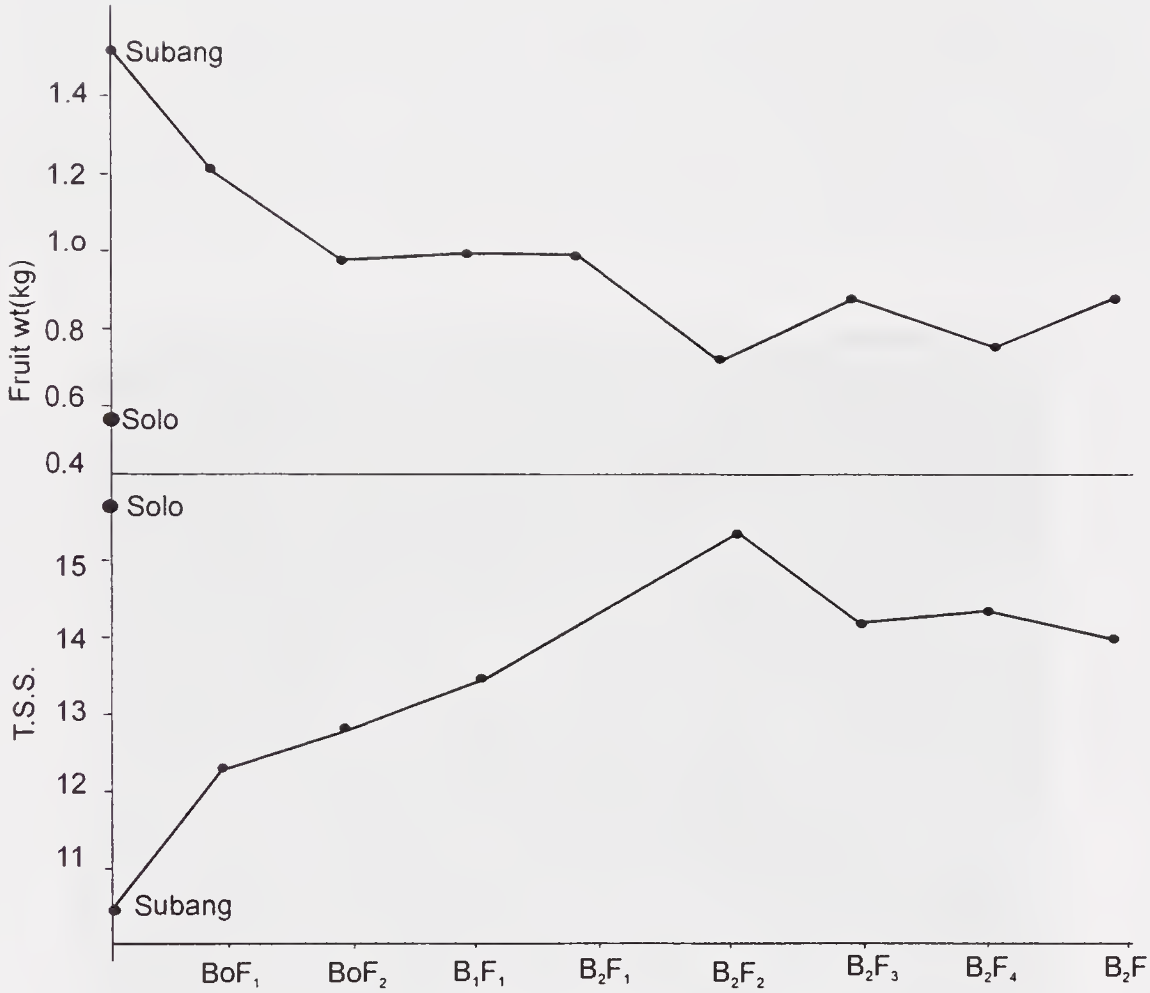


Fig. 11. Fruit weight and TSS of 8th generation of the backcross.

in Hawaii.

The existence of "a", "b", "c" and "d" genes is proposed by Hofmeyr (1953) and putforth the hypothesis that genes "a" and "b" are responsible for change from maleness to femaleness and genes "c" and "d" may cause a change from femaleness to maleness. There are 3 types of males (i) M_1m A-B-C-D (normal male showing no sex reversal), (ii) M_1m aa bb cc cc (male showing sex reversal) and (iii) M_1m AABBcc dd (male showing no sex reversal). Obviously the genes "c" and "d" do not appear to have any effect on M_1m genotype.

Out of the above 3 types of male, type II and III were involved in selfing and crossing programme and following results were obtained (Tables 3, 4).

Table 3. Progenies of sex reversing male after selfing.

Class	Sex reversing male	Pure male	Total	χ^2 value
4	103	35	138	0.01

Table 4. Progenies of crosses between sex reversing male and pure male.

Class	Sex reversing male	Pure male	Total	χ^2 value
4	147	153	300	0.12

The type II on selfing gave a segregation ratio of 3 sex reverting male and 1pure male. Evidently type II should have a heterozygous locus for segregation to the sex reversing and pure male types. In back crosses (Table 4) with pure males, the segregation occurred in the ratio of 1:1 which further confirmed the heterozygous loci for sex reverting type and homozygous recessive loci for pure males. It can be a case of multiple allelism at M_1 locus itself as on this locus there are two different forms. Accordingly it is proposed to symbolise the sex reverting males as $M_1^{RR}m$ or $M_1^{Rr}m$ and the pure male as $M_1^{rr}m$. The dominant allel at M_1 locus produces sex reverting types while the homozygous recessive breeds true for pure male type (Mansha Ram, 1982c).

The homozygous dominant genes in sex reversing males when involved in the breeding programme speed up in obtaining homozygosity in a faster rate than control (Fig 9). This supports that sex reversing female may reduce the period by one-third (Hofmeyr,1953). The sex reversing male and sex reversing females are the same for practical purpose since both are monoecious in nature.

Various morphorgenetics sex expression in papaya was observed and speed up breeding programme. The inclusion of homozygous sex reversing male in breeding programme also increased 10% fruit production which is clear from the Table 5.

Table 5. Yield data in different male cross combination (kg/ha).

Cross (F × M)	Total plant population	Female plant	Yield from female plant	Male plant	Yield from male plant	Total yield	Increase (%)
Pure male	2,500	2,250	78,750	250	0.0	78,750	1
Sex reversing male	2,500	2,250	78,750	250	7875	86,625	10

F, Female and M, Male

FURTHER RESEARCH

There is need to attempt a further research to fix the genetic make up of the prolife bearing hermaphrodite and non-fruiting (sterile) hermophrodite plants on the same pattern of sex reversing male and pure male.

Qualitative characters

Some of the mutant papaya genes were studied in the field as follows:

a, Albino plants recessive to normal green.

d, Dwarf plants recessive to normal tall plants characterised by early excessive branching.

dp, Diminative plants recessive to large plant characterised by short slender trunk, small leaves with short, slender petiole and small flowers and fruits.

cp, Crippled leaf recessive to normal flat leaf appearance similar to severe cripping by papaya mosaic virus.

rg, Rugose leaf, recessive to normal smooth leaf characterised by various degrees of curling of the margins.

w, Wavy leaf recessive to normal flat bladed leaf.

r, Red flesh of fruit recessive to yellow flesh.

Y, yellow flower colour dominant to white.

P, Purple stem and petioles dominant to green and golden yellow, intenstity of pigmentation may be affected by modifying factors and yet not analysed.

B, Gray seed coat dominant to black seed coat.

The mutant genes in the papaya revolved largely around attempts to find a sex-linked vegetative character which might be useful in separating the sexes at an early seedling stage. All the genes listed above however, excepting Y, P and B are inherited autosomals.

Hofmeyr (1938), Nakasone (1952), Storey (1943), and Hamilton (1954) studied quantitative growth characters but failed to detect any significant differencess between plants of different sexes.

6. Breeding for improvement

BREEDING is the technique to improve plant type with desirable traits.Amongst the several breeding methods, sibbing and selection are adopted for varietal improvement in papaya. Since papaya is a cross pollinated crop, its flowering and fruiting habit varies as a result variation exists in shape, size, quality, taste, flavour and colour of fruit. With continuous sib-mating and selection, the progeny may attain fair uniformity in desirable traits. Since yield is most important economic attribute, selection pressure is mainly on fruit yield and its component. The number of fruit per plant and maximum fruit width were the most important yield component. For making selection to increase fruit of papaya, weight per fruit, number of fruits per plant and leaf length to be important traits being positively correlated with it. Methods may vary depending on the lines available for improvement with desirable traits to be incorporated. The criterion for desirable traits in an improved papaya strain should have the following on the merit basis.

Vegetative characters

Under this character a good plant type should have (i) tree vigour, (ii) early flowering and fruiting, (c) low fruiting height, (d) freedom from branching habit, (e) freedom from diseases, (f) productivity of plant, (g) cent per cent fruiting plant, (h) well-spaced single fruiting on long stalk and (i) freedom from susceptibility to low temperature and waterlogging the following merits:

Fruit characters

The fruit should have (i) marketable size of fruit, (ii) uniformity in shape and size, (iii) uniformity in colour of skin in ripening stage, (iv) Ripening index or colouring before softening, (v) Colour of flesh, (vi) thick flesh, (vii) firm flesh of good texture, (viii) good taste, (ix) pleasant flavour, (x) small ovarial cavity, (xi) regularity of overial cavity for smooth removal of seed, (xii) good keeping quality, (xiv) high papain yield, and (xiii) free from blemishes.

However, all the objectives can not be taken up at a time. These objective should be taken up on the basis of priority. While selection is done, it should be watched and revised twice or thrice during life time of one plantation. The proven varieties of papaya fall into two broad groups viz. dioecious and gynodioecious based on parental combination of sex.

Sibmating and selection

Developing dioecious lines: A female is stable and more productive than hermaphrodite and sex reversing male plant, but due to out crossing most of the varieties are highly variable. Hence, it is considered appropriate to sibmate the selected female and male plant and planting them in fruit to row method to bring homozygosity. For this purpose suitable male plants are selected from the same progeny which have phenotypic resemblance with female plant viz. stem colour, leaf colour, thickness of stem and height of flowering etc. The best female plant should be crossed with such 3 male plants marked with serial number and after confirmation, the best male plant retained for back crossing for the maximum possible generation. Due to dioecious nature of papaya it may take 18 generations (Hofmeyr, 1953). Back crossing with retained male plant reduces this period. The progenies raised from S_1 inbreds are screened and desirable female plants are selected for further sibmating. This process is to be continued for 7–8 generations to achieve uniformity of a group of characters. The progenies will be female and male in equal proportion.

Developing gynodioecious line: Breeding for gynodioecious lines should be primarily followed by selfing a regular and prolific bearing hermaphrodite. Suitable hermaphrodite plants which do not vary with the climatic change are selected for breeding. In the subsequent generation the desirable female offspring should be crossed with at least 3 hermaphrodite plants as male parent similar to dioecious line. The major advantage of this method is that all the plants are productive. Sibmating in female and selfing in hermaphrodite may go simultaneously to speed up the breeding programme. Of the various types of flowers produced by a hermaphrodite plant, elongata and pentandria types are selected for selfing. This process is to be continued for 7–8 generations till the staisfactory homozygosity is achieved. The sex ratio (female : hermaphrodite) in sib-mating will be in equal proportion and in selfing hermaphrodite in 1/3:2/3 ratio in the progenies.

Agnew (1941, 1951) first evolved 2 varieties of papaya viz., improved Peterson and Bettina in Australia. Traub *et al.* (1942) also selected 2 varieties viz., Fairchild and Kissimmee for use as commercial varieties in Florida (USA). Subsequently a number of varieties were developed from local Solo in Hawaii (USA) viz. Sunrise Solo, Waimanalo, Higgins and Wilder by Hamilton and Ito (1968), and Nakasone *et al.* (1972 and 1974). Wang *et al.* (1999) recently developed Tainung No. 6, a gynodioecious variety by crossing Solo with Sunrise Solo in Taiwan.

The first gynodioecious selected variety of papaya was "Coorg Honey" from local grown Honey Dew, (Aiyappa and Nanjappa, 1959). This variety is popular

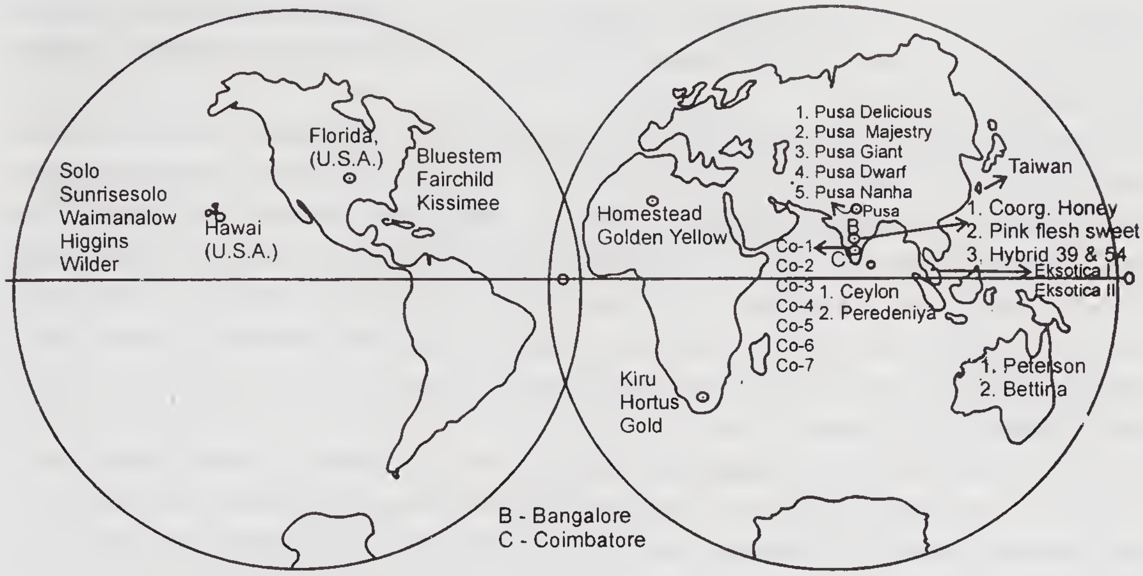


Fig.12. Improved papaya varieties in world.

in India. Four inbred selections having different attributes viz. Co1, Co2, Co5 and Co6 and 3 hybrids viz., Co3, Co4 and Co7 were evolved and released from Tamil Nadu Agricultural University, Coimbatore (Rao, 1974; Sundarajan and Krishnan, 1984; and Shanmugavelue *et al.*, 1988). Indian Institute of Horticultural Research, Bangalore evolved 2 varieties viz. Pink Flesh Sweet, and Surya. Similarly research work for the improvement of papaya is also being conducted at Punjab Agricultural University Ludhiana, Rajendra Agricultural University (Birauli) Bihar, Central Institute of Horticulture for Northern Plain (Lucknow) Uttar Pradesh, University of Agricultural Science (Dharwad), Mahatama Phule Krishi Vidyapeeth (Ganeshkhind, Pune), and Narendra Deva University of Agriculture and Technology (Kumarganj Faizabad) Uttar Pradesh.

Systematic work on breeding of uniform varieties with high-yield and good fruit quality for wider adaptability was started at IARI Regional Station, Pusa, Bihar (Mansha Ram, 1982 d). A wide range of collection was made from different parts of country and abroad (Mansha Ram *et al.,* 1985a) in which most of the strains were rejected owing to one or the other undesirable character and poor productivity. Amongst the various germplasm collected only Ranchi papaya was found most promising with special reference to its productivity and field tolerance against some diseases. As a result of sibmating and selection for 8 continued generations during 1966–1982, 4 uniform lines of papaya viz., Pusa Delicious (1–15), Pusa Majesty (22–3), Pusa Giant (1–45V) and Pusa Dwarf (1–45D) with desirable attributes were developed by conventional breeding method (Mansha Ram, 1981a, 1982, 1982a, 1984, 1984a, 1984b, 1987; Mansha Ram and

Majumder 1981a; Mansha Ram and Singh, 1984; and Mansha Ram *et al.*, 1981a). One variety viz. Pusa Nanha (Mutant dwarf) was developed by mutation breeding (Ram, 1983 f).

'Malay Yellow' is a yellow mutant papaya from Malaysia. 'Sunflower' is a line from Indonesia with undisected leaves similar to those of the sunflower (*Helianthus annuus*), and 'Saipan Red' is a red-fleshed variety of papaya from Micronesia. In Hawaii, most of the papaya cultivars are based on the variety 'Solo', which was introduced from Barbados and Jamaica in 1911. This small, pyriform papaya was named 'Solo' because it could be consumed as a single serving. 'Solo' gave rise to several varieties viz. 'Sunrise', 'Sunset', 'Waimanalo', and 'Kapoho' in Hawaii.

There are slight morphological differences between 'Kapoho' and 'Waimanalo'. 'Kapoho' produces small, firm fruits with pale orange flesh that is grown primarily for export. 'Waimanalo', which is the preferred commercial strain for the fresh local in Hawaii, is a short-statured cultivar whose average height to first flower is 81 cm. 'Waimanalo' is a result of crosses among 'Betty', 'Line5', and 'Line 8'. 'Betty' is a dioecious variety developed in Florida, while 'Line 5' is a gynodiocious variety developed at the Hawaii Agricultural Experiment Station. 'Waimanalo' (formerly 'Line 77') is an orange-yellow papaya whose fruits are round with a short neck weighing from 450 g to 1.1 kg, thick and firm flesh, and long storage life.

'Sunrise' is an inbred reddish orange strain resulting from a cross between 'Line 9' or 'Pink Solo' with the yellow-fleshed farmers' selection 'Kariya Solo' (Hamilton and Ito, 1968). 'Sunset' is also derived from the same selection and is therefore closely related to 'Sunrise'. Morphologically, there is little difference between the two cultivars except that 'Sunset' has firmer flesh than does 'Sunrise' at the same stage of ripeness (Hamilton, 1968).

'Cariflora' is a dioecious papaya cultivar developed by the University of Florida, Florida, USA. 'Cariflora' is tolerant of papaya ringpot virus (PRV) and produces spherical fruits (13.5–14.5 cm in dia.) weighing between 0.5 and 0.75 kg. The thick, moderately firm flesh varies from deep yellow to pale orange. Similar to the 'Cariflora' cultivar of Florida, 'Line 356', is also a dioecious PRV-tolerant papaya, developed at the University of Hawaii, with spherical fruits and thick firm flesh that varies from deep yellow to pale orange.

'Malay yellow' is a Malaysian mutant papaya which produces yellow-pigmented plants and fruits. The fruit skin of 'Malay Yellow' is devoid of freckles and is potentially useful for improving the appearance of other commercial cultivars. 'Bentong' is a large, elongated, red fleshed and thick-skinned gynodiocious papaya from Malaysia. Except for 'Eksotika', mostly papaya grown in Malaysia are not *bonafide* varieties.

'Saipan Red' is a red-fleshed variety with smooth, thin skin from Micronesia

(Richard Hamilton, 1954). 'Honey Gold' is a dioecious clone selected from the South African cultivar 'Hortus Gold'. 'Tainung 2' and 'Tainung 5' cultivars were both developed in Taiwan with PRV tolerance. Cultivars from other regions include 'Pitsanulok' from Thailand and Kiru from South Africa. Throughout Central America and South America, open-pollinated varieties are grown commonly in domestic gardens, while 'Sunrise' and 'Sunset' cultivars are produced commercially for export. In Mexico, 'Maradol Roja', the red-fleshed variety from Cuba, is grown commercially along with other open-pollinated types while 'Criolla' is grown in Puerto Rico.

The improved cultivars possess desirable morphological and physiological characteristics, e.g., reduced time to first flowering, increased fruit yield, quality and shelf life and resistance to pests and diseases, that have been selected by papaya breeders for crop improvement.

Being a polygamous outcrossing species papaya is traditionally propagated by seed, desirable characteristics viz. fruit quality, fruit size and fruit shape can be lost after a few generations unless care is taken to prevent the flowers from receiving unknown pollen. When papaya is grown as a plantation crop, the need to maintain and grow the most appropriate cultivar in a specific location for a specific market becomes critically important.

In the past, enzyme polymorphism has been used successfully to fingerprint cultivars of various fruit species. Isozymes are recognized as inexpensive, rapid, reliable, and consistent genetic markers free from confounding environmental influences. If papaya isozyme profiles were available, those cultivars with a unique genotype can be maintained so that this genetic descriptor can be used along with the morphological descriptors for characterisation and breeding purposes.

Backcross breeding

Backcross method of breeding has been successfully used in field crops for incorporating a simply inherited traits in an otherwise agronomically superior and high-yielding variety. The method of back crossing with modifications has been employed in papaya also for improvement. The F_2 progeny was generated and desirable single plant was selected. To this single plant the recurrent parent was back-crossed.

Two homozygous lines were developed from two crosses. These homozygous lines were then crossed with each other and the resultant F_1 was crossed and back crossed with one of the lines.

RESEARCH ACHIEVEMENTS

Development of eksotica

The "Sunrise Solo" was having all desirable traits except its small fruit size, weighing 250–400 g. The gene for large fruit size was transferred from local cultivar, "Subang 6", into "Sunrise Solo" by repeated back crosses of the selected progenies, to the latter parent. In transfer of a quantitative trait, viz. fruit size to the recurrent parent, an F_2 population was generated after each back cross to have segregants for this character for more precise phenotypic selection. The improved version of "Sunrise Solo" was designated "Eksotika". It bears the fruits of 600–800 g size and possesses other desirable traits (Chan, 1987). Presently, Eksotica is a popular improved variety of Malaysia.

Development of "Waimanalo"

The line 5-Solo was crossed with Betty a dwarf, early bearing, dioecious cultivar from Florida (Nakasone *et al.*, 1972). A low-bearing F_2 selection was back crossed to the Solo (line 5-Solo) and subsequently self pollinated. The line so developed was crossed with line 8-Solo to incorporate the fruit shape, size and skin texture. The F_1 of this cross was back crossed to another F_3 line and the desired F_1 was further proceeded by repeated inbreeding. After 8 generations of inbreeding the line was almost homozygous and was designated Waimanalo.

Development of Hawaiian-papaya lines Higgins and Wilder

From the backcross progeny of (Betty × line 5-Solo) × Line 5-Solo an individual plant with superior traits was selected and inbred for 6 generations (Nakasone *et al.*, 1974). One of the superior F_6 plant was crossed with 'Kapoho' Solo. From the F_2 population of this cross an individual plant was selected and inbred for 6 generations. The superior inbred line was numbered No. 17A.

Another line No. 25 was developed from the F_2 progeny of (Betty × line 5-Solo) × line 5-Solo. A single plant from F_2 was back crossed to line 5 Solo and a plant from this cross was selfed to produce the F_2 progeny. An individual plant from F_2 was crossed with the Kapoho Solo. From the F_2 of this cross an individual plant was selected and selfed for 6 generations to produce line 25.

Both the lines, 17A and 25 flowered at approximately half of the height of the check variety. Both the lines were early flowering. Line 25 flowered approximately 1.75 to 2.5 m lower and 2.5 to 4.0 weeks earlier when compared with line 17A. The range of different characters in 2 lines were observed during summer, winter and rainfall at different experimental stations upto 3 years (Table 6). The favourable performance of lines 17A and 25 under certain environments indicates the desirability of introducing them to the industry as commercial cultivars suitable for export.

Line 17A produces small fruits when grown in dry areas where precipitation is seasonal and irrigation is inadequate during the dry periods. With adequate irrigation and in areas with well distributed rainfall ranging between 200 m and 250 m/year, high quality, pound-sizes fruits can be produced. Therefore, line 17A was recommended for irrigated areas and for areas with moderate to high rain-all. The firmness of the fruit at yellow stage, besides a many other desirable attributes, makes it a desirable export papaya.

Table 6. Range of characters in 2 lines observed at different experimental stations during winter, summer and rain fall in 3 years.

Strains	Height to 1st flower (cm)	Week to first	Fruit weight (g)	Cavity size (%)	Soluble solids (%)	Total no. of fruit/ tree	Carpe-lloid fruits (%)	Cull-oid fruits (%)	Marketable fruits No. of fruits/tree	Marketable fruits kg/tree
No. 17A	83.25–106.5	28.0–39.8	310.2–459.6	13.4–21.6	15.0–17.8	47.5–182.5	0.0–2.3	2.0–26.3	42.9–	160.7
No.25	64.5–83.5	25.5 35.7	423–510.4	11.4–14.2	13.6–16.6	51.8–103.2	0.0–2.6	5.4–16.2	30.0–	87.1
Waimanalo (check)	59.25–80.5	26.1–36.1	603.4–1018	14.2–17.1	13.2–16.1	42.4–104.9	0.0–2.4	0.9–12.3	39.3–	94.4

1" = 2.5 cm; 1Oz = 28.2 g; and 1 pound = 0.4536 kg

Line 17A is named as "Higgins" papaya, in honour of Mr J E Higgins, who contributed significantly to the development of papaya and other tropical fruit crops during the early 1900's at Hawaii Agricultural Experiment Station.

Line 25 performed superior with uniformity over a wide range of environmental conditions. This makes it desirable as a commercial cultivar. It possesses uniformity in fruit size and firmness in the yellow stage which makes it suitable for export.

For the above reason line 25 has been named as "Wilder" papaya in honour of Mr Gerrit P Wilder, who first brought the seeds of Solo papaya to Hawaii in 1911.

Hofmeyr (1936) emphasized the importance of both male and female parents in developing improved varieties of papaya. Several Solo varieties of papaya in Hawaii have been developed through hybridization (Hamilton and lzuno, 1965; Hamilton and Ito, 1968; and Nakasone *et al.*, 1974). Originally Solo was a polygamous variety which was changed to gynodioecious variety by the use of several back crossing to a hermaphrodite source (Storey, 1953).

Heterosis breeding

Breeding methodology for heterosis is a understanding of inbreeding for homozygosity, the relation of inbreds to the performance of hybrid, technique for the quick testing for combining ability, a way of prediction of the importance of

Table 7. Correlation amongst varieties

Varieties	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Pusa 1–15	1	0.999	0.997	0.992	0.885	0.736	0.839	0.888	0.946	0.867	0.979	0.970	0.980	0.954	0.919	0.871	0.937	0.953	0.164	0.950
Pusa 22–3	0.999	1	0.995	0.995	0.871	0.757	0.858	0.902	0.956	0.883	0.985	0.977	0.987	0.964	0.933	0.887	0.948	0.963	0.196	0.960
Pusa 1–45V	0.997	0.995	1	0.998	0.841	0.716	0.825	0.876	0.933	0.862	0.972	0.963	0.972	0.945	0.908	0.853	0.928	0.952	0.145	0.953
Pusa 1–45D	0.992	0.988	0.988	1	0.893	0.788	0.890	0.920	0.967	0.909	0.990	0.986	0.994	0.981	0.955	0.910	0.963	0.977	0.257	0.974
Nongpoh	0.885	0.851	0.841	0.893	1	0.980	0.986	0.997	0.974	0.988	0.942	0.950	0.932	0.958	0.979	0.993	0.969	0.950	0.646	0.923
Halflong	0.736	0.757	0.716	0.788	0.980	1	0.970	0.962	0.914	0.956	0.857	0.871	0.846	0.888	0.929	0.968	0.908	0.875	0.779	0.840
Peradeniya	0.839	0.858	0.825	0.890	0.986	0.970	1	0.983	0.962	0.985	0.928	0.941	0.927	0.958	0.983	0.991	0.969	0.951	0.660	0.929
Chianki	0.888	0.902	0.876	0.920	0.997	0.962	0.883	1	0.986	0.987	0.961	0.967	0.953	0.971	0.985	0.992	0.978	0.966	0.591	0.940
Pantnagar	0.946	0.956	0.933	0.967	0.974	0.914	0.962	0.986	1	0.968	0.991	0.992	0.988	0.993	0.990	0.982	0.991	0.981	0.466	0.962
Waimanelo	0.867	0.883	0.862	0.909	0.988	0.956	0.985	0.987	0.968	1	0.947	0.958	0.941	0.964	0.983	0.979	0.980	0.970	0.623	0.958
Co 2	0.979	0.985	0.972	0.990	0.942	0.957	0.928	0.961	0.991	0.947	1	0.997	0.998	0.991	0.977	0.950	0.985	0.988	0.360	0.977
Washington	0.970	0.977	0.963	0.986	0.950	0.871	0.941	0.967	0.992	0.958	0.997	1	0.995	0.992	0.982	0.957	0.989	0.990	0.393	0.980
Homestead-1	0.980	0.987	0.972	0.994	0.932	0.846	0.927	0.953	0.988	0.942	0.998	0.995	1	0.994	0.978	0.947	0.985	0.987	0.346	0.998
Homestead-2	0.954	0.964	0.945	0.981	0.958	0.888	0.958	0.971	0.993	0.994	0.991	0.992	0.994	1	0.994	0.971	0.996	0.989	0.435	0.977
Homestead-3	0.919	0.983	0.908	0.955	0.979	0.929	0.983	0.985	0.990	0.983	0.977	0.982	0.978	0.994	1	0.989	0.996	0.984	0.525	0.969
Barwani	0.871	0.887	0.853	0.910	0.993	0.968	0.991	0.992	0.982	0.979	0.950	0.957	0.947	0.971	0.989	1	0.977	0.954	0.613	0.926
Co 1	0.937	0.948	0.928	0.968	0.969	0.908	0.969	0.978	0.991	0.980	0.985	0.989	0.936	0.996	0.996	0.977	1	0.989	0.487	0.980
Coorg Honey	0.953	0.963	0.952	0.977	0.950	0.975	0.951	0.966	0.981	0.970	0.988	0.990	0.987	0.989	0.984	0.994	0.989	1	0.424	0.994
Sunrise Solo	0.164	0.196	0.145	0.247	0.646	0.779	0.660	0.591	0.466	0.623	0.360	0.396	0.346	0.435	0.525	0.613	0.487	0.424	1	0.389
Golden yellow	0.950	0.960	0.953	0.974	0.923	0.840	0.929	0.940	0.962	0.958	0.977	0.980	0.998	0.977	0.969	0.926	0.980	0.994	0.389	1
Total	17.016		17.334		16.540		17.805		17.708		17.950		17.915		17.710		17.837		17.579	
	16.836		16.624		17.657		17.535		17.942		17.775		17.749		17.978		17.961		8.497	

genetic diversity to heterosis breeding and a basic knowledge for the genetic improvement of hybrid population. The related aspects of heterosis breeding is discussed as some of data have been generated on these aspects only in recent years.

Genetic diversity: The precise information about the extent of genetic diversity is crucial for a productive heterosis breeding programme.

Papaya seeds of 20 lines were planted in progeny row with 25 plants in each row. The data were taken on 10 randomly plants on days to first flowering, plant girth, fruiting height, leaf length, fruiting length, node at first fruiting, plant height, number of fruits/plant, fruit yield/plant and single fruit weight. The obtained data were put to cluster analysis on the basis of correlations, the clusters were formed, (Frutcher, 1967). However, the resolution of strains into distinct clusters was not very sharp. Consequently the largest cluster was further broken into the sub-clusters on the basis of the homogeneity of the strains within the largest cluster.

The correlation matrix among the various strains and formation of clusters are given in Tables 7 and 8 respectively.

Table 8. Distribution of 20 strains in different clusters.

Cluster	Strains included	Total Strains	Origin
A	Sunrise Solo	1	Hawaii
B_1	Pusa 1–15, Pusa 22–3 Pusa 1–45V, Pusa 1–45D	4	Bihar
B_2	Haflong	1	Meghalaya
B_3	Co 2, Homestead-3 and Washington	3	Tamil Nadu, Nigeria, Maharashtra
B_4	Co 1, Pantnagar, Homestead 1 and Homestead-2	4	Tamil Nadu, Uttar Pradesh Nigeria
B_5	Nongpoh, Barwani, Chianki Local, Peradeniya and Waimanalo.	5	Assam, Madhya Pradesh, Bihar, Sri Lanka and Hawaii
B_6	Coorg Honey and Golden yellow	2	Karnataka and Nigeria

Cluster A contains only one strain 'Sunrise Solo' which is quite distinct variety of Hawaii. Cluster B consisted of 6 groups covering 19 varieties, are from all leading papaya growing parts of the world.

Sub-cluster B_1 consisting of 4 varieties are from Pusa, Bihar. However, sub-cluster B_5 comprising of 5 varieties are mostly from India excepting Peradeniya from Sri Lanka and Waimanalo from Hawaii. Sub-cluster B_6 consisting only two gynodetious varieties viz. Coorg Honey and Golden yellow formed a group which have a very limited variability. Group B_2 having only one sparse fruiting variety viz. Haflong from Meghalaya formed a separate cluster. Group B_3 and B_4 consisted of varieties from India and Nigeria showing a wide geographical distribution.

Intra-cluster means for 10 characters are computed for each character in the each cluster (Table 9). The Intra-cluster mean shows that the highest number of desirable characters fall in group B_1 whereas the highest number of undesirable characters fall in group A. Group B_1 has highest yield of fruit, earliest to flower, lowest fruiting height, longest leaf length, lowest number of node to first fruiting, highest weight of single fruit and lowest height of plant. Although number of fruit was highest in group A but weight per fruit was lowest which is undesirable character. Other intra-cluster mean showing average performance fall in between 2 groups.

The clustering pattern of the varieties revealed that geographic diversity need not be related to genetic diversity. This may be explained on the basis of human selection pressure having been exerted for entirely different utility, purpose, climate, soil, management and other bio-factors being quite distinct.

Table 9. Intra-cluster mean for 10 characters

Cluster	No. of strains included	No. of days to first flowering	No. of fruits/ plant	Yield of fruit/ plant (kg)	Girth of trunk (cm)	Fruiting height (cm)	Length of leaf (cm)	Fruiting length (cm)	No. of node at fruit fruiting	Weight of single fruit (g)	Total height of plant (cm)
A	1	338++	50++	4.8	37.4++	136++	94.5	132.0	100++	96+	259.0
B_1	4	303+	30	27.9++	36.3	85.0+	119.8++	88.6	54+	982++	182.0+
B_2	1	337	35	11.8	31.7	105.2	109.7	148.0	++75	339	284.0++
B_3	3	324	34	22.3	32.1	92.6	110.6	113.8	69	670	216.2
B_4	4	317	48	24.3	34.1	85.1	107/2	104.7	57	509	205.6
B_5	5	321	34	16.6	36.1	106.3	91.1+	122.2	74	419	239.2
B_6	2	327	7+	4.2+	30.6+	102.3	109.6	30.7+	67	193.0	

++, higher value; +, lowest value.

It may be remembered that the papaya originated in Mexico and from there it was brought to many tropical and sub-tropical countries. Under domestication, these introduced population had a selection pressure for yield, since this is the most important economic attribute of this crop. These selected and limited population have been introduced and freely exchanged between major papaya growing area of the world. Almost all papaya varieties are exotic in India. Sunrise Solo papaya from Hawaii, forms its own cluster throughout.

There is an interesting finding that cluster B_1 has the maximum number of desirable characters viz., early flowering, high yield, low-fruiting height, longer leaf length, less number of node to first fruiting, higher weight of single fruit, and low height of plant. This shows that the 4 varieties of group B_1 viz. Pusa 1–15 (Pusa Delicious), Pusa 22–3 (Pusa Majesty), Pusa 1–45V (Pusa Giant) and

Pusa 1–45D (Pusa dwarf) developed at the Indian Agricultural Research Institute, Regional Station, Pusa are superior over all of the strains. Hence selection of the parents differing in these characters may be worthwhile for the selection of diverse material for heterosis breeding in papaya.

Tester method and combining ability

This was done by line × tester method (Chandra *et al.*, 1969). It was applied for determining general combining ability (gca) of the germplasm in papaya. The 'W' statistics or test criterian of Schumann and Bradley (1959) was adopted to measure the relative efficiency of the testers discriminating the gca of the lines. The 3 individual testers i.e. Homestead, Halflong and Ram Nagar local discriminated the lines viz. Pusa Delicious, Pusa Majesty, Washington Sunrise Solo and Waimanalo significantly for fruit yield (Ram and Akhtar, 1992, 1993). Homestead was found to be better tester followed by Ram Nagar local. Homestead has its origin from Nigeria possesses broad genetic base and geographic diversity. It possesses low gca and *per se* performance level.

The 5 lines and 3 testers in a line × tester analysis showed following characters and parents having good gca for it.

Table 10. The characters of papaya with parent and highest gca value.

S.No.	Character	Parent with highest gca value
1.	Numer of fruit/plant	Sunrise Solo, Ramnagar local
2.	Yield of fruit/plant	Pusa Delicious, Pusa Majesty, Ramnagar local
3.	Weight/fruit	Pusa Delicious, Pusa, Majesty Washington, Ramnagar local
4.	Fruiting height	Pusa Delicious, Sunrise Solo, Pusa Majesty, Washington, Homestead and Ramnagar local
5.	Number of nodes at first fruiting	Sunrise Solo, Washington, Pusa Delicious, Ramnagar local and Homestead
6.	Girth of plant	Pusa Delicious, Sunrise Solo, Ramnagar local
7.	Fruiting length	Sunrise Solo, Washington and Ramnagar local
8.	Length of leaf	Washington, Pusa Delicious Waimanalo, Ramnagar local
9.	Total height of plant	Pusa Majesty, Pusa Delicious, Homestead
10.	Days to first flowering	Pusa Delicious, Sunrise Solo, Homestead and Halflong

Among 5 lines, 2 lines viz. Pusa Delicious and Sunrise Solo were good general combiner for a number of traits. Pusa Majesty was second best combiner. Among testers Ramnagar local proved good tester.

Crosses between Washington × Ramnagar local was having the highest effect for the fruit yield/plant. Best general combiner lines and tester were not necessarily having the maximum specific combining ability effect. The average combiners from both lines and testers were having maximum sca effect.

Combining ability: It is important for a plant breeder to have information on the nature of combining ability of the parents to be used in the hybridization programme to achieve higher yield.

Character association: Economic characters like fruit yield, fruit quality and plant stature in papaya are generally complex in nature and influenced by many plant characters through different physico-biochemical mechanisms. Since they are quantitative in nature, these are supposed to be influenced by environment. Therefore, direct selection for these characters is neither suggestible nor feasible. So it may require the identification of yield, quality and stature contributing characters and quantification of their direct and indirect effects on economic characters to achieve success in the selection programme (Ram and Majumdar, 1984 a).

The variability, heritability and genetic advance in papaya showed phenotypic higher coefficient of variability than the genotypic ones (Khadi and Singh, 1980). High genotypic variability and heritability were observed in fruit yield/plant, number of fruits/plant, fresh and dry weight/fruit, number of seeds/fruit, leaf area/plant, peduncle length, fruit volume and weight/fruit which indicated that variability can be efficiently and effectively exploited for bringing considerable improvement in these characters. High heritability coupled with high genetic advance was observed for the characters like leaf area/plant, number of fruits/plant, fruiting length, number of seeds/fruit and fruit yield/plant which indicated the presence of additive genetic effects. Therefore, these characters can easily be fixed by selection in early generations. Dash *et al* (1998) studied 1.1 diverse varieties of papaya for genetic coefficient of variation, heritability and genetic advance (%) of 12 yield component and recommended phenotypic selection for fruit yield, fruit weight, fruit length and early flowering.

Simple correlations among different characters in papaya showed index in the breeding of new varieties. The close correlations of fruit weight with weight or number of normal seeds per fruit, the former being closer than the later irrespective of time (spring, summer or autumn) of sampling (Allan, 1969). A greater fruit weight was produced per unit number or weight of seeds in spring and autumn ripened fruits when compared with summer ripened fruits. The significant correlation between content of solids as determined in the field by a refractometer and the content of total sugars in papaya fruit (α, 0.57 S where α, total sugars as glucose and S, total solids) was positive (Valsechi and Mididieri, 1954). The correlation between flesh colour and dry matter content of the papaya fruit, position of fruit on the plant and productivity were reported by Pospisil *et al.* (1974). No correlation was found between sweetness and flavour of the fruit and the sex of the plant (Hiyane and Hamilton, 1960).

Selection indices by discriminate function are constructed with the primary objectives of obtaining maximum possible genetic advance from an optimum combination of number of economic characters. For the improvement of crop like papaya, plant breeders aim at developing varieties having higher fruit yield, superior fruit quality and moderate plant stature. Therefore, developing selection indices for economic traits in papaya would be helpful to the papaya breeders. Most efficient selection index for fruit yield was found to be the combination of plant height, number of fruits/plant, weight/fruit, fruit bearing length, total soluble solids and weight of fresh seed per fruit. Similarly selection index for fruit quality measured as total soluble solids comprised the number of fruits/plant, weight/fruit, fruit volume, width of the central cavity of fruit, weight of fresh seed/fruit and number of seeds/fruit. The selection index for plant stature measured as plant height comprised the height at first fruiting, leaf area/plant, stem girth, number of fruits/plant, fruit bearing length and fruit yield/plant. These selections can be used to get maximum genetic advance over straight selection for respective economic traits. Thus, one can make considerable improvement in papaya by giving proper weightage to various characters comprising a selection index. Dwivedi *et al.* (1999) studied correlation between vegetative plant characteristics and fruit production in papaya. Simple correlation coefficient, revealed that fruit production was significantly and positively correlated with plant girth and the number of leaves/plant at flowering. Plant height was correlated with plant girth, petiole length and the E-W spread of the plant. In regression equation, out of 8 fruit production traits measured, significant value for plant girth and number of leaves per plant at flowering indicated their important factor in the first cycle, followed by selection of plant, with the most leaves per plant at flowering in the second cycle.

The association analysis of the plant and fruit characters with the yield of latex revealed that the plant and fruit characters had an equal contribution to the fruit and latex yield (Anonymous, 1995). Differences were observed between dioecious and gynodioecious lines.

In both dioecious and gynodioecious lines, there was a positive association of plant height with fruit yield in number. However, plant height showed a negative correlation with fruit yield in weight in both the lines. In dioecious lines, plant height positively correlated with latex yield in both the periods. Whereas, it showed a negative association in gynodioecious lines.

There was a positive correlation of stem girth with fruit yield in number in both dioecious a nd gynodioecious. However, the correlation with fruit yield in terms of weight was found positive in dioecious lines and negative in gynodiocious lines. The association of stem girth with latex yield was found positive in dioecious lines and negative in gynodioecious lines.

The petiole length was positively associated with fruit yield in number and negatively in weight. The petiole length was negatively correlated with latex yield of dioecious lines and positively in gynodioecious lines. The number of functional leaves recorded at first harvesting stage was positively associated with fruit yield in weight in both dioecious and gynodioecious lines. However, the correlation of this character with fruit yield in number showed a non-significant negative correlation in dioecious (–0.0003) and significantly positive correlation (0.496) in gynodioecious lines. The association of number of functional leaves with latex yield was found positive in dioecious lines, and negative in gynodioecious lines.

In both dioecious and gynodioecious lines, positive correlation of leaf area with fruit yield both in number and weight was observed. The correlation, however, with latex yield was positive in dioecious and negative in gynodioecious lines.

The fruit weight was negatively correlated with fruit yield in number in both dioecious and gynodioecious lines, whereas highly significant positive correlation was obtained with fruit yield in weight in both dioecious (0.678) and gynodiecious lines (0.816). A positive association of fruit weight with latex yield was obtained in both the lines.

In both dioecious and gynodioecious lines, the association of number of seeds with fruit yield in weight was positive, whereas with fruit yield in number, the association was found to be positive in dioecious lines and negative in gynodioecious lines. The number of seeds was negatively correlated with latex yield in dioecious lines and positively in gynodioecious lines.

Phenotypic correlations in 5 lines viz. Pusa 1–15, Pusa 22–3, Washington, Sunrise Solo and Waimanalo which were crossed with 3 testers viz. Homestead, Halflong and Ramnagar local, and hybrids 15 F_1 (total 23) were planted in a randomised block design with 3 replications.

Phenotypic correlations among characters showed weight/fruit, number of fruits and leaf length to influence significantly (Table 11). Fruiting height had highly negative correlation with yield of fruit. Number of nodes at first fruiting influenced phenotypic character negatively at significant level (Table 10). Therefore for papaya improvement, 3 major traits viz. bigger size of the fruits, longer leaf length and larger number of fruit/plant should be taken into consideration.

Weight/fruit was negatively correlated with the total height of the plant, fruiting height and number of fruits/plant. As the fruit yield/plant was positively correlated with the weight/fruit and number of fruit/plant, the latter two having negative correlations, an optimum level should be selected for these two traits. An average weight (525 g) and average number of fruits (44)/plant should be selected for the maximum yield/plant. The maximum limit for fruit weight and number of fruits/plant is 952 g and 80 fruits (Table 12).

Leaf length was having significant positive correlation with fruiting length, height of the plant and number of fruits per plant and negative correlation with the number of days to first flowering. Number of fruit/plant and fruiting length were also having positive correlation with fruit yield/plant while height of the plant was having negative correlation with fruit yield. The height of the plant was 210 cm and leaf length was 114 cm, Table 11.

Data on the path coefficient analysis of the various characters with the fruit yield/plant showed maximum positive direct effect with fruit weight followed the number of fruits/plant and leaf length (Table 13). However, in correlation weight/fruit was having the maximum correlation coefficient with fruit yield/plant followed by leaf length and number of fruit/plant. As the weight/fruit was positively associated with the yield/plant the higher correlation coefficient of the leaf length was not owing to direct effect of these two traits but due to their association with the other characters. Thus while making selection for yield weight of fruit and number of fruits/plant are the important traits besides the leaf length. Therefore a good genotype of papaya for improvement should have bigger size fruit (525 g), longer leaf length (114 cm), and greater number of fruits (44)/plant. It should also flower early and start fruiting at lesser number of node (35–40).

The fruit yield of papaya was highly correlated with fruit weight, leaf length and number of fruit/plant, while it was negatively correlated with fruiting height and number of nodes at first fruiting.

Number of fruit/plant was positively correlated with fruiting length, yield per plant, leaf length and plant girth. Weight of fruit was positively correlated with yield/plant.

Path coefficient value denoted that weight/fruit was having maximum direct effect on fruit yield followed by number of fruits per plant and leaf length.

Hybrid vigour: In papaya either plant height or stem girth is a reliable index of hybrid vigour (Hofmeyr 1938). The hybrid performance between Betty variety and Line 5 Solo showed that neither hybrid vigour nor inbreeding depression was involved in the crosses (Nakasone 1952). In the crosses of two different Solo strains of papaya there was neither loss of vigour from inbreeding nor hybrid vigour in F1 plants in the progeny test (Hamilton 1954).

The heterosis in the cross between Philippine and Solo variety showed that F1 reduced number of seeds and enhanced vegetative vigour (Dai 1960). The heterosis showed in combination of Co1× Coorg Honey Dew for early flowering, reduced fruiting height, number of fruits and yield of fruits (Ahmad Shah 1973). A high positive heterosis for fruit size and number of seed was observed by Shah

Table 11. Phenotypic correlation characters Correlation Coefficient "r".

Characters	Correlation coefficient									
	1	2	3	4	5	6	7	8	9	10
Fruit number	–	0.34*	–0.32*	–0.12	–0.17	0.30*	0.65**	0.32	0.28	–0.39**
Fruit yield		–	0.69**	–0.45**	–0.36*	0.24	0.24	0.44	–0.23	–0.46**
Weight/fruit			–	–0.36*	–0.27	0.10	–0.15	0.11	–0.39**	–0.18
Fruiting height				–	0.79**	0.31*	0.07	–0.07	0.60**	0.36*
Node at first fruiting					–	0.22	–0.03	–0.01	0.54**	0.37**
Plant girth						–	0.39**	0.17	0.22	0.06
Fruiting length							–	0.34*	0.57**	–0.16
Leaf length								–	0.33*	–0.39
Plant height									–	0.02
Days to first flowering										–

*Significant at 5%; **Significant at 1%

Table 12. Path coefficient Matrix: Direct (Diagonal) and Indirect effects.

Character	Path coefficient									
	1	2	3	4	5	6	7	8	9	10
Fruit weight	0.80	–0.18	0.02	–0.03	0.01	–0.01	0.03	0.11	–0.02	0.72
Fruit/plant	–0.28	0.54	0.01	–0.02	0.01	0.03	0.10	–0.06	–0.03	0.29
Fruiting height	–0.32	–0.09	–0.05	0.08	0.01	0.01	–0.03	–0.16	0.04	–0.52
Node number	–0.25	–0.11	–0.04	0.09	0.01	–0.01	–0.01	–0.14	0.04	–0.40
Plant girth	0.11	0.19	–0.02	0.03	0.03	0.02	0.02	–0.07	0.01	0.33
Fruiting length	–0.16	0.38	–0.01	–0.01	0.01	0.04	0.10	–0.16	–0.01	0.19
Leaf length	0.08	0.18	0.01	–0.01	0.01	0.01	0.29	–0.06	–0.05	0.46
Plant height	–0.36	0.13	–0.03	0.05	0.01	0.03	0.07	–0.25	0.02	–0.34
Days to first flowering	–0.18	–0.19	–0.02	0.04	0.01	–0.01	–0.14	–0.05	0.09	–0.46

Table 13. Range of phenotypic co-relations among lines (5), Testers (3), and hybrids (15).

Characters	Line	Tester	Crosses
Yield of fruit/plant (kg)	4.4–25.9	13.1–32.5	6.2–30.4
No. of fruits/plant	18.4–47.8	41.0–54.0	24.2–80.0
Weight/fruit (g)	91.0–952.0	317.0–605.0	145.0–724.0
Fruiting height (cm)	61.0–126.7	69.4–88.8	47.3–75.3
No. of node of first fruiting	53.7–97.5	61.8–96.1	32.9–66.8
Girth of trunks (cm)	21.8–36.5	28.8–30.1	23.2–33.0
Fruiting length (cm)	86.2–130.9	110.5–138.0	81.8–151.3
Length of leaf (cm)	94.9–114.6	123.3–132.8	96.3–125.8
Total height of plant (cm)	184.7–242.1	191.3–250.0	153.0–225.0
No. of days taken to first flowering	295.3–342.0	275.0–313.4	296.2–319.4

and Shanumugavalu (1975) in the cross Co1 × Coorg Honey at Coimbatore. (Iyer and Subramanium 1981) observed heterosis for all the vegetative characters, fruit yield and its components. Heterobeltiosis up to 111.41% for yield was obtained in cross Solo yellow × Washington. High relative heterosis for fruit yield in certain crosses was observed in the combination-Solo Yellow Sweet × Washington, Pink Flesh Sweet × Coorg Honey, Pink Flesh Sweet × Washington and Thailand × Washington. High standard heterosis which is of practical utility was recorded in the cross Thailand × Washington. Saha (1998) reported maximum better parent heterosis for number of fruits/plant (21.7%) and individual fruit weight 47.5% in the 7 parents and 21 F_1 progeny in a diallel cross. Significant and positive heterosis for fresh thickness over better parent was in 8 crosses. Maximum heterotic effect for T.S.S. was recorded in the cross Pusa Nanha × Co2, whereas Shahi × Pusa Nanha showed the highest better parent heterosis (43.2%) for fruit yield.

The author made a study to have a detailed information on desirable parental combination exhibiting a high degree of heterotic responded with the ultimate objective of commercial exploitation (Ram *et al.* 1990 and 1999).The 5 papaya varieties viz. Pusa Delicious, Pusa Majesty, Washington, Sunrise Solo and Waimanalo were crossed with 3 varieties, viz. Homestead, Halflong and Ramnagar local which were chosen for broad genetic base and heterozygous nature. These parents were obtained from different geographic regions i.e. Pusa (Bihar), Poona (Maharashtra), Hawaii (United States of America), Ibedan (Nigeria), Halflong (Assam) and Ramnagar Local (Uttar Pradesh) respectively.

In heterotic studies between different cross combinations of 5 females and 3 males showed heterotic effects over mid-parent (relative heterosis) and better parent (heterobeltiosis) values for different characters. Most of the crosses were similar in heterotic rankings for relative heterosis and heterobeltiosis (Table 14).

Relative heterosis for fruit yield was maximum in Pusa Delicious × Halflong, when compared with Pusa Delicious × Homestead and Washington × Halflong crosses, and showed presence of hybrid vigour owing to over dominance of fruit yield in these parents. The cross Pusa Delicious × Halflong was having negative heterosis for number of days to first flowering. However, it is not the maximum fruit yielding cross. Cross Pusa Delicious × Homestead was having high relative heterosis and heterobeltiosis for fruit yield and heterobaltiosis for number of nodes at first fruiting. The cross Washington × Halflong was also having the high relative heterosis and heterobeltiosis for fruit yield and fruit/plant, negative heterobltiosis for number of nodes at first fruiting, relative heterosis for the girth of plant, but was not having good mean performance. Cross Pusa Delicious × Ramnagar local was having an average relative heterosis for fruits/

plant, girth of plant, length of leaf, and total height of the plant. This cross also had the maximum fruit yield. The parent Pusa Delicious showed high heterosis both over mid-parent as well as over better parent in crosses than the others. This showed that Pusa Delicious can be utilized as one of the parent for imparting high fruit yield in the hybrids. It was good combiner for fruit yield and other traits (Table 15).

Pusa Delicious × Ramnagar local had the high mean performance for fruit yield and complete dominance for the fruit yield, fruit/plant and no dominance for the weight/fruit (Table 15). Cross Pusa Delicious × Homestead was the second highest mean performance in the fruit yield. Cross Pusa Majesty × Ramnagar local was having the complete dominance for the fruit yield and partial dominance for fruits/plant and no dominance for weight/fruit. Thus for the utilization of these crosses in the hybrid development and its further utilization in the segregating generations will depend upon the type of gene action involved for fruit yield and contributing traits.

The marked heterotic response in fruit yield was 47.34% and 39.77% in the cross Pusa Delicious × Halflong and Pusa Delicious × Homestead, respectively over the mid-parent. Similarly significant heterotic response over better parent in fruit yield was found in the cross combination between Pusa Delicious × Homestead (31.29%) followed by the cross Washington × Halflong (25.13%) and Pusa Delicious × Halflong (21.96%). The highest heterotic response was found in fruiting height in the cross between Sunrise Solo × Homestead (–55.67%) and (–10.96%) over mid-parent and better parent, respectively resulting in low fruiting height. Heterotic response in fruiting length was highest in the cross Washington × Ramnagar local 44.63% and 36.92% over mid-parent and better parent, respectively. The highest heterotic response for earliness was found in the cross Pusa Delicious × Halflong (–10.96%) over mid-parent and in the cross Sunrise Solo × Homestead (–12.16%) over better parent.

Mutation breeding

Mutation breeding is accepted as one of the modern methods. The two-fold objectives of mutation research is development of efficient methods of treating selected plant material by mutagens and of post-treatment handling of the plants. Secondly the initiations of useful mutations for immediate application as improved culture or for use as parent material is conventional cross-breeding.

In principal and practice the method of induced mutation breeding in sexually propagated fruit crops does not differ from that of agricultural crops. The main advantage of mutation induction in fruit crops is the stability to change one or few characters of an otherwise outstanding cultivar without changing the

Table 14. Desirable mean performing and heterotic crosses.

Characters	Desirable mean performance	Relative heterosis	Heterobeltiosis
Fruit yield	1 × 8(30.43), 1 × 6 (29.93), 2 × 8 (28.77)	1 × 7 (47.33), 1 × 6 (39.77) 3 × 7 (35.81), 1 × 6 (35.98)	1× 6 (31.29), 3 × 7 (25.13) 1 × 7 (21.96)
Fruit/plant	4 × 8 (80.00), 4 × 7(56.50) 4 × 6 (54.13), 1 × 8 (53.90)	4 × 8 (56.96), 4 × 7 (56.93) 1 × 8 (41.28), 3 ×7 (40.30)	4 × 8 (47.78), 4 × 7 (45.40) 3 × 7 (13.50)
Weight/fruit (g)	1 × 6 (72.40), 1 × 7 (653.0)	5 × 6 (26.47), 3 × 8 (13.23)	5 × 7 (11.78)
Fruiting height (cm)	2 × 6 (45.3), 4 × 4 (45.3) 1 × 6 (48.6)	4 × 6 (55.67), 4 × 8 (–44.72) 2 × 6 (-44.82), 4 × 7 (–83.10)	4 × 6 (-62.65), 4 × 8 (–56.99) 4 × 7 (–51.60)
No. of nodes at first fruiting	2 × 6 (32.9), 3 × 8 (34.7) 1 × 6 (36.3), 4 × 7 (38.7)	4 × 7 (-60.02), 4 × 8 (–52.25)	4 × 7 (–60.33),4× 6 (–58.96), 3 × 7 (–54.53), 1 × 6 (–48.24)
Girth of plant (cm)	4 × 8 (33.8), 2 × 6 (31.8) 1 × 7 (30.7), 1 × 8 (30.7)	3 × 6 (7.34), 3 × 8 (3.98) 3 × 7 (3.82), 1 × 3 (3.67)	1 × 8 (1.43), 1 × 7 (14.05)
Fruiting length (cm)	3 × 8 (151.3), 4 × 8 (144.3), 3 × 7 (138.9)	3 × 8 (44.63), 5 × 8 (28.26), 4 × 8 (19.56)	3 × 8 (36.92), 5 × 8 (14.05), 4 × 8 (10.26)
Length of leaf (cm)	1 × 8 (125.9), 2 × 8 (122.7) 3 × 8 (119.3), 3 × 8 (115.3)	1 × 8 (6.77), 4 × 7 (5.69), 4 × 8 (2.22), 2 × 8 (1.54)	– – – –
Total height of plant (cm)	3 × 8 (225.0), 4 × 7 (220.0), 4 × 8 (220.0), 5 × 7 (216.0) 3 × 7 (214.4), 5 × 8 (211.5)	3 × 8 (8.60), 5 × 8 (7.22) 4 × 8 (1.50), 1 × 8 (1.01)	5 × 8 (4.08), 3 × 8 (0.89) – – – –
No. of days to first flowering	4 × 7 (297.3), 4 × 6 (297.0) 3 × 6 (296.3), 1 × 6 (294.7), 1 × 7 (282.3)	1 × 7 (–10.96), 4 × 7 (-8.73), 3 × 7 (–7.23), 4 × 8 (-5.72) 5 × 8 (–4.67)	4 × 6 (-12.16), 4 × 7 (–12.87), 1 × 7 (–11.97) 4 × 8 (–10.58)

1. Pusa Delicious, 2. Pusa Majesty, 3. Washington, 4. Sunrise Solo, 5. Waimanalo, 6. Homestead, 7. Halflong, 8. Ramnagar local

Table 15. Degree of dominance of fruit yield and important yield contributing traits.

Nature of heterosis	Fruit yield	Fruits/plant	Weight/fruit
Positive heterosis			
Over dominance	1 × 7, 1 × 6, 3 × 7	4 × 7, 4 × 8, 3 × 7	5 × 7, 3 × 6,
Complete dominance	1 × 8, 4 × 7	1 × 8, 4 × 7	1 × 6, 3 × 6
Partial dominance	3 × 8, 4 × 6, 4 × 8, 2 × 8, 3 × 6, 5 × 7,	1 × 6, 5 × 8, 5 × 7, 2 × 7, 3 × 8,	1 × 6, 1 × 7, 5 × 8, 2 × 7, 3 × 7, 4 × 6
Negative heterosis			
No dominance	5 × 6, 5 × 8,	2 × 6, 3 × 6, 5 × 6	1 × 8, 2 × 6, 2 × 8, 4 × 7, 4 × 8, 5 × 6
Over dominance	2 × 6	–	–

1. Pusa Deliciouse6. Homestead
3. Washington 7. Halflong
4. Sunrise Solo 8. Ramnagar local

remaining and often unique part of the genotype. Artificial induction of variability by use of high does of mutagen has the limitation of undesirable effects usually in M_1 generation.

Since papaya is a cross pollinated crop, hence much variability exist in this crop. But the breeders are looking for an outstanding economical mutant to boost the production and quality. Moh (1963) was first to attempt mutation in papaya with gamma (γ) rays irradiation and LD50 for papaya seed to be about 19 Kr. The gamma rays ranging from 5 to 15 Kr produced significant changes in characters like seed germination survival of seedlings and the proportion of male and female sexes in a population (Bankapur and Habib 1979). The direct effects of radiation may be measured as physiological damage which is estimated both horizontally and vertically. Some of the immediate effects of mutagenesis are decrease in germination and emergence, slow growth rate, less survival and increased sterility accompanied by morphological aberrations in M_1 generation. Though the problem of germination, emergence and survival of plants after irradiation has been discussed by many workers but in papaya (*Carica papaya* L.) information on such M_1 parameters are not adequate. Basic information regarding the effect of radiation on germination of seed, emergence and survival of seedlings may the basis of a detailed and planned work of mutation breeding for papaya, which has not been subjected to systematic mutation so far.

The effect of different doses of gamma-rays on seed germination, emergence and survival of seedlings in papaya was studied first time in India (Mansha Ram *et al.* 1983 b and Ram and Srivastava 1984).

Dry seed samples of papaya (*Carica papaya* L.) strain Pusa 1–15 were exposed to gamma-ray at the doses of 10, 15, 20, 25, 30, 40, 50, 60 and 70 Kr at Jawaharlal Nehru University, New Delhi in 1977. Treated seed samples and the untreated control were sown in nurserybed in randomized block design with 3 replication having a plot size of 100 cm × 75 cm and 400 seeds in each plot. The same set of seed samples were soaked in water for 24 hr and then kept in petri-dishes having moistured filter papers for germination count. Petri-dishes were kept at 35°C temperature and 90% humidity. The seed germination count was started on 6 day of seed sowing and continued up to 20 days. The emergence of seedlings was recorded from 10 to 25 day from the date of sowing. Survival of seedlings was determined on the final count recorded on 45 days after sowing.

Germination: The percentage of germination decreased with the increased doses of gamma-rays. At lower doses of 10, 15 and 20 Kr the germination was slightly inhibited, but considerable inhibition was observer at doses 40 Kr and onwards. Germination was also considered delayed in treatments of higher than 30 Kr doses. The decrease in the percentage of germination at higher doses may be due to the disturbances caused at the physiological level of the cells, or acute

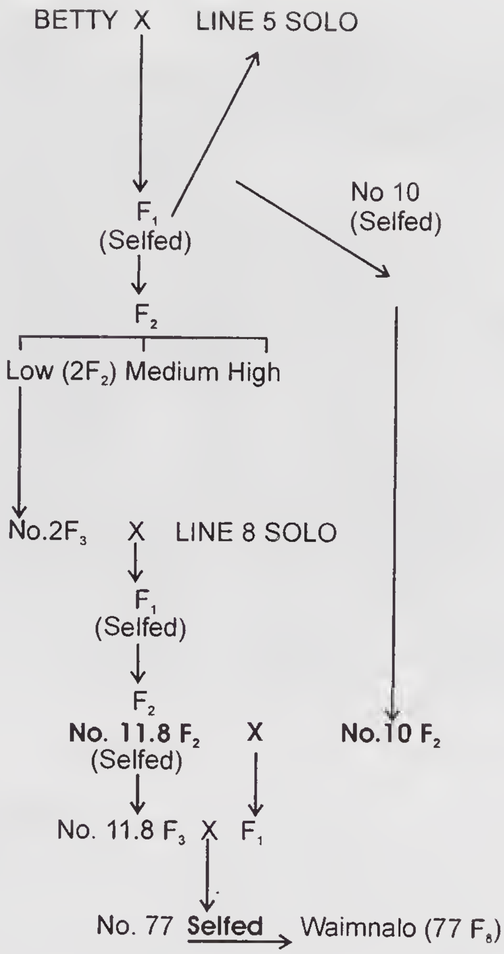


Fig.13. Derivation of the new papaya Waimnalo.

chromosomal damage or due to the combined effect of both.

Emergence: Radiation affected the emergence of seedlings quite adversely. There was dose related inhibition in emergence which failed completely at 70 Kr treatment. At lower doses of 10 and 15 kr, the effect was not very conspicuous (Moh 1963). Further decrease in the emergence percentage at higher doses, may be attributed to arrest of the development of the plumule after the initial stage owing to the damage of the physiological system at cellular level. At corresponding doses of treatments, the higher percentage of germination of seeds and lower percentage of emergence of seedlings suggest that the radiation has damaged the post-germination growth more rapidly.

Survival: There was dose related effect of gamma rays irraditation on the seedling mortality in papaya. Survival count of seedlings on the 45 day showed that doses of 50 Kr and upwards are completely lethal. Even at 30 and 40 Kr treatments, the quantum of mortality was alarmingly high. Any increase in the dose of irradiation was resulted in corresponding increase in seedling mortality.

Fig.14. Dwarf mutant (Pusa Nanha) in homozygous condition.

The radiation has affected the metabolic activities adversely and apparently due to gradual degeneration of the vital physiology of the seedlings, these did not survive. Higher than 30 kr of γ-rays seem to have done more severe physiological damage than the lower doses. This restricts in general the use of higher than 30 Kr doses of γ-rays in mutation breeding programme in papaya. The LD 50 seems to lie between 20 and 25 Kr of gamma-rays. It seems that the genotype of strain Pusa 1–15 is considerably radio sensitive and may be used successfully in mutation breeding programme in papaya (Ram and Srivastava 1984 a).

A dwarf mutant in papaya was first evolved by treating the papaya seed with 15 kr γ-rays (Mansha Ram and Majumder 1981). In the first and second generation there was no change in the various characters. However, in the third generation a very dwarf female (Fig.13) along with two dwarf male plants were observed. To maintain the dwarfness of female plant, it was sibmated with dwarf male. However there was continuous variation in the offspring with respect of plant height. But dwarf female was only selected and sibmated with dwarf male to increase the number of dwarf plants in the progeny in successive generations. By the continued process the plant population in sixth generation grown in 1980 was found cent per cent homozygous in respect of dwarfness (Fig. 14) with reduced yield per plant in terms of number as well as weight of fruits. The distance from plant to plant and row to row in dwarf papaya was reduced to

1.25 m × 1.25 m as against the normal 2 m × 2 m. And thus the plant population per hectare was increased from 2500 to 6400 (Ram and Majumdar 1984b and 1988a).

The mutant plants are chiefly characterised by reduction in plant height and leaf length. The girth of the trunk was also reduced. The average height of the plant was observed to be 106 cm as compared to 218 cm of the parent population. The reduction in leaf length was so conspicuous that a mean length of only 86 cm was found against the average length of 193 cm of the parent. The fruiting started at quite low height on the trunk which is in consonancc of dwarfism character in mutant. Practically no difference in days to first flowering or days to first fruiting was observed (Ram *et al.* 1981).

Besides the quantitative characters mentioned above, the quality traits such as fruit characteristics in terms of length and breadth of cavity, thickness of flesh, colour of flesh, taste, total soluble solids, size and shape of fruit was also changed. The mutant population had medium sized oval round fruit having smaller cavity and lesser thick flesh in comparison to parent. The total soluble solids was lower but the taste was normal sweet and no change in colour of flesh was observed. This mutant has been named as Pusa Nanha.

This mutant also had better tolerance to lodging as compared to tall as there was no damage in it from strong winds. It seems that the mutant viz "Pusa Nanha" has a promise for the fruit growers, and is also suitable in kitchen or nutrition garden and under pot cultivation where land is a limiting factor.

The achievements are not very alluring but of greater significance as mutation breeding as a method of crop improvement especially in fruit crop has made definite break through. For various reasons the possibilities of mutation breeding in fruit crops appears to be promising. The important point with regard to mutation breeding in such crop is to decide on the best possible mutagenic technique. The mutation breeding with all its limitations has come into its own with crops in which mutant trait can be maintained by vegetative propagation as it enables the improvement of the existing variety assortment (Ram and Srivastava 1984b).

Induction of polyploidy

The aim in polyploidy breeding is not the induction of polyploidy itself but breeding at tetraploid or triploid level in order to evolve better types which may be vigorous, fertile and may also combine other desirable characters. Among the various methods used for induction of polyploidy, the use of colchicine has furnished a sure means of obtaining polyploids in a high frequency. Very little work is available on this aspect on papaya improvement.

Hofmeyr and Elden (1942) reported colchicine induced tetraploidy in *Carica papaya* for the first time. Hofmeyr (1945) carried out detailed seed and progeny

Table 16. Effect of gamma-rays on seed germination, seedling emergence and plant survival in M_1 generation of papaya (Strain Pusa 1–15).

Treat-ments	Germination under lab. condition		Emergence in nursery bed		Survival at 45thday stage in nursery		No.of seeds
Control	Percen-tage	decrease over control	Perce-ntage	Decrease over control	Perce-tage	Decrease over control	
	83.00	–	82.00	–	81.25	–	400
10Kr	80.00	4.20	78.50	4.27	70.00	13.85	400
15Kr	82.25	1.80	76.00	7.32	68.25	16.00	400
20Kr	78.00	6.59	70.50	14.30	56.00	31.08	400
25Kr	67.50	19.17	69.00	15.86	31.75	60.93	400
30Kr	62.75	24.86	54.25	33.85	12.25	84.93	400
40Kr	51.25	38.63	36.75	55.19	2.50	96.93	400
50Kr	43.50	47.91	5.25	93.60	0.00	100.00	400
60Kr	31.25	62.58	2.00	97.57	0.00	100.00	400
70Kr	14.50	82.64	0.00	100.00	0.00	100.00	400

studies in the tetraploid papaya plants. He observed certain good characters in the progeny of tetraploid crosses and emphasized the need for more research to exploit the commercial possibilities of tetraploids. He found only 25% sterile pollen grains in the tetraploid males papaya. He reported that the tetraploid pollen functions normally in fertilization. Presenting this evidence on the basis of fruits, he found the cross between tetraploid and diploid where the diploid is staminate parent to be incompatible. Hofmeyr reported that fully developed tetraploid fruit has 150 to 450 seeds and diploid fruit 700–1200 seeds.

Singh (1953) also induced tetraploidy in papaya and found 0.1% colchicine to be the most effective for the treatment. He found that tetraploid plants are generally dwarf in nature and their flowers and fruits have a tendency to absicse easily. Fruiting in tetraploidy was sparse and the fruits were almost round in shape, reduced in size, and generally seedless. Only 28.4% of the plump seeds seemed to contain normal embryo. In his study the cross between female tetraploid and female diploid failed as also the cross between female tetraploid and male tetraploid. He found that the average number of seeds per fruit in the tetraploidy is negligible and may be attributed it to almost total sterility of female tetraploids.

Zerpa (1957) isolated two triploids (3n = 27) by culturing embryo from a cross of a tetraploid × diploid. Ricelli *et al* (1963) were able to induce tetraploidy (2n = 36) in *Carica monoica* by colchicine treatment.

The prospect of evolving some useful economic types appears to be great but the high sterility in tetraploid papaya has proved a great hindrance. This can in all probability be overcome by making a wide choice of initial material for induction of polyploidy. In case of high sterility in the tetraploids possibilities of exploiting these plants for commercial purpose become remote. It is however desirable to induce polyploidy in number of strains of papaya in order to study the effect of polyploidy in such materials for the evolution of useful economic types by suitable breeding methods.

7. Varieties of papaya

PAPAYA is cross-pollinated crop and has many sex forms. Several admixture and sex forms have given rise to numerous varieties. A large number of so-called varieties is found in cultivation. As a matter of fact none of these is a real variety since it can not be relied upon to reproduce the parental characters in all the progenies. However, the following are some of the distinct well known varieties with certain specific plant and fruit characters. The name of the varieties are derived largely from the place where they have been evolved or geographic location where the cultivars were developed. Few exotic varieties have also been found promising which have been imported recently in our country.

PUSA VARIETIES

These have been developed by the author (Ram 1983b 1984, 1984d, 1984e, 1986c and 1990) at the IARI regional Station, Pusa Bihar.

Pusa dwarf (1–45D): Pusa Dwarf, an original selection from Pusa Giant is a very popular dwarf plant variety in Eastern Uttar Pradesh and Northern Bihar specially in Faizabad and Samastipur districts for commercial production. Its fruit yield is very high and the plants start fruiting at about 40 cm above the ground. The total height of the plant is about 140 cm after one fruiting season. It is a precocious variety and even after harvesting three successive crops, it never grows very tall. Fruits are round or oval in shape, and are of medium size. It enjoys a special preference with the consumers because of its medium and convenient fruit size. The fruit cavity is 12 × 8 cm and flesh thickness is 3.5 cm. The T.S.S. ranges between 8 and 9%. Each fruit weights from 0.5 to 1.5 kg and the total yield per plant is between 30 and 40 cm. Because of its small height, this variety is not much affected by storms. (Fig. 15).

Pusa delicious (Pusa 1–15): Pusa Delicious is a new gynodioecious variety which has no male plant. This variety produces only female and hermaphrodite plants. The hermaphrodite plant is also productive, thus assuring fruiting in every plant. The variety is highly productive; its fruits are very delicious, have a pleasant flavour, the flesh is deep orange and the fruit weights from one to two kilograms. The shape of fruit is oblong. It starts fruiting at about 80 cm above the ground level and has a total height of slightly above two meters in one fruiting season. The flowering and fruiting time is about nine months, and the ripe fruits are available within one year of planting. The length and breadth of fruit cavity is 18 × 8 cm and flesh thickness 4 cm. It has a very high T.S.S. (10–13%). Each

Fig.15. Pusa Dwarf (1–450).

plant can give about 45 kg of fruits and three successive crops can be taken from each plant if proper agrotechniques are adopted. Pusa Delicious can be grown in any part of the country (Fig. 16).

Pusa giant (1–45V): Strong winds or storms are a bane to successful papaya cultivation in many parts of the country, which Pusa giant can withstand to a very great extent. The plants grow vigorously, yielding big size fruits. The fruits are born from 85 cm upwards and the plant attains a height of 225 cm after one fruiting season. It has a strong stem and has the highest plant girth amongst all the varieties. The fruit is oblong with a pointed end. The fruit cavity is 18 × 10 cm with a flesh thickness of about 5 cm. The T.S.S. ranges between 7 and 8.5%. Each fruit weight 1.5 to 3.5 kg with a yield potential of 30 to 35 kg per plant, and is ideally suitable for culinary, canning and processing purpose. The farmers of storm-affected areas and coastal region may go for successful papaya cultivation with this variety. This variety responds to the application of higher amounts of manures and fertilizers (Fig. 17).

Pusa majesty (Pusa 22–3): Some farmers grow papaya mainly for extracting

Fig. 16. Pusa delicious – female plant (*left*). Pusa Delicious – hermaphrodite plant (*right*).

papain, which has a potential export market. Pusa Majesty is a very suitable variety for papain extraction. On an average, a single plant of Pusa Majesty produces 460 g of papain a year: the highest recorded in India. Besides the fruit of this variety has a better keeping quality and, therefore, can be exported without much spoilage. Pusa Majesty is also a gynodioecious variety giving hundred percent productive plants like Pusa Delicious. This is a virus-tolerant plant under Pusa (Bihar) conditions. The fruit is of good size and weights from one to 3.5 kg each and the fruiting starts at about 50 cm height above the ground. The total height of plant is 175 cm. The fruit cavity is 17 cm × 9 cm and the flesh thickness is 3.5 cm with bright orange colour. The T.S.S. ranges between 9 and 10%. The total fruit yield per plant is 35 to 40 kg. An outstanding feature of this variety is that this hermaphrodite plant yields two or three times more in the second year as compared with that of the first year. This variety remains productive for at least 3 cycles. This is also a nematode resistance variety (Fig. 18).

Pusa nanha (Mutant Dwarf): This is a dwarf mutant, approximately 106 cm tall. Evolved by gamma irradiation, this variety is found to have 100% uniformity, and is a dioecious line. About 6400 plants can be accommodated in one hectare

Fig.17. Pusa giant (1–45V).

as compared to about 2500 plants per hectare of other varieties cultivated at present. The recommended planting distance is 1.25 m × 1.25 m (Ram 1983d 1984h, Ram and Sharma 1996). About 60 to 65 tonnes of fruits are produced per hectares as compared to 40 to 50 tonnes of fruits from the existing tall varieties.

Fig.18. Pusa Majesty female plant (*left*). Pusa Majesty hermaphrodite plant (*right*).

It is a very suitable variety for kitc0hen garden, pot and on top roof cultivation (Fig. 19).

Coimbatore varieties

These have been developed at T.N.A.U., Coimbatore. (Rao 1974, Sunderajan and Krishnan 1984 and Shanmugavelu *et al.* 1988)

Co1: This table variety is dwarf and dioecious with first fruiting at 60 cm above the ground level. Fruit size is medium with spherical shape, smooth skin with greenish yellow in colour, nipple slight and ridged at the apex flesh orange yellow in colour, soft firm and moderately juicy and free from musky odour (Fig. 20).

Co2: This variety is medium tall having good fruit quality with high papain yield. This variety produces 5 to 6 gram papain per fruit and has been a dioecious variety. Fruits are long weighing 1–½ kg, fruit cavity size large, flesh yellow and thick with a T.S.S. of 13.0° Bricks.

Co3: This is a gynodioecious variety with tall vigorous tree. The fruit is

Fig.19. Pusa Nanha.

medium in size, higher sugar content and red flesh colour. This is mainly preferred for dessert. This was evolved by crossing CO2 with Sunrise Solo. The fruits are medium sized weight about 1 kg. The T.S.S. is of fruit is maximum of 14.6° bricks.

Co4: This is a dioecious variety with medium tall vigorous tree. There are purple tinges on the stem, petiole and leaf. This variety is suitable for home garden both as ornamental and for its edible fruit. This is a hybrid between Co1 and Washington variety. This fruit is medium sized weighing 0.8 to 1.00 kg. The fruit contains a T.S.S. of 13.2° bricks. Flesh is yellow.

Co5: This variety is selection from Washington variety and is mainly recommended for papian production. It yields an average of 1500 to 1600 kg dried papain in a hectare and 14.45 g dry papain per fruit. Plant duration is two years and yields 75.80 fruits. The T.S.S. of fruit is 13° Bricks and papain contains 72.2% proteins.

Co6: This is a selection from Pusa Majesty. It is a dioecious plant having

Fig.20. Co_1 papaya

dwarf stature. It produces large size of fruit and is recommended for papain and dessert (dual) purpose. It produces fruit weighing 2 kg with yellow flesh colour.

Co7: This is a gynodioecious variety with red flesh colour and uniform fruit shape and size suitable for fresh consumption. The T.S.S. is 16% with low stamen carpellody.

Bangalore varieties

These have been developed at IIHR, Bangalore.

Coorg honey: This is a selection from Honey Dew variety made a Chethali Station of Indian Institute of Horticultural Research, Bangalore. This is a gynodioecious variety having excellent fruit quality under South Indian condition. Fruits born on female plants are generally seedless.

Pink flesh sweet: This is a selection made for excellent quality of fruit. The T.S.S. of pulp ranges from 12 to 14° Bricks. Fruit is medium in size with pink flesh recommended for fresh consumption.

Table 17. Chief characteristics of different varieties.

Varieties	Plant height (cm)	No. of fruit/tree	Yield of fruit/tree (kg)	Weight of fruit (g)	T.S.S. bricks°	Remarks
Pusa giant	220	16	38	2000	7–9	Dioecious
Pusa Dwarf	130	41	40	853	8–10	Dioecious
Pusa Delicious	216	39	45	1153	10–13	Gynodioecious
Pusa Majesty	196	40	42	1050	9–13	Gynodioccious
Pusa Nanha	100	25	25	800	8–10	Dioecious
Co1	112	42	50	1200	10–12	Dioecious
Co2	120	35	43	1250	10–12	Dioecious
Co3	150	35	31	900	10–13	Gynodioecious
Co4	250	40	56	1400	10–13.5	Dioecious
Co5	160	43	43	1000	10–12.5	Dioecious
Co6	170	38	42	1100	10–13	Dioecious
Co7	210	45	50	1110	10–13	Gynodioecious
Coorg Honey	210	46	41	890	10–13	Gynodioecious
Sun rise Solo	175	37	8	22	13.5–16	Gynodioecious

Surya: The hybrid 39 of the parentage Sunrise Solo × Pink Flesh sweet has medium size fruit (600–800 g) red flesh, high T.S.S. (14° Bricks) and low cavity (20%) with good peeping quality fruits.

Pantnagar variety

This has been developed at GBPAUT, Pantnagar Nainital (Singh 1990).

Pant papaya-1: This was developed by a selection. The plant is dioecious with medium fruit size. This variety is recommended for Tarai area in U.P. Reports are also available for Pant papaya-2 and 3 but neither seed is available nor there is any cultivation of these varieties in and around Pantnagar area in a recent survey made by the author.

Papaya cultivars

Ranchi: Ranchi variety is not in pure form and seeds coming from Ranchi are designated as variety. Although this cultivar has given rise to many varieties but due to high variability, it can not be recommended for cultivation. All the 3 sexes, males, female and hermaphrodite plants are produced in this variety. The fruit is medium to large weight 1 to 13 kg.

Washington: This is an important cultivar of Maharashtra and used for papain cultivation. The plants parts are violet in colour and fruits are green with good taste. It is domesticated in Maharashtra since long time. Flowers are deep yellow, fruit large, ovate in shape and born in large number. Plants are generally vigorous.

Additionally, there are several selections of local importance which are adapted in the specific region viz. Barwani, Honey Dew, Nongpoh, Halflong Ceylone, Peradeniya, Bangalore and Philippines. A number of some local varieties which exist in literature and seldome cultivated in some localities are Barwani Red, Barwani yellow, Santa cruz Giant, Singapore Pink, Chianki Local, Ram Nagar local and Gujarati.

Exotic varieties

Dominating cultivars of papaya in leading states of India are given in Table 18.

Solo: This is a gynodioecious variety of medium sized, good quality fruits from Hawaii. It performs well under South Indian condition (Salikeri *et al* 1977). Female plants produce round shaped fruit, whereas hermaphrodite plant produce elongated fruits. The T.S.S. is 14° Bricks. The flesh is firm and fruits keeping quality is better.

Sunrise Solo: This is also a gynodioecious variety having pink flesh colour and good taste from Hawaii. It is an inbred strain resulting from a cross between line 9 or Pink Solo with yellow fleshed farmer's selection.

Taiwan: This is also gynodioecious variety with blood red flesh colour and good taste. Fruit are medium to large and ovate shape on female plant whereas hermaphrodite plant produced elongated fruit of medium size.

Thailand: This is also a gynodioecious variety having deep red flesh colour and good yield. The fruits are also very sweet.

Eksotica: This is an improved variety in Malaysia which was developed by back crossing method involving local Subang and Sunrise Solo. This is a high yielding medium bearing and early variety with 50–80 marketable fruits and T.S.S. 13–15° Bricks. Hermaphrodite fruits are pyroform while the females are round in shape. The average weight of fruit is around 600–800 g, a convenient size for serving in halves. Carpellody is less than 5%. The average yield is 30

Table 18. Cultivars of papaya grown in different parts of the country.

State	Cultivars
Bihar	Pusa Dwarf, Pusa Majesty, Pusa Nanha, Pusa Giant, Pusa Delicious and Ranchi
Uttar pradesh	Coorg Honey Dew, Pusa Dwarf, Pusa Delicious, Co2 and Local
Orissa	Co2, Coorg Honey Dew, Washington, Local, Ranchi, Pusa Dwarf and Pusa Delicious
Karnataka	Coorg Honey Dew, Solo, Co2 and Washington
Maharashtra	Washington, Co2, Pusa Delicious, Pusa Majesty, Local and Ranchi
Tamil Nadu	Co2, Co3, Co4, Co5, Co6, and Coorg Honey Dew
Others	Barwani Red, Co2, Coorg Honey Dew, Washington, Pusa Dwarf, Pusa Delicious

Source: K.L. Chadha, Scenario of papaya production and utilization, National Seminar on papaya-Coimbatore 1992.

tones per hectare.

Waimanalo: This is a high quality variety with orange yellow flesh resulting from cross between the Betty variety of Florida and the line 5 and line 8 Solo strains. The fruits are round with short neck, weighing about half kg. The fruits are smooth, shining and have a star shaped cavity. It is an improved variety of Hawaii (U.S.A.).

Higgins: This is gynodioecious variety suitable for dry area. The fruit is medium small weighing half kg Besides firmness of fruits at the yellow colour stage makes it desirable export papaya in Hawaii (U.S.A.).

Wilder: This is another gynodioecious variety of Hawaii suitable for export which has been developed by backcrossing method, Uniformity in fruit size and firmness in the yellow colour stage make this a desirable export line.

8. Propagation, tissue culture and biotechnology

Although several vegetative methods are possible for propagation, yet papaya is commercially grown by seed. This leads to variation in the subsequent generations. Vegetative propagation offers a means of avoiding the difficulty arising from dioecious nature and standardising the quality. To perpetuate the papaya plant, true to the type like other fruit crops, utilisation of the vegetative multiplication is an alternative method. Budding and micropropagation are immediate means for enhancing vegetative propagation. Tissue culture and micropropagation are recent techniques for propagating papaya plants, which has a potential scope to utilize them commercially. Although research works are in progress towards this direction but papaya is still commercially grown by seed.

Clonal propagation assumes the retention of the characters of the selected plants through its clone as it duplicate nuclear and cytoplasmic components of the cell. Certain attempts were made to multiply papaya asexually by the conventional methods like grafting, budding and cutting which resulted into little success.

Pope (1930) found that vegetative propagated plants failed to produce the varietal characteristics, which rooted in from 3 to 5 months. Cutting ordinarily develop more slowly than seedlings and both cutting and grafted plants seem to lack in vigour and to bear poorer fruits than their parents. Traub and Marshall (1936) secured of high percentage of success using a solar propagating frame or a greenhouse. Sengupta and Chattopadhyay (1954) reported that all lateral branches produced roots in about 9 months when treated with 3 or 5% indole butyric acid and the roots were formed in the central or with the treatment with NAA. Grafting may be done with the young seedlings or after they have flowered. In the former either cleft or whip grafting may be used, the seedlings being a fourth to a half inch in diameter. Scions should be from good plants of the same thickness. In larger plants cleft or saddle grafting may be used. Recently, Singh *et al.* (1985) found 90% success in patch budding and advocated its commercial adaptability. The *in vitro* cloning methods are the only alternative when the conventional vegetative propagation methods are impractical for large-scale clonal multiplication of the selected genotypes. The *in vitro* cloning methods based on the totipotentiality of the cell also enable production of disease-free plants and improvement in the crop. It is therefore necessary to develop a commercially viable clonal multiplication system for papaya using tissue culture which seems a challenge for the present research.

Tissue culture for vegetative propagation in papaya has been attempted with substantial success. A good deal of research work on micropropagation of papaya has already been done at the Indian Agricultural Research Institute, Division of Fruits and Horticultural Technology and at NRC on Plant Biotechnology, IARI. As a result a protocol for mircopropagation through shoot tip culture from papaya seedlings was developed. Adventitious shoot formation on papaya stem callus was reported by Arora and Singh (1978a,b). They noted profuse callusing onto LS medium supplemented with 2.0 mg L^{-1} kinetin and 0.2 mg L^{-1} NAA. Pandey and Rajeevan (1983) reported callus initiation from stem segments on MS medium containing 5 µM kinetin and 10 µM NAA. Later rooting of the regenerated shootlet was observed on half strength MS along with 10 M IBA, 3.0% sucrose and 0.6 to 0.8% agar (Rajeevan and Panday, 1986). Further, Rajeevan and Panday (1986a) reported shoot proliferation on seedling auxiliary bud on MS medium with 50 µM + 10 µM NAA for establishment followed by rooting on full MS containing 2.0 µM BAP + 10 µM NAA. Studies on varietal differences on *in vitro* establishment and proliferation rate was conducted by Purnima and Bisht (1988). Further more, effect of plant types on shoot establishment and proliferation was noted by Sharma and Singh (1990). They observed that pistillate plants gave rise to higher prolificacy. Field performance of the *in vitro* raised plantlets were studied in detail by Pandey and Singh (1988). They observed that tissue cultured plantlets were superior over seedlings in following characters, viz. number of stomata per unit area, leaf area, stalk diameter, leaf petiole, photosynthetic rate, chlorophyll content, early bearing and ripening and higher number of fruits per plant in Pusa Delicious variety of papaya.

Preliminary report on embryo culture of papaya was given by Phandis *et al.* (1970). They were successful in raising embryos in White's medium containing 0.05 mg L^{-1} Kinetin with or without 0.1 mg L^{-1} GA_3 and IAA.

Application of tissue culture method for non-conventional breeding employing embryo rescue in interspecific crosses (Phandis *et al.,* 1970) hybrid embroys of *Carica papaya* 'Washington' × *C. cauliflora* were rescued, which were found to be resistant against Leaf Mosaic virus. Later Sharma and Bedi (1990) demonstrated the role of sucrose in germination of normal embryos. They procured normal leaved plantlets, which embryos were cultured on MS medium with 2.0 g L^{-1} BAP and NAA and sucrose 30 or 45 g L^{-1}, incubated pigments on hybrid placemental culture of *C. papaya* × *C. cauliflora* was noted when initially incubated for 24h in darkness (Sahijiram and Doreswamy, 1993). Efficient callus culture from leaf explant was observed on MS medium supplemented with 0.2 mg L^{-1} NAA. However, Balakrishnamurthy *et al.* (1992b) reported that the optimum combination was 0.25 mg L^{-1} BAP + 0.1 mg L^{-1} NAA. They reported callusing from stem, root, leaf and petiole of the seedling papaya plants. Attempts were made by Mondal *et al.* (1990) to reduce the contamination through antibiotic. They reported 43 and 69% contamination free cultures from fruit bearing and saplings after spraying the plant with gentamycin (1000 mg L^{-1}) for 7 days. Further, Mondal *et al.* (1994) reported callus culture in papaya cv. Honey Dew on half strength MS containing 0.5 mg L^{-1} IBA + 1 to 2 mg L^{-1} kinetin. Multiplication of selected female species by embryo culture and micropropagation has been suggested by Gnanakumari and Reddy (1992). Shoot tip culture and clonal multiplication was also reported by Balakrishnamurthy *et al.* (1992a).

Unlike most of the tropical and sub-tropical fruit species, the papaya represents the herbaceous group which bent to *in vitro* treatments. Methods exist for regeneration of plantlets from shoot tip and callus by organogenesis and somatic embryogenesis. Embryo rescue allowed the culture of hybrid embryos before their abortion for the recovery of interspecific hybrids with desirable characters.

Debruijne *et al.* (1974) successfully cultured the mature embryos of papaya on MS without m-inositol, casein hydrolysate or vitamins but containing 58.4 mM sucrose. Hybrid embryos after 90 days of pollination (*C. papaya* × *C. cauliflora*) were rescue on White's medium. Later, Yang (1986) reported the successful culture of embryos excised after 30 days. Both mature and immature embryos of the above cross in Cuba was reported on MS medium with 200 ml L^{-1} coconut water or 10 ml L^{-1} in white's medium with vitamins (Farinas *et al.,* 1990). In ovule cultures followed by somatic embryogenesis has been reported by Fitch and Manshardt, (1990), Earlier, Litz and Conover (1982) were able to obtain somatic embryos from interspecific crossed ovular callus. Embryogenesis took place on White's medium with/without coconut milk, in liquid culture containing 1 to 2.0 mg L^{-1} 2, 4-D. Genetic transformation of somatic embryos was attempted by Fitch *et al.* (1990). They transformed the papaya somatic embryos by particle bombardment following culturing on MS medium devoid of 2,4-D.

Callus culture has been induced from almost all parts of papaya like petiole, seedling, shoot tip and auxiliary buds, hypocotyl, leaves, roots and cotyledons etc. Debruijne *et al.* (1974) were able to get good callus from petiole segments on MS medium supplemented with 0.2 mg L^{-1} NAA and 2.0 mg L^{-1} 2.ip. Again, Yie and Liaw (1977) reported callusing from stem segments on MS medium containing 1.0 mg L^{-1} NAA and 0.1mg L^{-1} kinetin. Medora *et al.* (1979) found 1.8 μM 2,4-D ideal for callus induction. Coconut water and NH_4^{-}-nitrogen were found to be effective, while BAP and GA_3 were inhibitory. Earlier, Mehadi and Hogan (1976) had also noted 2.0 μM 2,4-D superior over other auxins.

Callusing from leaf lamina and midrib of seedlings was observed by Litz *et al.* (1983). Shoot tip and stem segments were easier to induce callus than other explants (Dewinnaar, 1987). Further, Dewinnaar (1987) reported that adenine sulphate, casein hydrolysate and ascorbic acid were essential for callus induction.

Somatic embryogenesis was reported by Debruijne *et al.* (1974) on seedling petiole explant with 1.0µM NAA and 10 µM 2ip, while maturation occurred with 0.01 µM BA and 0.5 µM NAA without vitamins. Chen *et al.* (1987) noted high frequency somatic embryogenesis on half strength MS medium containing 1.0 mg L^{-1} NAA, 0.5 mg L^{-1} kinetin, 1.0 mg L^{-1} GA_3 and 160 mg L^{-1} adenine sulphate. Again, Fitch (1993) was able to induce somatic embryogenesis from seedling hypocotyl. Embroyogenesis was found to be dependant on osmoticum of the medium and 7.0% sucrose gave the best response. Shoot inducing callus from cotyledons was obtained on MS medium added with 0.0–0.2 mg L^{-1} NAA + 0.05–1.0 mg L^{-1} BAP while adventitious roots were formed with 0.1–15.0 mg L^{-1} NAA and 0.0–0.5 mg L^{-1} BAP (Litz *et al.*, 1983). A step towards mechanization of micropropagation, viz. callus suspension culture was demonstrated by Litz and Conover (1982). Direct or somatic embryogenesis on leaf segment has also been reported by Yang and Yae (1992); Fitch (1993) and Hossain *et al.* (1993).

Whilst, establishment of seedling explant is comparatively easier and faster, the shoot tips and axillary buds from mature plants are comparatively difficult. Litz and Conover (1978) noted 95% contamination due to the presence of endophytic bacteria. Multiplication by proliferation of seedling shoot tip was first attempted by Yie and Liaw (1977) on MS medium supplemented with 0.05 mg L^{-1} IAA with either 5.0 mg L^{-1} kinetin or 1.0 mg L^{-1} BAP. Litz and Conover (1978) established the shoot tip of mature plants on MS supplemented with 50 µM kn+10 µM NAA. With maximum proliferation on 2.0 µM BA + 1.0 µM NAA. Drew (1988) and Drew and Miller (1989) suggested that phytosanitary measures is a must to establish explants from field grown material. They recorded highest explant establishment with 0.1 mg L^{-1} NAA + 0.5 mg L^{-1} BAP (Drew, 1988) while, Dewinnaar (1990) observed maximum establishment and proliferation on seedling auxiliary buds with 0.1 mg L^{-1} NAA and 0.5 mg L^{-1} BAP. In a preliminary experiment, Reuveni *et al.* (1990), were successful in improving the explant, establishment by spraying field plants with rifampicin (250 mg L^{-1}) before explant collection.

9. Soil with special reference to pH

PAPAYA can grow in a wide range of soils provided the soil is well drained and aerated. A rich well drained sandy loam soil is the best for papaya cultivation. Like other fruit trees, it grows well in deep rich alluvial soils on the banks and deltas of big rivers of India. Papaya can also be grown in calcarious and stony soils provided with heavy dose of organic manures. (Anonymous, 1997). Soils with high pH(8) and low pH(5) should be avoided. Papaya prefers slight acidic soils and clayey soil is unsuitable for this crop.

Presently major portion of land has become alkaline due to excessive use of chemical fertilizers in various part of country. The availability of all 16 types of nutrients depends on the pH status of soil. The balance of uptake of nutrients is disturbed if the soil pH is excessively low or high. All the major and micronutrients are available to the plant in between 6.5 to 7.5 pH. Hence the efforts should be to maintain soil pH around 7.00. In order to correct the alkaline soil, pyrites, lime, gypsum and sulphuric acid should be invariably applied in the soil. Besides, micronutrients fertilizers like zinc sulphate, iron elements and ammonium molybdate should be supplemented from time to time along with general manuring.

Cultivation of Dhaincha (*Sesbania indica*) along with pyrites improve soil pH at a faster rate. Cultivation of Karnal grass also helps in improving soil pH. The poor farmers who cannot afford for costly gypsum and pyrites can easily adopt growing Karnal grass in some way or the other for improving the soil suitable for papaya cultivation. Contrary to this, in acidic soil (low pH) 2–4 tonnes per hectare of lime application is recommended.

Rao (1974) reports that papaya thrives well in the plains of Tamil Nadu, Mysore, Maharashtra, Andhra Pradesh, Orissa, West Bengal, Bihar and parts of M.P. In parts of U.P., upper parts of M.P., Rajasthan and Punjab papaya can be grown if it is protected against the hot wind in June and frost in winter by growing tall wind-breaks or shelter belts of shisham around the plantation. It also grows well in the medium black soil of the Deecan Plateau as well as in the lateritie soils of the Western Ghats. It does not thrive in calcarious and stony soil which contain little organic matter.

Being a shallow rooted plants, the papaya can be grown in soil of a depth of about 45 cm. overlying a porous substratum of murum in the Deccan, but it is particularly susceptible to lack of drainage and accretion. The roots of plant are fleshy, spongy and extremely fragile. Therefore, they rot in ill-drained soil which lack aeration. The papaya plants in such conditions makes poor growth, leaves turn yellow and the yield goes down. Therefore well drained soils not likely to suffer from the ill effects of over-watering especially in the areas fed by canal should be selected.

10. Climate

Climate includes temperature, light, humidity, wind and rainfall etc. Papaya is a tropical fruit and grows well in the mild sub-tropical regions of the country and from sea level to elevation 2000 m above mean sea level. Dry climate with meagre rainfall add to the sweetness of fruit whereas wet climate with heavy rainfall tends to reduce sweetness. The effect of temperature, rainfall and wind is detailed herewith.

Temperature

Temperature is one of the most important climatic factor which determines the success of papaya cultivation. The best germination of papaya seed has been found around 35°C and it is adversely affected if the temperature goes below 23°C or beyond 40°C. All commercial plantings of papaya are now located in areas that are considered warm. The papaya can grow and produce fruit at higher elevations where the temperature is lower but fruit quality is poor. Also the sugar concentration of papaya fruits in the winter months is lower than in the summer months. The refractometric dry solids present, and indication of sugar content showed as much as 3.5 per cent difference between seasons at Pusa Bihar, a sub-tropical zone.

The temperature of a locality influences the type of flowers and fruit formed on a tree. With some commercial gynodioecious varieties, a decrease in temperature results in a decrease in the amount of marketable fruits produced. Research has shown tremendous differences in papaya plants response to temperature. Night temperature below 12 to 14°C for several hours i.e. during the winter seasons affects the growth and production. It is very sensitive to frost. Winter temperature below 4°C may kill the plants. The frost affected plant oozes out milky latex from the stem and ultimately it dies.

The overall performance of the papaya has been observed at its best in tropical regions characterised by high temperature, humidity and rainfall. Prolong droughts associated with high temperature adversely affects fruit production by inducing abortion of floral and fruit structures, leading to sterile phases or fruiting skips along the stem. On the other hand under cool temperature and wet conditions there may be a tendency for hermaphrodite flower to revert to femaleness (carpellody of stamens) which leads to formation of misshapen fruits.

In the plains of North India the papaya is adversely affected during summer by high temperature and during winter by low temperature. Although there are a number of well known precautions designed to ward off the effect of mild frost including close spacing of plants but none is advantageous when grown on commercial scale. Burning effect on fruits and stem is frequently observed in hot summer resulting anthracnose disease.

Rainfall

The papaya is adapted to a wide range of rainfall conditions. In the high rainfall and humid sections of country the fruit produced are larger than those grown in the low rainfall area.

The moisture required to grow papaya differs in each location, depending on the ecology of the area. Rainfall, temperature, light, wind, soil type and elevation of these environmental conditions play an important role in determining the amount of moisture needed to keep the papaya tree in good productive condition. The age of the tree is also important in determining moisture requirement. Young papaya seedlings need more moisture than older trees, which can maintain normal growth with little moisture because of their slower rate of vegetative growth. In addition, the root system of older trees is more extensive and the tree is able to absorb available moisture more readily. In irrigated orchards, young papaya seedlings are irrigated about once or twice a week, whereas older bearing trees may be irrigated every other week.

Although bearing papaya trees do not need water as critically as small seedlings, it is important that the tree has ample water at all times. Lack of moisture over any prolonged period will slow down growth and encourage the production of a number of male or sterile flowers. The result is that fewer fruits are set on the tree.

Wind

Papaya plants are sensitive to strong winds, lest the tree break down. In open and high lying area where plants are exposed to strong winds or storm, suitable wind breaks are essential to protect them. Papaya trees can withstand winds up to 50 to 75 km an hour if the tree has a deep, well developed root system. Winds accompanied by rains can loosen and break roots sufficiently to cause the papaya trees to fall, resulting in severe losses to the commercial grower. Low temperature with strong winds also damages the crop severely. Strong winds besides uprooting, blowdown and break down, tear the leaves and drop down the flowers and fruits. Leaf tearing reduces the supply of organic materials to the fruit. This can affect the quality of the fruit specially if they are in the process of development during strong winds. Slow recovery of affected plants results in the production of undersized and small fruits.

The wind-break is provided by growing natural trees border of suitable plant species in different papaya growing areas of the world like seed banana (*Musa balbisianum*), coral hibiscus (*Hibiscus schizopetalus*), and Ohialahua (*Metrosideras collina*). The cunningham iron wood (*Casurina cunninghamiana*) is well adapted to papaya growing areas of low rainfall and should serve as good wind break in large papaya orchards. Fast growing strain of subabul (*Leucaena lencocephala*), Euealyptus species, silver oak (*Glyrecidia sepium*) and jaint (*Sesbania eagyptiaca*) are also very effective as wind break.

11. Production technology

To obtain higher yield improved cultural method should be adopted (Ram 1981c, 1982b, 1987a and 1993) as follows:

Nursery management

Seed rate: For one hectare planting, about 250–300 g papaya seed is sufficient.

Raising of seedlings in nursery: Nursery bed should be prepared at least one month in advance of seed sowing and thorough weeding should be done before sowing the seeds. The seedlings can be raised in nursery bed measuring 3 m. long 1 m wide and 10 cm high. Seeds can also be germinated in seed pan tray

Fig.21. An ideal nursery.

made of hard black plastic measuring 53 cm × 27 cm containing 98 drainage cells available in the market. The seed should be sown 1 cm deep in rows of 10 cm apart and covered with fine compost or leaf mould to get highest germination.

The nursery bed may be covered with polythene sheet or dry paddy straw to protect the nursery against adverse weather conditions (Ram 1981d)

Depth of sowing the seeds in nursery is an important aspect for higher germination. It may vary from soil to soil i.e. 2 cm deep in sandy soil, 1.5 cm in sandy loam and 1 cm deep in clay-loam soil. In an experiment conducted by the author, the highest germination was found in 1 cm deep sowing followed by 2 cm in semisandy soil (Ram, 1989). Light watering with the help of watering-can in the morning hour is preferred.

Tender seedlings should be protected against heavy rainfall. Dusting of 10% BHC insecticide should be done to protect the seedlings against insect pests. The most serious disease in the nursery is "damping off". Treating the seed with 0.1% Monosan (phenyle mercury acetate), Ceresan, Agrosan or Thiraum dust before sowing is the best preventive measure against this disease. Also the nursery bed should be treated with 5% formaldehyde solution before sowing. If the disease appears in the nursery, Bordeaux Mixture (1%) or copper oxychloride (0.2%) should be sprayed. The damaged plants by this disease should be burnt as a preventive measure for future spread of the disease. It is experienced that papaya seedlings raised in polythene bags stands better than those raised in seed beds. Perforated polythene bags of 20 cm × 15 cm size can be used as container. Polythene bags are filled with mixture containing farmyard manure, soil and sand in equal proportion. Four to 5 seeds are sow in each bag and after germination only 3 seedlings are retained. Seedlings in polythene bags are best suited for long distance transportation.

Transfer of seedlings: When the seedlings are growing densely, they can be transferred to next nursery bed or pots or plastic bags to avoid overcrowding and further check of growth of seedlings. This is also useful when the field is not ready for planting in time. Generally the seedlings become ready for transplanting in the field in about 2 months when it is 15–20 cm high. Watering in the nursery bed should be stopped one week prior to transplanting. This helps better stand population in the field.

Selection of land, field preparation, and provision of windbreak

Since papaya does not withstand waterlogging, a well drained upland should be selected for cultivation. Papaya plants are also sensitive to strong wind, lest the tree break down. In open and high lying area where the plants are exposed to strong winds or storm, suitable windbreak are essential to protect them. Such windbreak also saves the trees to great extent from damage caused by cold wind or frost. (Fig. 22) Jaint (*Sesbania aegyptiaca*) should be sown around the field on the onset of the monsoon to act as an effective wind-break. This windbreak is quick growing hedge commonly used in the eastern parts of the country. (Ram 1981b and Ram 1983e).

For better fruit yield, papaya is planted in pits (60 cm × 60 cm × 60 cm) which is opened for about 15 days earlier in summer and filled with the top soil along with 20 kg farmyard manure, 1 kg neem or Karanj cake and 1 kg bonemeal or fishmeal. Tall and vigorous varieties are planted at greater spacing while medium and dwarf varieties are planted at closer spacing. Accordingly pegging should be done to open the pits in the field and filled with organic manures on the onset of monsoon. If there is no rain, heavy flood irrigation should be done to settle down and decompose the organic manures in the pits prior to transplanting (Ram 19969).

Planting season

Planting of papaya is done in 3 distinct seasons for commercial purpose. They are Spring (February–March), Monsoon (June–July) and Autumn (October–November). Spring planting is done in area where the climatic condition is mild throughout the year. Monsoon planting is preferred in the frost prone area, as plants become hardy when the frost occurs. Plants are protected against frost damage by covering with polythene structure in the frost prone area. Autumn planting is generally done in the regions where the rainfall is high and virus problem is acute in rainy season.

In an experiment the author has found the highest yield and least infection of virus when the seeds were sown in the nursery in 3rd week of August and planted in the field in the middle of October under sub-tropical condition of North Bihar. This finding is very suitable for North Eastern regions of India including West Bengal, Eastern Uttar Pradesh, Bihar and Orissa. (Fig. 23).

It should be remembered that flowering and fruiting takes place after more than 5 months of transplanting and fruit sets in the monsoon season from July to October only. Hence in frost pronged area the seeds can be sown in the month of September and protected under plastic cover throughout the winter and planting can be done in Spring (February-March) to catch the ensuing monsoon season of flowering and fruiting.

Planting distance

Planting distance is determined by the integration of light interception, cultivar and economic consideration. The spacing of 1.8 m × 1.8 m is normally followed for the most of cultivars. A closer spacing of 1.33 m × 1.3 m (5609 plants/ha) was found to be optimum under Bangalore conditions for Coorg Honey papaya. The spacing of 1.4 m × 1.4 m or 1.4 m × 1.6 m is best suited for papaya cv. Pusa Delicious under sub-tropical conditions of Bihar while the spacing of 1.6 m × 1.6 m recorded highest yield of fruits as well as papain in Tamil Nadu. A closer spacing of 1.2 m × 1.2 m for Pusa Nanha has been adopted for high density orcharding containing 6400 plants/hectare and yielded 103 tonnes of fruit. Since sufficient space is available in between two rows of papaya in the first year, a number of intercrops are taken for better economic return. (Fig. 24) Under such circumstances the distance from plant to plant and row to row may vary greatly. The number of plants per hectare has been shown according to different distances in Table 19.

Table 19. Number of plants per hectare in square, triangular and rectangular system.

Planting distance (m^2)	No. of plants/ha			
	Square system	Triangular system (m^2)	Rectangular system	
			Plant distance	No. of plants/ha
1.2 × 1.2	6400	–	1.8 × 2.1	2646
1.8 × 1.8	3086	3571	1.8 × 2.4	2315
2.1 × 2.1	2268	2625	1.8 × 2.7	2058
2.4 × 2.4	1736	2008	1.8 × 3.0	1852
2.7 × 2.7	1372	1585	2.1 × 2.4	1984
3.0 × 3.0	1111	1284	2.1 × 2.7	1764
			2.1 × 3.0	1577
			2.4 × 2.7	1543
			2.4 × 3.0	1389
			2.7 × 3.0	1235

Planting operation

Planting of papaya seedlings in the field should be preferred in evening. The seedlings from nursery-bed are lifted with ball of earth and planted in the field. Plants raised in polythene bags are planted after removal of polythene. Three seedlings should be planted in each pit followed by light irrigation. Only one seedling may be planted with pure gynodioecious variety. It is also important to keep some extra plants reserved in the nursery or in polythene bags for gap filling in the field. It is desirable to maintain full population in the field otherwise there will be economic loss at the rate of Rs 100 per gap at the minimum (Ram 1999).

After care and gap filling

Proper care should be taken to save the seedlings in the field specially against insect pests and heavy rainfall in the early stage. In frost prone area, these should be protected with small thatches or polythene structure. Some extra seedlings kept already reserved in the nursery for gap filling may be utilised for planting in the gaps as soon as possible. Mechanical damage of young seedling or plants is frequently observed which should be avoided during cultural operations in the field.

Fig.22. Onion as intercrop in papaya.

Intercropping and crop rotation

In the beginning sufficient space is available and therefore, some crops can be taken up with advantage. The papaya based cropping system (sequential and intercropping) are found most remunerative as they give high net returns in case of papaya + tobacco intercropping in North Bihar. In an experiment it was found record net return to the tune of Rs 1,67,000 per hectare in 1 year 8 months in case of papaya + tobacco intercropping in North Bihar (Ram and Pandey, 1990 and Singh and Chari, 1991).

Table 20. Income from papaya-cum-tobacco intercropping.

Intercropping system	Yield (q/ha)	Total income (Rs/ha)	Production Cost (Rs/ha)	Net return (Rs/ha)	Total net income (Rs/ha)
Tobacco sole crop	20.00	60,000	14,524	45,476	45,476
Papaya sole crop	900.00	135,000	35,000	1,00,000	1,00,000
Tobacco	20.00	60,000	14,524	45,476	
+	+	+	+	+	1,67,000
Papaya	900.00	1,35,000	13,476	1,21,624	

1. Rate of tobacco (Dried leaves) = Rs 30.00/kg
2. Rate of papaya fruit = Rs 1.50/kg
3. Fruited plants in 1 ha = 2250
4. Yield of fruit/plant = 40 kg

N.B: when papaya is grown in tobacco, no digging of pits and basal dose of organic manure is required. This is because the farmers give heavy dose of manures and fertilizers in tobacco crop. Hence the cost of the cultivation is drastically reduced when both crops are combined together.

It is advised not to grow crops like chillies, tomato, brinjal and lady's finger to avoid viruses as they act host. No intercrop should be taken when flowering and fruiting start. A suitable crop rotation must be followed up to maintain soil fertility and to avoid replant problem. Intercropping of leguminous crop after non-leguminous one, shallow-rooted crops after deep rooted ones are beneficial. Few crop rotation already standardised are given below:

1. Papaya (October–May), maize (June–September), Wheat (November–April) and pigeonpea (June–September).
2. Papaya (October–May), Green manuring (June–September), Wheat (November–April) and maize (June–September).
3. Papaya (October–May), Legume (June–September), Potato (November–February), Sugarcane (March–February) and moong (March–June).

Interculture weeding and hoeing

Grasses cause much damage to papaya plants in the early stage. The weeds grow luxuriantly in the papaya field and exhaust most of the applied nutrients. In the beginning, they also compete for light, air and water which result poor papaya fruiting. Deep hoeing is recommended in the first year to discourage weed growth. In no case hoeing should be done in rainy season after fruiting as the plant of papaya is a shallow rooted crop. Over-growth of weeds also causes the waterlogging conditions and makes the plants vulnerable to root rot and roof rot in rainy season. Therefore weeding should be regularly done specially around the plants. Gramoxone at 1.0 litre per/ha controlled weeds and gave maximum fruit yield in papaya (91·tonnes/ha) under west Bengal conditions, Paraquate (1.0 litre/ha) applied twice at 90 and 180 days after transplantation caused maximum reduction of weeds, improved plants growth, advanced flowering and resulted in higher fruit yield. At IIHR Bangalore Diuron 2 kg/ha was found effective in controlling weeds without any adverse effect on papaya.

With the increasing labour cost, chemical weed control appears to be suitable measure for operation. Application of fluchloralin or Alachlorin or Butachlorine at 2.0 kg/ha as pre-emergence application, two months after the transplanting papaya can control all the weeds for a period of 4 months.

Removal of unwanted male plants

It is necessary to keep 10% male plants in the orchard for good pollination where dioecious variety is cultivated. As soon as the plants flower, the extra male plants should be uprooted. The hermaphrodite plants produce good quality fruit which should not be confused with male plant while removing them from the orchard. While removing the extra plants, weaker and diseased plants should be uprooted.

Thinning of fruits

Healthy papaya trees can be expected to flower about 4–6 months from the time of transplanting in the field. Fruit thinning is an important practice that will regulate production and improve the percentage of uniform size marketable fruit.

After fruit set, the initial stages of fruit development are very rapid. Therefore, any fruitlets that remain under-developed after a week or so from setting is unlikely to develop into marketable fruit. The poor development is normally due to poor pollination and fertilisation of the ovules. Such fruits are normally seedless and very small and should be picked off by hand at the early stage.

In some instances, particularly during very wet and cool conditions, the papaya develops carpelloid fruits. The malformation is evident even at the flower stage and detection and elimination of such fruitlets can be done very early. Other fruitlets which should be discarded are those that have apparent damage due to thrips, mites and disease.

The improved varieties of papaya set a single fruit. It is also recommended that a single fruit per node should be retained. On occasions when some nodes carry two or more fruitlets, only the largest one should be retained. Fruit thinning will result in a high percentage of well formed, uniform size fruit because very early in their development all parasitic malformed fruit which do not have economic importance have been removed.

Earthing up

After ensuring one plant per pit, earthing up should be done 30 cm in radius around the plants on or before the onset of monsoon to avoid waterlogging. It also helps the plants to stand erect.

Nutrition and fertilizers

Papaya is a heavy feeder crop since it grows vigorously and continuously and give high yield of fruits. Adequate and efficient manuring of young and mature tree is essential to maintain the health of papaya and to obtain profitable yield.

Manuring start from raising the seedlings in the nursery for the production of vigorous healthy plants. During preparation of nursery bed, 20 kg fine compost should be applied in each nursery bed measuring 3 × 1 m. After germination where the seedlings are one month old liquid solution of fertilizer of 10–10–10 if applied correctly produce healthy seedlings specially in poor soil.

Manurial experiments in fruiting orchard carried out all over the world have indicated positive response to nitrogen, phosphate and potash and to several micronutrients in papaya. Both organic and inorganic manures are beneficial to the papaya plants. Organic manures like farmyard manure, sheep manure, neem cake wood ash and bonemeal improve yield and quality of papaya fruits. Hence manuring in papaya should be half from organic manures and half from chemical fertilizers (Rajput and Sharma, 1970).

In an experiment on the nutrition of papaya Cunha and Haag (1980) estimated the removal of major and minor nutrient per tonne of papaya fruit as follows:

1770 g N, 200 g P, 2120 g K, 350 g Ca,
180 g M, 200 g S, 989 mg B, 300 mg Cu,
3364 mg Fe, 1847 mg Mn, 8 mg Mo and 1385 mg Zn.

From the uptake studies, requirement of N, P and K was estimated to be 140; 40: 200 gm per plant per year. However from field experiments 140–350 gm N, 70–375 gm P and 0–500 gm K per plant per year have been found to be optimum depending upon cultivars and agro-climatic condition. 200 gm N was also found optimum for fruit yield at Pusa but papain yield increased with dose up to 300 gm at Coimbatore. Invariably 200–250 gm each of NPK are recommended for high yield of papaya. Purohit (1977) reported highest yield of Coorg Honey papaya at 250 g N. 110 g P and 415 g K per plant per year applied in 6 split application. In another experiment he reported a dose of 250 g N, P and 500 g K per plant per year in 6 split application to be the best. At Coimbatore a dose of 200 g each of NPK per plant in 4 split doses during 1,3,5 and 7 month after planting resulted in higher yield of papaya variety Co_1. For papain production from Co_2 variety a dose of 250 g N/plant/year in 6 split doses at bimonthly interval commencing from the second month after transplanting was found the best. Singh *et al.* (1998) found maximum fruit yield with 200 g N, 300 g P_2O_5 and 150 g under Chhota Nagpur (Jharkhand) condition. A dose of 350 g N, 250 P and 200 K per plant per year applied in 6 split doses was best for Solo variety spaced at 2 m × 2 m (2500 plants/ha) under Bangalore condition. A fertilizer dose of 200 g N, 300 gm P and 600 gm K per plant gave highest fruit yield in Ranchi variety under West-Bengal condition. For maximum papain yield (4.45 g/fruit) fertilizer dose of 200 g N, 300 g P and 400 g K was found optimum. Not many field trials have been conducted to determine the micronutrient requirement of papaya. The Boron deficiency develop bunchy top and deformed fruit. To remove this malady Borax (0.1%) should be sprayed on foliage.

Deficiency of lime and boron has often been observed in papaya orchard. Two spray of 0.5% zinc sulphate and one spray of Bordeaux (0.1%) may be required depending upon the nutrient status of soil.

Ghanta *et al.* (1992) conducted an experiment to study the effect of foliar application of micro-nutrients viz. B (0.1%) Mn (0.25%) and Cu (0.25%) applied singly and in combination at 2 and 3 months after transplanting on growth flowering yield and quality of papaya cv. Ranchi. All the micro-nutrients significantly increased the growth of plant, numbers of leaves produced per plant and length of petiole (5th leaf). Application of micro-nutrients hastened flowering by 2 to 10 days. Combined application of Mn and Ca produced the highest yield (97.44) tonnes/ha compared with 67.01 tonnes/ha in control. All the micronutrients increased individual fruit weight, fruit size and pulp thickness of fruit and reduced the seed content of fruit. Combined spraying of Mn and Cu showed best response in increasing the T.S.S. (9.67) total sugar (6.84%) reducing sugar (6.29%) sugar/acid ratio (58:46) ascorbic acid (56.79 mg/100 g pulp) and total carotene (4635.7, μg/100 g pulp) content of fruit.

Irrigation

Maintenance of optimum soil moisture is essential for plant growth, fruit yield and quality. Under low moisture conditions floral sex shifts towards female sterility resulting in low productivity. At the same time over irrigation may cause root rot disease. Thus efficient water management is required. Number of irrigation depends upon soil type and weather conditions of the region. Protective irrigation is required in the first year of planting. In the second year when the plants are ladden with fruits, irrigation at fortnightly interval in winter and at 10 days interval in summer is needed from October till May. Excessive moisture is more detrimental to plant than moisture stress necessitating the effective drainage system, especially in heavy soils under high rainfall conditions, to avoid plant mortality. Studies conducted at Coimbatore have also indicated that the papaya has high tolerance for heat and soil moisture and for higher productivity however moisture stress at fruit development stage should be avoided. Total water requirement of Co2 papaya under tropics is estimated to be 1800–1900 mm and excessive depletion of moisture causes reduced growth and yield (Balasubramaniyam and Rao, 1984, 1988) However, intermittent moisture stress induces deep root

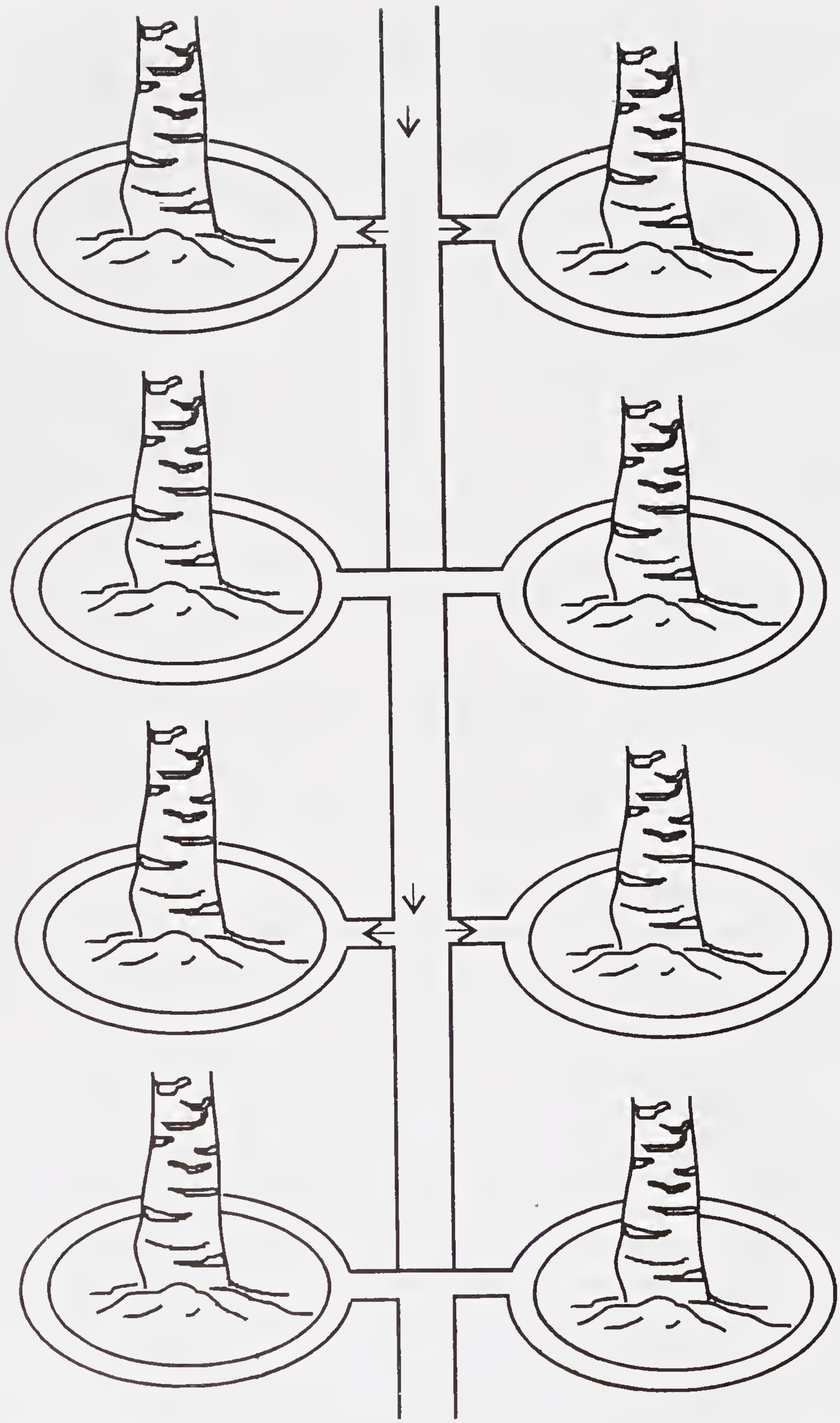


Fig. 23. Ring system of irrigation in papaya.

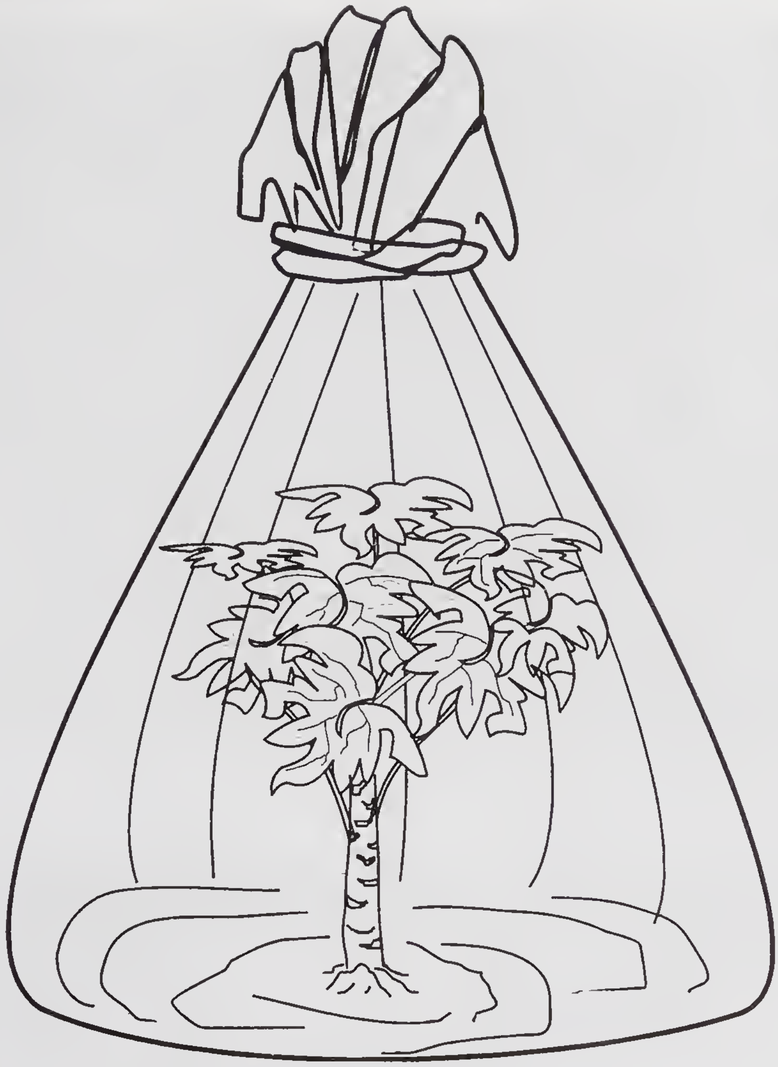


Fig. 24. Protection against frost.

penetration. Depletion of soil moisture also causes increase in N and Mg content while Ca content is reduced. Irrigation at 60–80% available soil moisture (ASM) depletion is found to be optimum for papaya.

Generally basin system of irrigation is followed but care is taken to avoid water stagnation around the plant (Fig. 26). In low rainfall area, where the water is scarce, sprinkler or drip system of irrigation can be adopted for higher production. These system save water from 60 to 80% according to method and region.

Drainage

It should be remembered that papaya plants are very susceptible to waterlogging. Even 24 hours stagnation with water may kill the well established orchard. (Fig. 27) It is there fore most important to select upland for papaya plantation. It may further be shaped sloppy in heavy rainfall area. It is essential

Fig. 25. Papaya orchard damaged due to water-logging.

Fig.26. Papaya cultivation in pot.

to make few furrows or trenches for quick and complete drainage of water during rainy season, Earthing up around the plant may be repeated according to

Fig.27. Pusa Nanha in kitchen garden.

need during rainy season.

Staking and protection against Adverse weather conditions

The fruited plants should be covered with gunny bags against high temperature in summer and low temperature in winter. White polythene may also be used for this purpose. Covering of young plants against strong summer wind, frost and schorchy sun rays is also essential to protect them. Covering of young plants of papaya should be done in advance in frost pronged areas. While covering the young plants, care should be taken that the southern east portion of plant is opened so that sufficient air and light is available to the growing plants (Fig. 28). When there is forecast for frost in the ensuing night. Irrigation must be done in the plantation. Smudging around the field may also help to protect against frost-along with the irrigation. If the plantation is well managed with effective wind break, it also saves from such adverse conditions.

Pot cultivation of papaya

The Indian Agricultural Research Institute, Regional Station, Pusa Bihar has evolved Pusa Nanha, an extremely dwarf variety of papaya. Since there is potential scope of papaya cultivation in urban area where land is a limiting factor, Pusa Nanha papaya can easily be grown in big pots. (Fig. 29) Half cut iron drums and wooden crates can also be used for this purpose. The following aspect should be taken care of while growing papaya in pots (Ram 1998a).

Size of pot

The size of pot should not be less than 75 cm × 40 cm. The following quantity of manures should be filled in each pot before planting papaya plants:

1. Soil 1/5 parts
2. Compost 3/5 parts
3. Neem cake 2 kg
4. Sterra meal or Rallis meal 1 kg
5. Wood ash 2–3 kg

Raising of seedlings: Papaya seedlings can be raised in August-September. The polythene bags used for raising seedling should be filled with 1/3 part sand. 1/3 part compost and 1/3 part soil. The seeds should be sown one cm deep with 5–6 seeds in each bag. It should be watered regularly with watering can. When the seedlings are 10 to 15 cm high they should be planted in the pot (already prepared) in the month of October-November. Atleast 4 plants in each pot should be planted and finally thinned out to one after removing male and other diseased or weaker plants.

Nutrition: Apart from the organic manures already given in the pot, the following dose of chemical fertilizers should be applied as top dressing:

1. Nitrogen 50 g
2. Phosphorus 50 g
3. Potash 75 g

These chemical fertilizers should be applied after flowering. The same quantity should be repeated in each month from July to October. Precaution should be taken that these fertilizers are applied at least 15 cm away from the plant in a circular fashion. Water should be immediately applied after each top dressing.

Cultivation of papaya in kitchen garden and on roof tops

There is potential scope of papaya cultivation in kitchen garden and on roof tops by the amateur growers in big towns with dwarf varieties like Pusa Dwarf and Pusa Nanha. While growing papaya in the kitchen garden, the southern and western side of plot should be selected (Ram 1994) It should be grown in one line reducing distance to half from plant to plant. The border area can be better utilized. Other operations like planting, manuring, irrigation, interculture and insect and pest management should be same as in commercial plantation.

For growing papaya on roof tops, soil up to 30 cm high should be put and maintained. The soil should be collected from the place where there is no weed or weed seeds. 20 kg farmyard manure 1 kg/Neem cake or Karanj cake and 1 kg Bonemeal or Single Superphosphate should be spread in 36 square feet. The number of plants can be kept according to family, need assuming 20 kg fruits per plant in variety Pusa Nanha and 35 kg fruits in Pusa Dwarf.

The planting distance, application of fertilizers and diseases and pest control should be same except irrigation. Frequent light irrigation is given and sprinkler system should be preferred. Staking of plants with bamboos should be done when the plants are ladden with fruits. This is essential to protect against strong winds. Drainage point should be blocked in other season, and opened in only rainy season for quick drainage of water (Ram 1995).

Cropping system and mixed cropping

In the commercialised agriculture, mixed cropping in papaya needs more emphasis than growing papaya as monocrop. Besides taking more profit per unit area and per unit time, it is advantageous in maintaining and sustaining soil fertility, water conservation and availability in situ efficient utilization of sunlight and recycling of these resources for long time use in better production and productivity. This system will be proved as a boon for a poor and marginal land holding. The incidence of insect pests and diseases is also minimised. The papaya is a delicacious crop and its cultivation in the cropping system approach depends on the climatic condition, soil type and choice as well as marketable value of the crop. However, there are few tips which are of immense importance for papaya cultivation and higher production in cropping system.

1. The crop which have higher water requirement should not be grown with papayas as it affects the papaya crop adversely e.g. paddy in papaya.
2. Papaya is a tropical fruit which requires maximum sunlight. In such situation crops like bottlegourd, spongegourd, kheksa, tinda and squash should not be grown as catch crop, mixed or intercrop.
3. Papaya is highly susceptible to virus diseases. As such no crop should be grown with papaya which are not only affected by virus but also acts as an alternate host i.e. brinjal, tomato, lady finger and chillies etc. Some suitable mixed cropping system in papaya is given below:
   (a) Papaya can be grown as filler crops in newly planted orchard of litchi, mango, sapota, citrus, guava, pomegranate and coconut etc.Some intercrops can also be taken like different types of vegetables, leguminous crop, covercrops, and spices in its inter and intra row space of plantation.
   (b) Papaya and banana can be taken as companion crop. In the beginning, garlic, coriander, onion, legume, safflower, can also be taken in the little space of papaya and banana plantation.
   (c) Some precrop can also be taken in papaya field such as short duration

crops like cucumber (June to September) in the pits filled with organic manures meant for papaya plantation (October planting).

(d) Some relay crops can be grown in papaya field and after planting papaya, some sequential crops can be grown in furrows. Some examples are potato (Sept.), papaya in furrows (Oct.) and mustard or coriander in scattered manner in wheat (Nov.) sown in the interspace of papaya plantation.

(e) Semi shade or shade loving crops can be grown in papaya plantation like turmeric, ginger, suran and calocasia as an intercrop.

(f) Multistoried or tier system of cropping scheme can be easily followed in the tropical or semitropical regions which comprises of coconut, arecanut, papaya, different spices, tapioca and sweet potato (underground crops).

Thus these papaya based crop production systems are not only capable of improving the economic condition of the farmer but also have substantial employment potential for rural poors and landless labourers, women and tribals in its cultivation as well as in processing, manufacturing, packing, marketing, transportation of end products or industrial produce manufactured based on these agricultural raw materials. Besides, there is a substantial scope for alternate uses of papaya through its commercial exploitation for industrial and pharmaceutical values as mentioned earlier.

12. Parthenocarpy and unfruitfulness in papaya

SOMETIMES seedless papaya (parthenocarpic) fruits are found in the market with no seed at all. Seedless fruits develop from the pure female or hermaphrodite flowers which by chance do not get fertilized by the pollen from male or hermaphrodite trees. This type of fruit is born generally in the beginning of fruiting season when there is lack of pollen. Seedless fruits are generally smaller in size and very sweet. At Tamil Nadu Agricultural University, Coimbatore, it was found that spraying female flowers with gibberellic acid (200 ppm) was useful in producing seedless fruits of Honey Dew papaya. GA3 treated fruits

Fig.28. Unfruitfulness in papaya.

contained only 10 to 87 seeds compared with 500 to 800 seeds in untreated fruits. The Vitamin C content was also doubled.

When papaya plants bear no fruit or sparse fruiting takes place in the orchard is called as unfruitfulness. (Fig. 31) Unfruitfulness in papaya has been observed in many places. If the following points are kept in mind, this malady can be removed (Ram 1983a)

Lack of pollination

Pollination is required for good setting of fruits and seed production. The farmers generally remove all the male plants considering them to be unproductive, Fruiting can not take place in absence of pollination. For good fruiting pollination is essential and for good pollination adequate pollinisers are required. It is essential to maintain 8–12% male plants in the population in dioecious varieties for good pollination.

Choice of variety

Heavy or shy bearing is a genetical character in papaya. But some acclimatised varieties give good yield in a specific zone. Cv. Ranchi is acclimatised to Jharkhand condition and has a wide adaptability under North Indian condition. Coorg Honey perform well in South India specially in Karnataka but a poor yielder in North India. Similarly Barwani in Central Zone, Washington in Western Zone and Co varieties in good part of Southern zone perform well. Exotic varieties like Solo, Sunrise Solo, Waimanalo, Taiwan and Thailand perform well in Southern and Western India but give poor performance under North Indian condition. Homestead from Nigeria shows good potential in yield all over the country. Pusa varieties have also shown good performance under most part of the countries. Therefore, only tested varieties suitable for a specific zone should be grown.

Basal dose of organic manure in the pits

Basal dose of organic manure should be applied in pits and not flat bed. In a field trial papaya 'Pusa Delicious' was transplanted in (a) pits dug 90 days and filled with manures 60 days ahead of the transplanting date (b) pits dug and filled with manures 2–3 days ahead of the transplanting and (c) in flat lands (beds) prepared 2–3 days ahead by deep ploughing after broadcasting the manures in a meter wide band running along the planting row. Plants getting treatment (a) flowered quite earlier than those under treatment (c) and produced the highest fruit yield (36.4 kg) per plant. The result with (b) was statistically comparable to that of (34.5 kg) (a). Transplanting in flat land (c) brought about significant reduction in the plant productivity (9.1 kg). These observations bent strong support for transplanting papaya in pits dug and manured either recently or in advance in heavy soil (Ram and Ray 1995).

Planting season

Papaya is a tropical fruit and it requires warm and humid season. Winter season retards the growth and fruiting of this crop. Most of the parts of our country are subtropical. The papaya starts flowering and fruiting after about 6 months under normal condition. Therefore, planting should be manipulated in such a way that fruiting may continue for a longer period. The optimum period has been found to be August-September for sowing seeds in the nursery and October-December planting. This provides an extended long range of warm and humid condition for fruiting (Ram and Ray 1992b). Planting done in other season either takes a longer time for fruiting or leads to sparse fruiting in the first season.

Nutrition

Papaya is a heavy-feeder fruit crop. If sufficient amount of balanced fertilizer is not applied to the plants, they fail to produce fruit or give meagre fruiting. It is also necessary to strike a balanced (carbon: nitrogen) ratio for fruiting properly. Besides, some micronutrients also play a vital role in fruiting. The following dose of manures and fertilizers per plant has been standardized after experimentation to obtain the maximum fruit yield.

Organic manures (basal dose)		**Inorganic fertilizers (top dressing)**	
(i) Compost	20 kg	(i) Nitrogen	200–250 g
(ii) Cake	1 kg	(ii) Phosphorus	200–250 g
(iii) Sterrameal or Ralismeal	1 kg	(iii) Potassium	250–500 g

This dose makes a good balance between vegetative growth and fruiting. Generally the farmers apply excess of nitrogen, which increase vegetative growth and leads to poor fruiting.

Weed control

The weeds grow luxuriantly in the papaya orchard and exhaust most of the nutrients applied to it. They also compete for light, air and water, which results in poor fruiting in papaya. Even after repeated weeding they come up regularly. The experiment conducted at this station shows that the best way to manure is to apply a basal dose in the pits of 60 cm × 60 cm × 60 cm and then plant papaya. At this depth the grasses are generally unable to share the nutrients. The inorganic fertilizers in the form of top-dressing should be applied around the plant and covered with reasonable amount of soil in the root zone. Weeding should be done regularly, especially around the plant, so that the nutrients applied to the plant are not taken up by the weeds.

Water requirements

Papaya is a crop that cannot withstand waterlogging but needs plenty of water, specially when it starts fruiting. However, this requirement is fulfilled in the rainy season. If there is drought or scanty rain, irrigation must be provided copiously. From October to April, when the upper fruits are still developing, the plant should be irrigated frequently. Irrigation can also be given after top-dressing in the rainy season, if the rain fails. Lack of moisture over a prolong period will slow down growth and encourage the production of a number of male or sterile flowers. The result is that fewer fruits are set on the tree resulting unfruitfulness in papaya.

Intercropping

In the first year of planting, sufficient space is available in between two rows of papaya plantation, in which intercrops can be grown successfully. The crops so selected should have no adverse effect on papaya. The following few points should therefore be considered:

1. The crops that compete with papaya or suppress its growth should not be included in the intercropping.
2. The crops normally affected by viruses should not be grown, like tomato, brinjal and okra.
3. Leguminous crops of low height like gram, greengram, blackgram should be preferred, which besides suppressing the weeds add nitrogen into the soil.

Crop rotation

A suitable crop rotation is necessary for a good crop of papaya. Taking continuously the same crop year after year results in complete exhaustion of some essential macro and micro-nutrients. Besides, it increases the intensity of pest and disease, which leads to poor production of the fruits. Intercropping of leguminous crop after non-leguminous ones and shallow-rooted crops after deep-rooted ones removes this problem. A few suitable crop rotations are:

1. Papaya (October–May), maize (June–September), wheat (November–April), and maize (June–September).
2. Maize (June–September), papaya (October–May), green-manure crop (June–September), and wheat (November–April).
3. Sugarcane (February–February), Greengram (March–June), maize (June–September), papaya (October–May), green-manure crop (June–September), and Potato (November–February).

Diseases and pests

Root-root: In the damp climate of heavy rainfall area, the plants sometimes appear healthy but still give sparse fruiting.

Examination of roots reveals that tap root or most of the deeper roots are rotten. This is owing to over-saturation of water in the subsoil. The uptake of nutrients by the superficial fibrous roots is partial, as a result there is no fruiting in papaya.

Therefore, the area having water-table very high or near the ground level should be avoided. However, the up and sloppy land in such an area may be utilized for planting papaya. If at such places there is danger of root-rot, 100 g copper sulphate and 1 kg lime should be added along with organic manures in the pits as a basal dose.

Viruses

In the north-eastern region of India, the climate is humid, which is very favourable for the spread of viruses. Plants heavily infected with this disease either fail to produce fruits or give markedly reduced yield. As a result, papaya was wiped out in the last two decades (1950–70) in this area. The research work at IARI Regional station Pusa showed that the juvenile papaya seedlings which have least faced the period of rainy season are generally free from this disease. Therefore, seeds should be sown in the nursery in the beginning of September and the crop should be planted in October, so that it escapes rain in the first year. The plants become hardy in the ensuing winter and summer seasons. Thus, there is little infection of viruses in the next rainy season and the fruiting in papaya is at its maximum.

Nematodes

The reniform nematode (*Rotylenchulus reniformis*) is a serious pest of papaya roots. This results in stunted plants and reduced fruit production. The nematode may be detected on well washed root as a tiny grain of sand like body attached to its surface. An economically feasible chemical control is the application of ethylene dibromide at the rate of a about 3 q/ha or carbofuran 2 kg/ha. The fresh cowdung liquid manure application may check this in early stage.

Insects

A number of insects like, red spider, mites aphids, mealybugs, scale insects, thrips, fruit flies, hoppers, beetles, moths and white flies, though minor pests to papaya, cause sometimes severe damage when the sanitary aspects of orchard is neglected. Different species of aphids and other insects cause more loss as a vector than the pest. Besides employing suitable insecticides, these insects can be controlled to a large extent by way of keeping the papaya orchard relatively free of weeds.

Thus if the above factors are taken into consideration, the poor yield and unfruitfulness in papaya can be overcome to a greater extent.

13. Ripening, harvesting and yield

RIPENING is a complex process which occurs during the final stages of fruit development through senescence, when a fruit experiences a series of physiological and biochemical changes. It is genetically controlled and involves a number of genes which are activated (Grierson, 1987), leading a dramatic changes in fruit quality and acceptability. Physiological and biochemical studies are essential in efforts to modify papaya ripening through genetic manipulation, which might serve as the basis for effective post-harvest handing and storage. Unfortunately, little is known regarding the regulation of ripening in the papaya.

Unlike the banana or mango which are harvested before any evident ripening changes have taken place, papaya are harvested after the mesocarp has developed colour and the peel shows colour on at least 3-6% of its surface. Papaya ripening proceeds to completion if the fruit is left on the plant. The response of the fruit to the post-harvest environment is affected by the stage of ripeness.

In tropical climate the papaya bears fruit throughout the year but in Northern India the first fruit ripen about November and the crop ends in May. Papaya fruits attain full size and mature in about 3 to 5 months after fruits set, when it should be harvested. A good crop may fail if harvesting of fruits is not done properly due to perishable nature of fruit. The fruit should be left on tree until they mature fully. Usually the fruits are harvested when they are full size, light green with tinge of yellow at epical end. On ripening fruits of certain varieties turn yellow but some of them remain green. When the latex ceases to be milky and become watery, the fruits are considered suitable for harvesting. Pal *et al* (1980) found that the trace ripened fruits were superior over room ripened fruits with regards to increased pulp proportion, pulp : peel ratio, dry matter, alcohol, insoluble solids, T.S.S., total sugars, glucose, vitamin A and soluble amino acid content.

Harvesting is a simple operation when the papaya trees are short and the fruits may be reached by hand by an individual on the ground. All fruits showing a tinge or more of yellow at the apical end of the fruit are picked and placed in a picking bag, a plastic container, or a galvanized pail. They are then hauled to the packing shed by trucks. During the cool months when the fruits ripen slowly, the papayas can be left on the tree to develop more colour before harvesting to obtain optimum flavour development without causing additional post-harvest handling problems. Fruits that are left on the tree with more than half of a colour have a shorter shelf life and are more susecptitele to fruit fly infestation.

14. Grading, packing and storing

The harvested fruits should be collected in single layers in shallow baskets padded with straw or similar soft material and taken to the packing shed. Before packing, suitable grading of fruits should be done to get higher price. Damaged and diseased fruits should be rejected which can be utilized in local consumption only. Fruits are graded on the basis of skin colour, weight, size and shape. They should be uniform in colour and shape viz. round or pear shape. For the Solo types, large fruit weighing 500–700 g, medium 350–499 g and small 250–349 g should be graded. If the fruits are to be sent to a distant market, they should immediately be packed in single layers after harvesting, one above the other and separated by straw puddings and should be sent to the market as soon as possible. Packing of papaya fruits differ from place to place and marketing distances in our country. For local markets the fruits are generally heaped in castload with or without wrapping with newspaper. For semi-distant markets the fruits are individually wrapped with newspaper and packed in shallow bamboo baskets with straw or shredded paper around the fruit layer each packing, weighing 20–25 kg in weight. For fairly long distance transportation wooden crates or plastic containers are used in which fruits are arranged in single layer wrapped in newspaper each packing weighing about 15 kg. Sawdust, straw or plastic foam are used as cushion.

For export market papaya fruits are wrapped with white polythene sleeves which serve as cushion material in Malaysia. This prevents fruits from brushing transportation. Fruits of Solo type can also be wrapped individually using onion skin paper. They are then packed in single layer with the skins end facing down in corrugated fibre board cartons, which may or may not have horizontal or vertical position. For Eksotica papaya the net weight of each carton is 6 kg which may contain 9–10 fruits for large grade, 12–15 fruits for medium and more than 15 fruits for small grade.

In Hawaii (USA) after the vapour treatment the fruits are cooled with circulated air, then packed in corrugated carton with shredded paper in a screened area to prevent reinfestation. The packed and sealed cartons are then trucked to the ship and loaded into the ships refer or they may be loaded into a refrigerated container for surface shipment at about 50 or they may be shipped by air.

As soon as the papaya trees grow tall enough that the picker cannot reach the fruits from the ground, harvesting aids must be used.

The step ladder is used to reach the high papaya fruit by some of the small growers. It is tedious, time-consuming, and costly method of harvesting. After ripening, unless picked before it begins to get soft. It is difficult to protect it from birds and to market it without spoilage. However, few precautionary measure may help to a great extent to protect the fruits from the birds:

1. Poison baits may be put in cut fruits and scattered in the whole orchard.
2. Fruits on plant may be covered with gunny bags with opening towards lower side for regular picking.
3. Birds scaring by manual labour for a few months and hanging dead birds or effigies of dead birds on poles located at all corners.

While picking the fruits from the tree, care must be taken that they are free from any scratches or blemishes, otherwise there will be attack of fungus and fruits may start decaying during marketing. Even when picked while the latex is still milky, good quality is said to be secured by using ethylene to ripe the fruit. Overnight treatment with one part of ethylene in 5,000 is sufficient but as the gas enters the cavity of fruit, aeration for 24 hours is necessary. The fruit should be then consumed within 2-3 days. Chutichuted and Chutichuted (1997) studied on prolonging storage life of papaya fruit. The treatments were dipping in hot water of 50°C for 20 minutes, dipping in 100 ppm Clorax solution (Sodium hypochloride) for 20 min. dipping in 1000 ppm Benlate (benomyl) solution at 50°C for 30 min or no treatment (control) on the storage life of papaya Benlate treated fruits exhibited the longest storage life (10 days compared with 4.25 days in the control) and showed no sign of infection by fruit not pathogens. These fruits exhibited the lowest weight loss, the lowest ripening and were the most firm of all treatments.

The fruit yield of papaya varies widely according to the varieties, soil, climate and management of the orchard.

Papaya fruits begins to ripen in about 10-14 months from the time of planting. The production of fruits is practically continuous during the life of the tree. The fruit yield in the second year is observed to be higher than the first year. In an experiment of 5 years crop, the author found 40 kg fruit yield per plant in the first year, 45 kg is the second year, 40 kg in the third year and 35 kg in the fourth year. On an average each plant of improved varieties bears 30-45 fruits weighing 40-75 kg in one fruiting season. On an average yield of 60-75 tonnes/ha. may be expected in a season from an orchard of papaya. Fruit yield in the kitchen garden, on roof or in the pot cultivation is 20 to 35 kg per plant in Pusa Nanha and Pusa Dwarf.

As the plants become older, after two years, the yield is reduced. Yield per hectare may vary according to the number of female and hermaphrodite trees remaining in the orchard after removal of unwanted male trees. In different parts of India the annual yield varies from 30 to 100 tons per hectare.

The life of papaya tree is generally 3-4 years giving 2-3 successive fruit yield. After this the tree should be removed and fresh planting should be done in another field.

Post-harvest treatment of fruits with silver nitrate or cobalt chloride extends the shelf life without affecting the palatability. Papaya fruits at colour turning can be stored at 7°C which will have normal ripening. Shelf life of fruit is also extended by storing at 13°C with 1-0 to 1-5 per cent oxygen or at 10 per cent CO_2 Waxing of fruit and storage under the low pressure (LP) have also been found in reducing the disease incidence and increasing the shelf-life of papaya (Chadha 1992).

Reduction in temperature or treatment with retardants reduces the duration of ripening and enhances shelf life. Post-harvest treatment of fruits with silver nitrate or cobalt chloride extends the shelf life without affecting the palatability. Papaya fruits at colour turning can be stored at 7°C which will have normal ripening. Shelf life of fruit is also extended by storing at 13°C with 1.0 to 1.5 per cent oxygen or at 10 per cent CO_2. Waxing of fruit and storage under the low pressure (LP) have also been found in reducing the disease incidence and increasing the shelf-life of papaya (Chadha 1992).

15. Marketing in India, ASEAN and Hawaii

It is presumed that the present area under papaya cultivation is about 60,000 ha and production is about 13,00,000 metric tonnes which varies from year to year. According to FAO production year book (1992) our country was ranked 5th in production with percentage share out of world's total production of papaya being 8.14.

INDIA

Although papaya is grown throughout the country excepting the temperate region, the leading papaya states are Maharashtra, Karnataka, Madhya Pradesh, Uttar Pradesh, Bihar, West Bengal, Andhra Pradesh, Gujarat and Rajasthan which send their fruits to big cities. Huge consumption of fresh fruits is mainly in big cities and industrial towns like Bombay, Delhi, Calcutta, Madras, Hyderabad, Bangalore, Bokaro, Tatanagar, Bhilai, Kanpur, Chandigarh, Siliguri, Surat, and Ahmedabad although other cities have good market. Hence marketing the fruits and production around these cities are highly profitable. Out of total production, about 3% fruit is being consumed locally and rest is marketed.

Fruits of papaya orchard are generally marketed by the middlemen and contractors. A study on marketing of papaya was conducted in a cluster of 3 villages located in Samastipur district of Bihar state where papaya is grown intensively around Pusa for market purpose (Ray and Singh, 1992). The study was based on primary data collected through interviewing farmer respondents (45), wholesalers (10), traders (24) and retailers (39). An analysis of the collected information revealed that in general, there are two marketing systems prevalent in the locality for trading papaya fruits. One that has gained a ground in the recent past is sale of the bearing plantations to the contractors on the basis of the crop load on the plants well before start of the harvesting of the fruits. As much as 25% of the total produce of the area was sold through this system. The remaining 75% produce was sold through 5 different marketing channels prevalent in the area.

Among the 5 common marketing channels three namely "Producer-Trader-Retailer-Consumer" (Channel-I), "Producer-Trader-Wholesaler-Retailer-Consumer" (Channel-II) and "Producer-Wholesaler-Retailer-Consumer" (Channel-III) jointly accounted for trading of papaya over 90% of the produce. This reflects the marketing system of papaya in India in varying degree prevalent in different states of our country. Two channels, namely producer-consumer and producer-retailer-consumer accounted only 10% of produce.

The prices in the market vary greatly according to season and availability of fruits. In the winter season the prices are low while in summer and rainy season the prices are high to very high. The fruits are available abundantly in the market during winter and summer seasons but rare in rainy season. Ripening takes place in succession starting from October up to the month of May. Ripening is also highly associated with higher temperature which results into huge supplies of ripe fruits in spring and summer season.

An observation was made by the author on flowering, fruiting and ripening of papaya fruits on different plants i.e. hermaphrodite of Pusa Delicious and female plants of Pusa Dwarf under Pusa (North Bihar) condition.

Table 21. Showing flowering, fruiting and ripening in different months.

Months	Hermaphrodite plant			Female plant		
	No. of flowers opened	No. of fruits set	Fruits harvested in the month of	No. of flowers opened	No. of fruit set	Fruits harvested in the month of
May	0	0	–	0	0	–
June	13	0	–	5	0	–
July	87	5	November	17	10	October
August	93	13	November–February	29	25	October–January
September	95	21	February–April	39	28	January–April
October	11	9	April–May	8	5	May
November	0	0	–	0	0	

From the table it is evident that sample taken only form two plants i.e. one from female and one from hermaphrodite plant, maximum harvested fruits are last January to last April and peak season fall in between these months. Apparently March was the only month when Patna market was found with a glut of ripe fruits of papaya which indicate the same trend in north India.

In general the marketing of papaya in India is relatively simple even though many factor are involved within the marketing system including collectors, wholesaler, grocers and retailers. Basically the marketing activities are the collecting or bulking of the fruit and distributing them. Bulking consists of accumulation and transmission of successively smaller parcels of papaya until a limiting consignment size is reached. Distribution is the reverse of bulking and transmission of successively smaller parcel of papaya until finally they reach their minimum size at the last transaction between retailer and consumer.

ASEAN

In general the marketing of papaya in Association of South East Asian Nation as (ASEAN) is relatively simple like India even though many factors are involved within the marketing system including collectors, wholesalers, grocers and retailers. Basically, the marketing activities are the collecting or bulking of the fruit and distributing them. Bulking consists of the accumulation and transmission of successively larger parcels of papaya until a limiting consignment size is reached. Distribution is the reverse of bulking and transmission of successively smaller parcels of papaya until finally they reach their minimum size at the last transaction, between retailer and consumer (Santika *et al.* 1994).

Most of the papaya fruit produced in ASEAN are marketed locally but export are gradually increasing especially from Indonesia, Malaysia, Philippines and Thailand.

Indonesia

Indonesia with a population of more than 180 millions is a great potential market for papaya. The cheaply available fruit is popular with the locals and within the five years from 1987–1990 changes in income and consumption patterns brought an increase of about 20.5% in the consumption of papaya. With annual production of more than 350,000 tonnes, most of the fruit are marketed locally for both fresh consumption and industrial use.

The demand for the various types of papaya produced in Indonesia is greatly influenced by the income status of the population. Evidence indicates that upper-status people prefer taste rather than colour in buying papaya (Table 22).

Table 22. Papaya consumption and consumer preference in Jakarta, 1992.

Income group (Rs/month)	Household consumption* (kg/month)	Preference
251,000–500,000	3.40	Colour, taste
501,000–1,000,000	8.80	Colour, taste
1,000,000	7.96	Taste

*Average family member/household: 6 persons

Source: Santika (1993)

The National Planning Board (1993) projected that the per capita consumption of fruits in Indonesia would increase 3.6% annually whilst fruit production would increase 3.7% annually during 1994–1998. Additional demand will come from expanded export markets and a wider selection of processed products available for both export and domestic consumption.

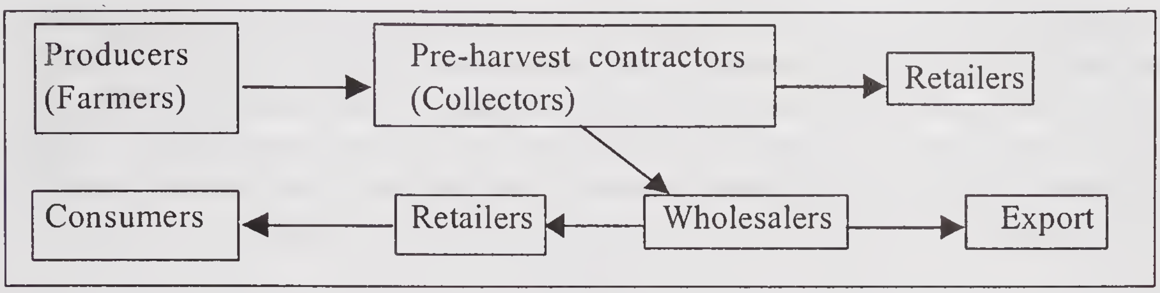


Plate 1. Marketing channels for papaya in Indonesia

Santika (1993) reported that over 70% of papaya fruits are sold by farmers to preharvest contractors. The collectors generally have a verbal contract with the farmers and they buy the fruit well in advance of maturity. Most collectors, who are also farmers, therefore, undertake the full responsibility of picking, packing, transporting and bearing the risks and uncertainties at all stages of distribution.

There are several interesting issues which arise from the papaya marketing system. This type of marketing system is sustained because both farmers and traders are dependent on each other. However, the farmers' positions are always weak because they are tightly bound to the traders. The traders, in turn, pay a down payment to the farmers as a binder to assure supply of the commodity. In the existing marketing system, price information for farmers is limited. Price information is normally received by the farmers through the village traders.

Farmers transport the papaya to the collectors by carrying the fruit on a pole or motorcycle. Intercity transportation is by truck or pick-up. Bamboo baskets of 30 kg capacity are used for packing the papaya for transportation. Each fruit is wrapped in newsprint to prevent friction so as to minimize damage during distribution. Sometimes, the papaya are loaded directly on the vehicle without packing them in bamboo baskets. This method of inappropriate postharvest handling cause substantial losses during marketing.

Exports: Only a small quantity of the fruit produced in Indonesia are exported. Although fruit exports increased from 1986–1990. Indonesia's position internationally was only 0.3% of world fruit exports (Anon, 1993). Exports were mainly to Singapore, Taiwan, Saudi Arabia, The Netherlands, Hong Kong and France.

Malaysia

Papaya is a popular dessert fruit in Malaysia. Domestic consumption increased from 48,000 tonnes in 1985 to 96,000 tonnes in 1990, an increase of about 44% (Table 52). With per capita consumption of 3.6 kg (Singh, 1992) the volume of papaya consumed by the locals continues to increase.

In Malaysia, trading of papaya begins at farm level. Mature fruit are harvested by the farmers, collected by the wholesalers, distributed to the retailers before finally reaching the consumers. Fruit are also directly sold by the farmers to the wholesalers, exporters and processors. Determination of price at the various levels (Farm gate, wholesalers, retailers) depends on the availability of fruit and demand from the consumers. However, fluctuations in price rarely occur and the papaya price is one of the most stable for fruit in Malaysia.

Table 23. Consumption of papaya in Malaysia.

Year	Consumption (tonnes)
1985	47,854
1988	63,728
1990	68,717

Source: Singh (1992)

Exports: There is an expanding export market for papaya from Malaysia. Additional demand has been created with the introduction of the new variety, Eksotika. An increase of about 45% for papaya exports has occurred from 1987 to 1990 (Table 24). In 1991, the value of export continued to increase because the export market favoured the Eksotika variety but the volume decreased because of declining sales of other varieties. There was a reduction in the volume of exports because cultivars with large elongated fruits were no longer suitable for the export markets.

Table 24. Exports of papaya from Malaysia

Year	Quantity (tonnes)	Value (RM)
1987	21744	6129228
1988	23736	12057032
1989	23217	18002501
1990	31444	21003677
1991	22773	23800000

Source: Department of Statistics, Malaysia

Phillippines

The Phillippines trading system for papaya is relatively simple compared to that of banana or mango. The marketing channels involve the assembler, wholesaler-retailer, wholesaler trader-distributor and retailer. These middlemen collect the fruit from the farms and transport and distribute them. Some growers, however, deliver their produce directly to buyers like restaurants, processors or supermarkets.

In the production areas, fruit are sold on a 'per-piece' or wholesale or consignment basis. Sorting is not commonly practised by growers although a few classify the fruits according to size, shape, appearance and degree of ripeness.

Jeepneys, pick-up vans and small trucks are the common means of transportation of papaya to market outlets. For hired public transport, big-sized fruit are charged double the transport cost of smaller ones. Transport cost covers the loading and unloading services as well as the fare of the distance travelled. In the jeepneys, fruits are stacked with bigger-sized and less-ripe fruit at the bottom. Plastic liners are used only to delineate ownership of fruit among small traders. On the other hand, bamboo crates are also used when transporting quality fruit to institutional buyers. Newsprint or plastic liners are often used with these crates.

In the local markets, retailers who own permanent stalls display more ripe fruit and store the green ones. However, transient retailers, display the fruit in the sidewalks or streets lined with any available material e.g. sacks. An improvised shed or umbrella is sometimes used to protect the fruit.

Price variation is correlated with the availability of the fruit. Farm prices are high in January, with a peak in February when production is low. During the summer months, however, prices go down reaching their lowest from May to June. Wholesale prices are more stable than farm prices. They fluctuate similar to farm prices, but in contrast, wholesale prices are highest in December.

Exports: Although papaya is grown primarily for the local market, the Philippines exports about 1% of total production. In 1992, the volume of fresh papaya exported was 1,270 tonnes valued at approximately US $500,000. Fresh fruits were shipped to Hong Kong (85%), Japan (10%) and to other countries like UK, Singapore and Saudi Arabia.

On the other hand, exports of dried papaya reached 141 tonnes valued at FOB US $190,000. Australia was the biggest buyer consuming 78.3%, followed by US (16%), Spain (4%) and Germany (1%). Papaya exports follow a simple distribution route. Local growers usually have production-marketing contracts or linkages with multinational corporations or with exporters.

Singapore

Papaya in Singapore is mainly sourced from Malaysia. It is transported from Malaysia packed loose in lorries. The wholesaler at Pasir Panjang wholesale Centre sorts out the ripe (three quarters to full coloured) fruit and packs them into bamboo baskets lined with newspaper. The remaining unripe fruit are packed into wooden crates approximately 1.2 m × 1.2 m × 1.2 m, covered and exposed to carbide overnight. The wholesaler grades the fruit into three size grades, viz. big (2 kg and above), medium (800 g to 2 kg) and small (below 800 g). Variety, maturity, pest and disease injury and mechanical injury are criteria for grading. Retails sales are carried out at wet market stalls in the Housing Development

Board (HDB) housing estates, fruit shops and supermarkets.

Papaya is traditionally imported from Malaysia. About US $ 5.6 million worth of the fruit were brought into the Republic in 1992. A small quantity is also imported from Thailand.

Thailand

Usually the collectors or wholesalers collect the fruit from the growers. They then send the produce to either a regional market or a Bangkok market where it is purchased by retailers and exporters. The farm price may be only 1.5–3 Baht/kg but by the time it reaches consumers in Bangkok, the price may be 10–20 Baht/kg.

Beside fresh consumption, papaya is also processed into several food items. In Thailand papaya has been canned and processed into chilli sauces and mixed pickles. The demand for papaya for processing is as high as 2,000 tonnes per year, but a survey by the Department of Agricultural Extension in 1988 indicated that processing factories could obtain only about 200 tonnes or 10% of their requirements. So the supply of papaya for processing is well below the demand.

Exports: Since most of the papaya is marketed locally only a small quantity is available for export. The export markets for Thai papaya are Hong Kong, Singapore and some European countries.

HAWAII

The State of Hawaii (USA) produces large scale of papayas. The principal market for the papayas is Honolulu. A gradual change is taking place in papaya marketing with an increasing amount of fresh fruit being shipped to the mainland United States. Most of the fruit comes from the island of Hawaii to Honolulu in 25 pound lugs. The volumes that reaches the market fluctuates with the season and is larger during the late-spring and summer months and shorter during the fall and winter months. Correspondingly, the price decreases with an increase in fruit supply and increases with a decrease in supply. Papayas are channelled into the market by the producer or his representative (1) through the jobber to the wholesaler, then to the retailer; (2) through the wholesaler then to the retailer; or (3) through direct sales to the retailer. The sales to wholesalers by the producers have been on a consignment basis but there is a movement towards outright cash sales. The normal commission charged by handlers is 20% (Ishida, 1970).

Honolulu is the only market in the state capable of handling a large volume of fresh papayas. As a result, the wholesale price of papayas is largely determined by the wholesale market in Honolulu. Prices reach a peak during the late winter when production is low and competition from season fruits such as peaches, plums, and cantaloups is also low.

Before 1948, shipments to mainland markets were negligible. In 1952, 5% of the fruits produced was shipped to the mainland. In 1969, 31% of about 7.6 million pounds were exported. In the first quarter of 1970, roughly 3 million pounds were exported. Exports are expected to continue to increase because of improved transportation facilities, lower freight rates, new markets, improved handling practices, better marketing methods, and increased demand for papayas on the mainland. Initially, ocean shipment was the only means of transporting fruits to the mainland United States. In 1961, curtailment of ocean shipments because of disturbances in the maritime industry forced producers and shippers to use air cargo services as an alternative. Since then most shipments of fresh fruit have been sent via air freight. In 1973, Hawaii exported 7.9 kt. of fruit mostly to the Western United States and Japan.

Air shipments have stimulated papaya exports and decreased the time lag between the producer and the consumer. Faster delivery service has resulted in high-quality fruit, less spoilage, and a longer shelf-life at the retail market.

Currently, most papayas are shipped in 10 pound cartons to mainland markets. The number of fruits in the carton varies from 9 to 13. A 15 pound carton is also being used by the shippers. The papayas are shipped directly from Hilo or from the neighbour islands to Honolulu and then transshipped to the mainland United States.

Fruits marketed on the mainland are much smaller in size than those sold in Hawaii. They are sold by the piece and average 12 to 16 ounces in weight. On the other hand, in the islands papayas are usually sold by weight and weigh as much as one or more pounds, although a few stores are now selling papayas by the piece. According to a recent mainland study papaya sales at the retail stores are affected to a greater degree by such factors as available supply, condition of the product, shelf position in the store and display rather than price changes.

India has not exported papaya fruits so far like mango, banana, and other fruits. In view of the large production base available and the fact that the internationally popular varieties like Solo, Sunrise Solo already being grown in the country, it is considered that if adequate steps are taken, papaya can become a good sources of foreign exchange earner and employment for million as in the ASEAN countries and Hawaii island.

16. Diseases

Papaya is affected by diseases and intensity of damage depends upon agro-ecoligical regions. The following are some of the important diseases which cause considerable loss to the crop.

Viruses

Virus disease is the major limiting factor in the cultivation of papaya. Three types of viruses viz. Mosaic, Distortion Ring Spot and Leaf curl are prevalent in different parts of the country except some of southern regions of India. These

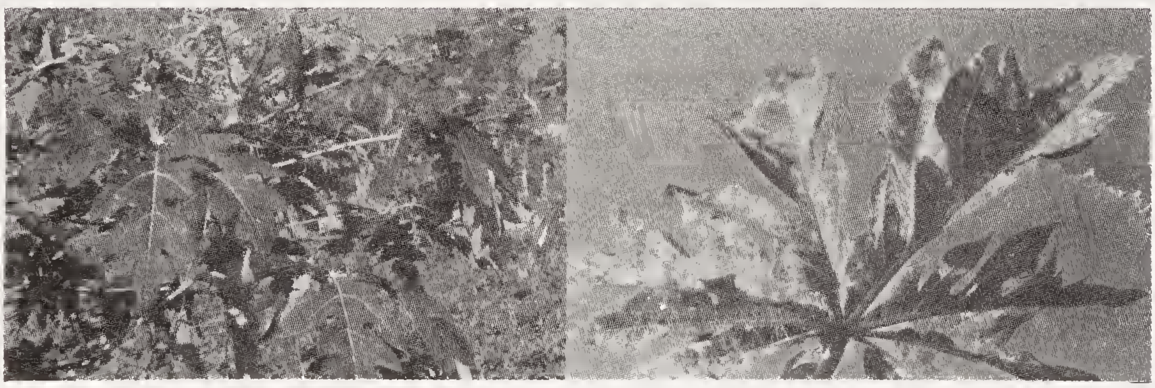


Fig. 29. Distortion ringspot virus *(left)*. Papaya mosaic virus *(right)*.

diseases are transmitted by sap and aphid vectors.

Mosaic virus: In this infection the younger leaves of the crown are generally stunted and severely chlorotic with veins banding or transparent oily area are found scattered over the leaf or along the leaf veins. In mature leaves, the chlorotic pattern frequently is a light colour between the veins accompanied by numerous small rings ranging form transparent yellow to tan in colour. The tree remains stunted for a few months and ultimately dies. This type of virus never recovers to normal green. Presently the mosaic disease is very destructive, losses ranging from 5 to 20% are common in many orchards but losses as high as 80% have occurred. Stem, petiole and fruits are also affected showing distinctive symptoms.

Distortion ring spot virus: In this virus infection, the younger leaves are distorted and side leaves appear which are also distorted. The tree remains stunted and no flowering and fruiting takes place on the plant. In due course of time some of the plants recover and new healthy leaves are produced on the plant. The fruits on such trees are adversely affected showing disfigured fruit and very low yield.

Fig.30. Leaf curl virus (Mycoplasma).

Leaf curl: In this infection the top leaves become curled and plant remains stunted. (Fig. 34) If some fruits have developed, they appear quite spongy and when they ripe, they become tasteless. This type of virus very rarely recover.

There is practically no control measure for these viruses. However, rouging of diseased plants is most effective measure to minimise the incidence of the disease. It can also be minimised by planting the crop in the field after rainy season (Ram 1984 g). Spraying suitable insecticides against vectors may check the further spread of viruses. Application of neem cake is also a preventing measure to certain extent. Addition of heavy dose of organic matter results in lesser disease incidence than application of chemical fertilizers. Homoepathic drug Thuja (2%) have been reported to control the disease upto 73% (Cheema *et al.* 1992).

Damping off

Damping-off disease is a condition in which the tissues of the papaya seedling stem at the soil-line become water-soaked and collapse due to the growth of fungus in these tissues. The emerging young seedling rapidly dry out and die. Young seedlings are very susceptible to damping off and become resistant to this disease as they become older. A number of fungi, including *Pythium aphanidermatum,, P ultimum, Phytophythora palmivora,* and *Rhizoctonia* sp., can cause damping-off of papaya seedlings. These fungi live in the soil. The disease is particularly severe in warm, wet weather and is more severe when seedlings are crowded.

Control: It is important to know that the fungi causing damping-off are found in moist soils and that the disease is favoured by certain conditions. High temperature and wet weather have already been mentioned as conditions favourable to the disease. Other conditions encouraging development of damping -off include wet soils, poor drainage, deep planting of seeds, thick planting of seeds, poor soil aeration, and high levels of available nitrogen in the soil. Any practice to minimize these conditions will help control the disease. Once damping-off has started in a bed, little can be done to save the infected plants. Thus, the soil must be treated before planting to rid the soil of the fungi that cause damping-off. This can be also controlled by spraying Bordeaux Mixture (5:5:50). As a precautionary measure, seeds should be treated with Bavistin, Ceresan or Emesan (0.2%) and nursery bed should be treated with formaldehyde (10%) before sowing.

Stem and root-rot

These diseases are caused by soil-borne fungus namely *Phythium aphanidermatum* and *Phytophthora palmivora*. The incidence of these diseases would be severe during rainy seasons and very commonly found in papaya plantation raised in ill drained soils. The collar of the trunk near the ground surface show a water soaked appearance and softness and ultimately fall down as this spreads further. The roots are also infected and decayed resulting death of the plant. These fungal diseases are more prevalent in heavy rainfall areas. Hence proper drainage should be provided. The infected portion on stem should be cleaned and pasted with Bordeaux paste (5:5:20). Application of 1 kg lime and 100 gm copper sulphate in the pits before planting may reduce the root rot problem in heavy rainfall area. It would be very difficult to control the disease after infection. However drenching of Ridomil (0.2%) as soon as the incidence is noticed and second drenching after 15 days results least mortality.

Bud and fruit stalk rot of papaya

This is a newly discovered fungal disease *(Fusarium solanai)* which affects some strains severely. The infection affects stalk and newly born fruits and drop down. The disease first manifests as pale yellow discoloration near the base of stalk, which later on spreads to the whole stalk. Afterwards, some stalks turn dark brown to black. The flower buds in their early stages are normally infected.

Fig. 31. Bud and fruit stalk rot.

The corolla and rudimentary calyx of such a flower turns yellow, dries and finally drops down. The infection spreads to the ovary, which gets shrivelled and mummified, and ultimately drops (Fig. 35). The young papaya fruits are also affected. The infection starts as water-socked lesions on the skin with appearance of fructification. Gradually the infected portion turns brown to black and sunken. The fruits decay and fall down. The matured fruits are rarely infected locally and they still remain hanging on the plant. The infected portion turns black-brown and white (Fig.35). Except a few suspended fruits the plant remains almost barren. Prophylactic spray of 1-5% Bordeaux mixture controls this disease (Ram 1984 *c* and Ram *et al (1983)*

Powdery mildew

This disease is caused by fungus known as *Odium caricae* and may be serious in the humid tropics. White powdery appearances is seen on the leaf and the affected leaves dry up. This fungus does not penetrate the fruit but is found on the undersurface of leaves, withdrawing nutrients from the cells of the leaf surface by specialized absorbing structures, known as haustoria.

Patches of whitish, powdery material found on the underside of diseased leaves are the main body of the fungus, and they are associated with the discoloured spots found on the upper surface of the diseased leaves. At the infection spot, the leaves show blotches of yellow or pale green, usually near the veins, surrounded by normal coloured tissue. Early, less conspicuous symptoms consist of tiny, pale-yellow spots near the veins. These spots look somewhat water-


Fig.32. Anthracnose disease on fruit.

soaked. The fungal mass growing on the underside of the leaf produces chains of spores which are carried by wind to healthy leaves. These spores germinate, send haustoria into the leaf, develop a fungus vegetative body, and reproduce the disease cycle. Occasionally, the fungus may attack the stems and petioles of young seedlings that are growing under reduce light. The stems have the typical powdery growth, and under severe attacks the top portion of the seedling may die. Good control can be achieved by spraying Bavistin solution (0.1%) and spraying wetable sulphur 2% in water.

Besides the above diseases, a number of other fungal diseases like leaf blight *(Helminthosporium rostratum)* and fruit rot *(Macrophomia* spp.) are frequently observed in the field which are not serious. However these may be controlled by spraying fungicide like Dithan M-45 (0.2%) or Bordeaux mixture (1%) when observed in the field.

Anthracnose

The fruits and trunk of papaya tree on the side exposed to the southerly west are affected due to sun. The green fruits are affected by fungus in which light yellow patch appears on the side exposed to sun. The patch slowly softens, turns brown and extends to half the fruit. Later on black spots in concentric rings and pinkish pustules appear on the enlarged patch. In this disease, the fungus *Collectotrichum gloeosportioides* attacks not only the fruit on which it causes the most damage, but also the petioles of the low, older leaves that begin to turn yellow.

The first symptoms of anthracnose usually are small, round, water-soaked areas on ripening portions of the fruit. As the fruit ripens, these spots enlarge rapidly, forming circular, slightly sunken lesions. These lesions enlarge as the fruit matures and may become 5 cm. in diameter. The fungus frequently produces large, light-orange or pink masses of spores in the centre of the lesions. Sometimes, the spores are produced in concentric rings, giving the lesions the appearance of bulls eye. In addition to producing this surface damage, the fungus also advanced into the fruit. In the early stages the affected portion can be lifted from the healthy fruit as a hemispherical plug. Later the tissue rots, becoming soft and somewhat dark-coloured.

Occasionally green portions of the papaya may become affected with anthracnose. The disease first appears as small, water soaked lesions. Soon after the fungus penetrates the fruit, the latex in the papaya oozes out in sticky mounds or horns. These lesions enlarge very slowly and rarely become larger than 1.25 cm in diameter as long as the fruit remains green.

The fungus causing anthracnose on fruit also attacks the petioles of lower leaves as they begin to die and are shed from the plant. Infections on these petioles are important since they may act as a source of inoculum for infection of fruit. The trunk also get scorched on the side exposed to sun and develops sunken area on its bark which get dry and fibrous, causing the plants to collapse during the summer season.

In the initial stage of the disease it can be controlled by spraying Dithan M-45 or Dithan Z-78 (2,5%). Since the disease is associated with scorching sun, shading the fruits and trunk is a preventing measure. Closer planting and frequent irrigation may reduce this malady. Papaya grown in drier area are usually not badly affected with the fungus than those planted in high rainfall area. Decay occurring in storage after harvest can be materially reduced by hot water treatment.

17. Pests and their control

THERE is practically no serious pest attacking papaya and therefore the damage is limited. However in the recent past some of the following pests have been found damaging the crops of papaya.

Nematode

According to recent survey, nematodes cause about 15% loss of yield on world basis (Nath and Pathak 1992). Among several nematode recorded from papaya plantation, root-knot nematode (*Meloidogyne incognita)* and reniform nematode *(Rotyrenchulus reniformis)* are found widespread and pathogenic to papaya. Nearly 100 host species for the reniform nematode *(Rotylenchulus renoformis)* have been reported. Many cultivated plants as well as weeds are hosts for this worm. The larvae are able to move short distances in undisturbed soil, cultivation and surface water aid the spread of larvae in field. Larvae of the reniform nematode are less than 0.01 cm or 0.5 mm inch long. The young females penetrate the root, after which they do not migrate. The portion of the body which remains outside the root enlarges until it resembles a kidney. After the female matures she secretes a gelatinous substance around her body in which are laid about 100 eggs. A com-

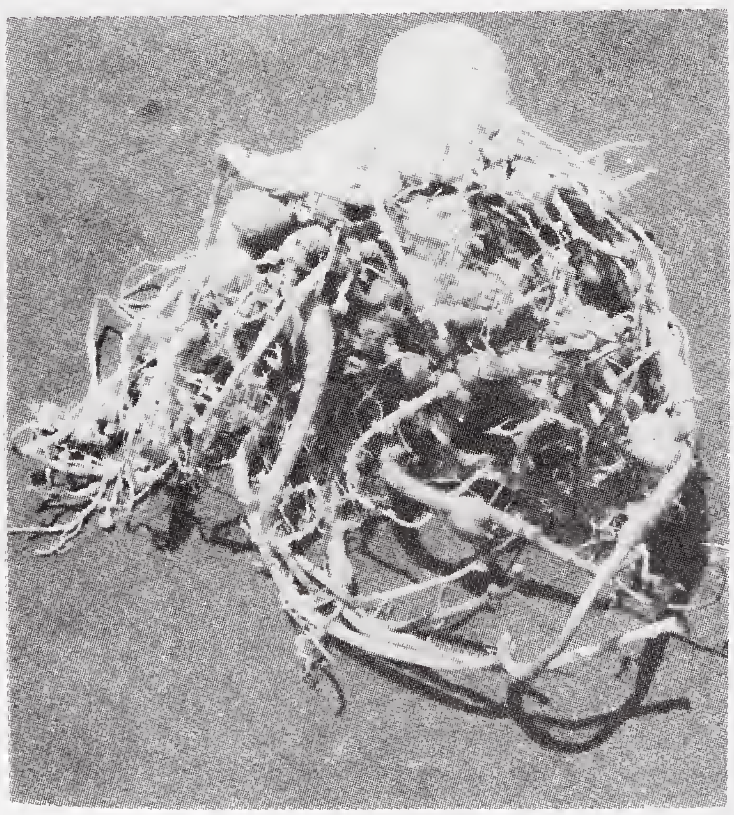


Fig. 33. Nematode affected root.

Fig. 34. Nematode affected plant.

plete life cycle is possible in about 25 days. The infected plants dries from top and spreads downward. Fruits already set on the tree also fall down. The trees of infected plants are sensitive to stresses and wilt more readily than non-infested ones. If smaller fruits are hanging on tree may be tasteless. Affected seedlings which survive in sick plots develop into under sized plants. Such plants show delayed flowering and fruiting. Shedding off of female flower is not very uncommon. The size of male flower remain smaller and also shed off prematurely. The number or size of fruits are considerably less. Leaves of such plants start drying from margins and entire crown may shed off leaving few apical younger leaves. In several conditions flowering does not appear and senescence of plants occur untimely.

Below ground level symptoms in 2-month-old plant appear in the form of knots on roots. Devitalized seedlings show complete destruction of roots. Older plants (9 months to 1 year), when uprooted, reveal big-sized (1.5 to 5 cm in diameter) rounded to oblong and regularly distributed galls throughout the root system. The feeder roots lack and root hair are usually full of minute galls. Tip of the infected root may swell resulting in arrest of further root growth. Above such devitalised root tip, formation of side rootlets are seen. The size and form of the galls depends on the number of nematodes in the tissue and the age of roots as well as plants. When plants are severely attacked by root knot, whole root system is reduced to only few severely galled lateral roots with disorganised vascular system. Complete destruction of tap root is usually noticed. Carbofuran 2 kg/ha is most effective in checking the population. Pusa Majesty is resistant to root-knot nematode and can be grown in the region having nematode incidence.

Red spiders and mites

Occasionally the red spider mite is found on papaya which attacks the leaves and fruits. In severe cases the new leave become distorted. Seven species of mites colonize on different parts of the plant and feed on the plant, causing premature leaf drop, reduced tree vigour, and external blemishes on the fruit that reduce its market value. Mites puncture the plant tissue with their needle-like mouth parts and feed on the juices of the tissue. Some of them multiply prolifically throughout the year and can cause widespread damage in a very short time.

Three species of spider mites feed on the mature, older leaves-the Texas citrus mite and the citrus red mite on the upper surface and the carmine mite on the lower surface. Feeding punctures resemble stippling and are visible on the upper surface of infested leaves. In heavy infestations, the entire leaf surface is bleached with feeding punctures. Leaves become matted with webbing when infested by the carmine mites, while webbing is not prominent on leaves infested by the other two spider mites. All stages-eggs, six legged larvae, eight-legged protonymphs, deutonymphs and adult-are present on the leaves. Only males emerge from eggs deposited by unmated females and both sexes emerge form eggs of mated females. Spider mite adults are about 0.50-0.40 mm long. The female has plump, oval, sac-like body and the male a cone-shaped body. The immature stages are shaped like the adults but are smaller and lighter in colour. Besides occupying different parts of the leaves, these spider mites are different from each other in the characters which may be seen with the aid of hand lens capable of magnifying 10 X.

The life cycle of the spider mites is greatly influenced by temperature. At an average temperature of 28°C, a generation is completed in 7 to 10 days, but under cooler conditions 20 or more days are required. The carmine mite is a more serious pest of papaya-growing areas and reproduces throughout the year on many kinds of plants besides papaya. The citrus red mite and the Texas citrus mite are more limited in their distribution and host range, and outbreaks of them occur only periodically.

The broad mite is very damaging to seedlings and young plants. It feeds on the lower surface of tender, young leaves and causes them to become stunted and distorted. In extremely heavy infestations, the growing tips· are aborted. This species is difficult to see even with the aid of a hand lens. Unlike many other mites in the family Tarsonemidae, males of this species are very common and frequently seen carrying on their backs the white "female" pseudopupae. At an average temperature of 21°C, the life cycle, which includes eggs, larvae, pseudopupae, and adults, is completed in 4 to 5 days. mating takes place soon after the emergence of the females. Each female lays from 18 to 24 eggs during a short life span of about 2 weeks. The eggs are ovate, flattened, and translucent, and it has several white, raised spots on the upper surface, which give the egg a speckled appearance. The broad mite is more prevalent during cool months.

The red and black flat mite is one of the major pests of papaya for it causes scarring of fruit which greatly reduces its market value. Their body color ranges from red, red with various patterns of black pigmentation, to black. Males are red, flattened, wedge-shaped, and rather scarce. Reproduction is primarily without fertilization. About 50 to 70 reddishorange, elliptical eggs are laid singly during the life span of about a month by each female. The life cycle, which includes eggs, six-legged larvae, eight-legged protonymphs, deutonymphs, and the adults, is approximately 3 weeks during the summer and 4 to 5 weeks during the winter. All stages are found during all seasons on the stem, usually at the level where the lowest leaves are attacked to the plant. As the population increases, the mites gradually feed upwards on the stem and outwards onto the leaf petioles and fruits, leaving a large, conspicuously damaged area behind them. The affected area is slightly sunken, tan, and has a corky appearance. This is controlled by Sulphur dust or spraying 0.1% Kelthane.

Aphids

Aphids are one of the minor pests of papaya causing damage to the plant by way of sucking the juices with their long piercing sucking mouth parts. They feed on the under surface of the leaves and cause them to become curled and crinkled. The petioles of heavily infested leaves generally drop downward. They also secret some kind of a honey dew which attracts ants and there by promote the growth of shooty mould on the papaya plants. Besides causing direct damage to the papaya plants by feeding on them, some of the aphids are vectors of viruses.

Aphids are softbodied insects of 2.08–1.38 mm inch long having long antennae and legs. They may be green, yellow, redish or black in colour with and without wings. Aphids can be controlled to a large extent by way of keeping the orchard free of weeds. In case of severe attack, sulphur dust and kelthane solution

(0.2%) or any suitable insecticides can be employed to control the aphids.

Other insects

Some insects like mealy bugs, scale insects, thrips, fruit flies, leaf hoppers, beetles, moths and white flies have been reported as minor pests. Since injuries to papaya have been less, their entomological studies are limited.

18. Post-harvest physiological disorders

PHYSIOLOGICAL disorders in harvested fruits refer to the disturbances in the normal functioning of the fruit tissues due to adverse environmental conditions during handling, improper postharvest handling and storage treatements, or nutritional deficiency during growth and development. In papaya, two physiological disorders have been studied in some detail. These are chilling and hyperthermal injuries (Biglete *et al.* 1994).

Chilling injury

Chilling injury in papaya is induced by exposing fruit to low but non-freezing temperatures. Factors such as cultivar, storage temperature, duration of exposure, stage of ripeness as well as climate and soil factors during cultivation influence the response of papaya fruit to low storage temperature.

Some of the common chilling injury symptoms which develop when fruit are transferred to ripening temperatures are uneven ripening, failure to ripen, skin discolouration, sunken spots and blisters on the skin, increased susceptibility to fungal infection and development of flavour and odour.

Papaya fruit exhibit signs of chilling injury when exposed to temperatures of about 10°C or lower. Accelerated ripening is another symptom of chilling injury of papaya fruit. Fruits of 5% yellow stored at 10°C for 15 days remained at the same colour stage with only a slight decrease in tissue firmness. Ripening was accelerated upon transfer to ambient temperature after 5, 10 or 15 days at 10°C. Fruit previously stored for 5 or 10 days at 10°C changed to full yellow and were comparable to the control fruit upon returning to ambient, while those kept for 15 days developed pale yellow skin colour. In some instances, chilling temperatures may suppress certain biochemical changes associated with ethylene metabolism.

Chilling injury can cause a major problem as the affected fruit are not saleable. Alleviation of chilling injury is important to reduce losses especially if the fruit are transported using refrigerated sea containers which take longer times to reach their destinations.

Hyperthermal injury

Hyperthermal injury occurs in papaya when exposed to heat. This can be due to vapour heat treatment, hot water treatment, or high ambient temperatures.

Vapour heat treatment (VHT) of papaya involves the uniform heating of fruit with water-saturated air at an indicated temperature and duration for disinfestation of fruitflies. This heat treatment is applied to fresh fruit intended for export. Three types of fruit injury observed from vapour heat treated fruit at the table ripe stage were softening of the mesocarp, formation of starchy tissues and pulp separation.

Softening of the mescarp can appear in two forms: (i) as a water-soaked and soft inner mesocarp, with a normal outer measocarp or (ii) as delineated tissues where colour, firmness and/or translucency of the outer mescarp is different from the inner mesocarp. Starchy tissue is characterized by the presence of white lesion in the outer and middle portions of the mesocarp. In slight cases, this disorder can appear as small, pin-head sized or granular-like white lesions, while in severe cases, it can aggregate to form white streaks along the mesocarp.

In pulp separation, the outer mesocarp separates lengthwise from the peel in one line, forming a hollow space which can extend to the stem-end or blossom-end of the fruit. Although vapour heat treated fruit is comparable with untreated fruit with respect to acceptable overall flavour and absence of off-flavour, the general acceptability rating for treated fruit is still lower due to inferior texture and firmness.

Susceptibility to hyperthermal injuries generally increases with increasing ripeness of the fruit during treatment: Exposure of fruit to hot water treatment and high ambient temperatures (40°C) also caused hyperthermal injury. This is characterized by symtoms similar to chilling injury where the fruit developed skin discolouration and failed to ripen normally.

Post-harvest decay of papaya fruits

Besides above physiological disorders, post harvest decay of fruits is commonly found in all parts of papaya growing belt. This refers to common fruit decay due to attack of sevral fungi. This can be controlled by Benlate (1000 ppm) treatment. Effective control of papaya storage rot can also be done by Thiabendazole and Benomyl (Bolkn *et al* 1976). The Benzimiduzole group of fungicides are relatively safe for use as post harvest treatment of fruits and are being used on commercial scale in many countries.

19. Constraints in papaya production

PAPAYA is a remunerative but problematic crop and very much sensitive to agro-ecological and other factors (Ram 1984f). This may be grouped in 4 broad category viz. (i) Ecological, (ii) Technological, (iii) Physical and (iv) Social factors.

The successive factors will high light about this in detail which has resulted in a great loss to the farmers and a set back to papaya fruit industry in the country.

ECOLOGICAL

Temperature

Although papaya is a tropical fruit, it is also cultivated under sub-tropical

Fig.35. Papaya plant damaged by frost.

conditions. However it thrives best in areas where the maximum temperature does not exceed 40°C or the minimum drop 10°C. The plants are very susceptible to cold and frost right from germination till maturity as these not only affect the plant but also disfigure the fruits due to oozing of latex. Also on ripening frosted fruit do not have a normal taste and flavour and thus unmarketable (Fig 39).

In the plains of North India the papaya is adversely affected during summer by hot winds thus frequent irrigation is necessary during this period. Prolong droughts associated with high temperature adversely affect fruit production by inducing abortion of floral and fruit structure leading to sterile phases or fruiting skip along the stem. Fruits grown in M.P., Rajasthan, Western U.P., Punjab, Haryana, Delhi, H.P. and Jammu are affected by low or high temperature or both.

Waterlogging

Waterlogging is very harmful and imperfect drainage encourage root and stem rot diseases which take a heavy loss of papaya plants. Both these diseases are caused by a fungus and show almost identical symptoms. The roots and the collar of stem start rotting and the foliage of the effected trees then wilt and turn yellow, those symptoms being followed by premature leaf fall. This results finally in complete defoliation and death of plants.

Fig.36. Papaya orchard damaged by storm.

This type of situation comes in clayee soil, low land and heavy rainfall areas like West Bengal, Assam, and Kerala. No practical control measures have yet been found to save the affected trees, excepting to take preventive measures to plant papaya on higher or sloppy land.

Strong wind and strom

Papaya plants are very fragile with hollow stem which can not withstand strong winds and storm. Most part of coastal part of India are storm proned areas where papaya cultivation is not possible specially in Andhra Pradesh, Tamil Nadu, Kerala Maharashtra, Gujarat and Orissa which are frequently facing typhoon (Fig 41).

Flood. Unlike orchards of other fruit crops papaya orchards are wiped out within few days floods of in different parts of country every year.

TECHNOLOGY

Sex of plant

The sex forms of papaya present a special problem both to the breeder and the grower. As is well known, there are three basic sex forms in papaya: (1) Male, (2) Female and (3) Hermaphrodite. Of these only the female is stable type, the flowers of male and hermaphrodite vary in sex expression in different environmental conditions. As the result of a study, Story (1958) reported that there are 32 heritable sex forms in papaya. However, these forms are all quite variable and this classification is of little value from the growers point of view. The gynodiocieious varieties claimed to be cent per cent productive plant, a wide variation in hermaphrodite population is observed giving a few fruit to a number of unmarketable fruits. Under such circumstances farmers has to shift to dioecious varieties giving 50% productive plants.

It is generally agreed that as a population of 5–10% male plants in a dioecious population, a grower should aim at securing a maximum number of female plants. This can be accomplished in two ways. Either he should be able to identify their sex in the nursery stage or he should plant at least 3 seedlings at each point when transplanting papaya in the field. The latter technique involves thinning out the male plants at the first expressing of sex, a rather cumbersome method. It would simplify matters if the sex of plant could be ascertained in the nursery, but attempts to do this have not as yet provided a practical solution. The task is of course, rendered more difficult by the fact that no sex-linked characters have so far been observed in papaya.

Damping off

Besides stem and root rot disease "damping off" of papaya seedlings in the nursery is yet another problem and results in a loss of 80–90% of the seedlings. It has been observed that seedlings are more susceptible to this malady if they are raised in pots or pans. It is therefore advisable to raise seedlings in narrow raised seedbeds preparing these from a mixture of well rotted leaf mould, sand and soil. Where summer seasons are severe, nursery beds should be provided with a limited amount of shade. Seedlings also need protection from direct rains as toretial rain falling directly on young plants and affect them adversely.

Viruses

Recently papaya mosaic virus disease has been reported from a number of place although a number of viruses are found to attack this crop. Virus disease is a major limiting factor in the cultivation of papaya in North, East, West and Central India specially Assam, Bihar, West Bengal, Orissa, Madhya Pradesh, Uttar Pradesh, Maharashtra, Haryana and Gujarat. The affected plants become stunted in growth, the leaves show signs of curling up and characteristic blister like patches develop on green parts. The leaf stalk is reduced in length showing long watery spots. The disease is transmitted by aphids and no method of control is available. As a result the plant ultimately dries out and if plant is alive, produce no fruit of economic importance.

Lack of distinct variety

Papaya essentially a dioecious plant and in consequence it is cross pollinated. Since it is propagated by seed, the progenies are very variable. In fact there is hardly any true variety of papaya under cultivation. The only commercial variety that appears to be stable is Solo and Solo group produced in Hawaii. In this case the difficulties created by sex variation have been overcome by breeders who have developed Solo a gynodioecious habit in this variety. Originally it was a polygamous and highly variable variety. Now every tree of this variety is a bearing tree and for seed production, pollination is restricted to the selfing or intercrossing of hermaphrodites. However these gynodioecious types are likely to be unstable in their sex expression where seasonal temperature difference are very marked. Ultimately, they may prove to be undesirable for commercial production. Thus Solo when grown under North Indian condition has failed to respond in the same way as it does in Hawaii, where the climatic conditions are milder.

Viability of seed

The viability of papaya seed is only for a year or so. Due to short viability of papaya seed, its shortage has been felt at all times. The papaya seed is neither recalcitrant nor orthodox in its viability and germinability. Several methods have been adopted to store the seed to maintain the viability but with a very little success. Some literature is available regarding its duration and actual percentage of germination after storage which does not show uniform trend.

Although papaya is still being commercially propagated by seed and consequently it also lead to variation, vegetative method of propagation seems to offer a means of avoiding the difficulty arising from dioecious nature in standardizing the quality and sufficient availability of planting materials on large scale. But asexual propagation by different methods have failed to fulfil the objective.

Shelf life of fruit

The shelf life of papaya is very short and the harvesting period is very long ranging from October to June. The perishable nature of fruit creates great problem in long distance transportation and marketing. The prolonged harvesting period involves much wastage of time and money. Along with the perishable nature, large size fruit also makes marketing a difficult task.

PHYSICAL

Non-availability of seed

Seed is a most potential factor determining successful cultivation of papaya. Presently the seeds are procured by most of the farmers either from nurseries of from local market which have the mixture of different local types. The mixed seeds is being supplied to grower under different names. Under the prevailing conditions the purity of seed is generally not reliable. Ironically there is no organization like State Seed Corporation or National Seed Agency in the country which produces and distributes genuine papaya seed to growers. Only a few Agricultural Universities and Research Centres in the country are dealing with papaya. No centre is in a position to meet the increasing demand of seed to the farmers in required quantity.

Unlike other crops papaya seed production is itself a tedious job. The seed can be produced either under controlled pollination or in isolation. The quantity of papaya seed produced under controlled pollination is also very limited. An area of one hectare land producing 50 tonnes of fruit gives around one quintal seed provided all fruits are converted into seed on the farm under isolated condition. This is only possible where ripe cut fruits have an assured market or it can be processed in a factory.

Marketing and socio economic factors

The papaya is an important fruit in India. Besides providing food to the people, the economic value of crop has potential to be exploited as an income generator. This can be accomplished by supporting and strategic marketing especially in countries where the fruit is in demand. There are fairly good markets for the fresh fruit in the Middle East, Japan and Hongkong. Imports of the fruit appear to be growing annually in these countries. With the introduction of exotic varieties like Solo, Sunrise Solo, Taiwan and Pink Flesh sweet etc. which have better quality and uniform grades the fruits are readily acceptable in many markets and this certainly can lead to expanded market. The important product from papaya is papain which is in a great demand in the international market particularly in the United Kingdom and USA. In India the potential of the papain industry has not been fully exploited. Papaya fruit processing and by-product industries are also lacking. Lack of good storage facilities, quality control, credit facilities and minimum support price which are essential to boost production and marketing has not been set on the expected line.

SOCIAL

Competition with traditional crop

The papaya is in a great competition with traditional fruit crops like banana, pineapple, grapes, guava and plantation crops. In spite of its nutritional and medicinal importance, the papaya is finding restricted place in the farming systems and is not being exploited commercially. The traditional fruit crops have established their place in farming system and developed fairly good liking, market and extension support, whereas papaya is confined to homeyards or near irrigation sources of farming communities. Hardly 2 to 5 plants are seen to these places, but it is an usual practice with most of the farmers. The common uses for which it is grown are raw fruit as vegetables and ripen fruit as medicine for setting right stomach disorder. The reasons for its exploitation for gainful employment are many. The major reasons for commercialization are lack of proper market, farmers perception of risk, complex crop, lack of technology, lack of extension support and misconception or prejudices against papaya amongst the society etc. The research and extension efforts are required to make this crop competitive and relatively advantageous for generating income and employment.

20. Seed production, storage and germination

MAJOR constraint in commercial papaya production in the country is the non-availability of pure seed of papaya after evolution of new varieties. Since so far our country is producing only 1% of its demand, about 60,000 hectares of land occupies mostly with the mixture and so-called varieties of papaya. Quality seed is important for successful production and establishing papaya based industry. Unlike other seed propagated crops, the seed production of papaya requires some technical know-how due to different sex types and being a highly cross-pollinated crop. In open pollination production of pure seed is not possible because of its wind and insect pollination nature and high isolation distance requirement (Prest 1955). Pure seed of papaya can be produced in artificially controlled condition or in isolation. The controlled pollination maintains maximum varietal purity and this is mostly adopted where diversified lines of papaya are grown. This method is cumbersome and requires skilled labour. On contrary to this seed production in isolation is easier but the extent of seed heterozygosity is higher. Although the controlled pollinated method maintains maximum varietal purity but seed produced by this method is limited with very high cost whereas seed produced in isolation is higher with low cost (Ram 1986b, 1988, 1990, Ram and Majumdar 1988, Ram and Roy 1993).

In an experiment the author found 391.5 kg seed in Pusa Dwarf followed by Pusa Giant 295.7 kg, Pusa Delicious 102.5 kg and Pusa Majesty 52.5 kg/ha under controlled pollination (Ram and Majumder, 1990). Thus, seed yield in diocious lines was higher than in the gynodioecious lines. The highest quantity of seed was produced by Pusa Dwarf (391.7 kg/ha) followed by Pusa Giant (295.7 kg/ha), both dioecious lines. On the other hand, the lowest seed yield was from Pusa Majesty (52.5 kg/ha), followed by Pusa Delicious (102.5 kg/ha), both gynodiecious lines. As the dioedious lines produced more seed, the cost of seed production per kg was lower. Seed production was most economical in Pusa Dwarf (Rs 61.10/kg) followed by Pusa Giant (Rs 75.60/kg). The cost of seed production was the highest in Pusa Majesty (Rs 416.60/kg) followed by Pusa Delicious (Rs 213.40/kg) (Table 25).

The higher quantity of seed produced in dioecious lines can be attributed to higher fruit bearing population in a hectare. There were 2188 female plants in each of the dioecious lines populations, as against only 1250 female plants in gynodioecious lines. The seed yield per plant was also relatively higher in dioecious lines than in the gynodioecious lines. The dioecious lines produced more seed per plant i.e. Pusa Dwarf (174 g) and Pusa Giant (131.4 g) than the gynodioecious lines viz. Pusa Delicious (82 g) and Pusa Majesty (42 g). Similarly, the number and weight of seed produced per fruit were also higher in dioecious lines. Pusa Giant produced 472 seeds/fruit weighing 7.3 g followed by Pusa Dwarf which produced 404 seeds weighing 5.8 g. The seed production by gynodioecious lines was low in terms of number and weight per fruit.

Table 25. Seed yield and cost of production in gynodioecious and Dioecious lines of Papaya under hand pollination.

Line	Cross	No. of fruits crossed per plant	No. of female parent plants per ha	No. of crossed fruits per ha	No. of seeds per fruit	Weight of seed per fruit (g)	1000 seed weight (g)	Seed yield per plant (g)	Seed yield (kg/ha)	Total cost of seed production (Rs/ha)	Cost of seed production/kg (Rs)
Pusa Delicious (1–15)	FXH	20	1250	25000	233	4.1	17.6	82.0	102.5	21875.00	213.40
Pusa Majesty (22–3)	FXH	20	1250	25000	194	2.1	10.8	42.0	52.5	21875.00	416.60
Pusa Giant (1–45V)	FXM	18	2188	39384	472	7.3	15.5	131.4	295.7	22363.00	75.60
Pusa Dwarf	FXM	30	2188	65640	404	5.8	14.3	174.0	391.7	23938.00	61.10

F, Female; M, Male; H, Hermaphrodite.

The higher seed production by a single fruit in dioecious lines is attributed to good pollen producing capacity of numerous staminate flowers. Where as the pollen producing capacity of hermaphrodite flowers was characteristically lesser in gynodioecious lines.

In another experiment while producing seed of Pusa Dwarf under controlled pollination and isolation the author (Ram, 1995) found that the net seed yield in isolation condition was relatively high (579.18 kg/ha) than the seed produced under controlled condition (361.78 kg/ha) (Table 26). Since seed yield under isolation condition was higher with no extra expenditure (Table 26), the cost of seed production per kg was low (RS 82.65/kg) as compared to hand pollinated seeds (Rs 190/kg).

On an average only 25 fruits out of total 31 fruits per plant were crossed under controlled condition whereas 32 fruits out of 34 fruits produced seed in open pollinated (under isolation) situation. Each fruit under controlled pollinated condition had 469 seeds weighing 7.8 g whereas under isolation condition it was

547 seeds weighing 9.7 g. Number of fruits and seeded fruits per plant showed significant differences under the two conditions. However, in the remaining fruits, the number of seeds and their weight per fruit were at par under the two conditions. Since papaya is problematic and a delicate crop, the loss of seed is bound to happen even after the crop is managed well due to damage of plants by strong winds and heavy rains, rejecting 'off' type plants and fruit spoilage by birds etc. Hence a margin of 15% from the total estimated seeds was deducted to get estimates of net seed produced per hectare. Higher production of papaya fruits and seed in isolation may be due to high initial stratified fertility present in the soil as this crop was grown for the first time in that particular field. Higher number of seed producing fruits were mainly due to open pollination from any male plant which might have produced pollen earlier in the grove whereas higher number and weight per fruit in isolation were due to larger size of fruit.

Table 26. Details of seed production for different methods.

Character	Hand pollination	Isolation	Calculated 't' values (5%)
Fruits/plant	31	34	2.348
Seed producing fruits/plant	25	32	3.42
Seeds/fruit: No.	469	547	NS
Weight (g)	7.8	9.7	NS
Seed/plant: No.	11 725	17 504	
Weight (g)	194.6	3 11.5	
Female plants/ha	2 187	2 187	
Seed producing fruits/ha	54 675	69 984	
Total seed produced/ha: No.	25 64 0000	3 82 80 000	
Weight (kg)	425.62	681.38	
Loss of seeds (15%) during entire period (kg/ha)	63.84	102.2	
Net seed produced/ha (kg)	361.78	579.18	
Total cost of seed production (Rs)	68768.00	47862.00	
Production cost of seed/kg (Rs)	190.00	82.65	
1 000 seed weight (g)	16.6	17.8	N.S.

The low seed production under controlled condition in comparison to open pollination under isolation was due to lower yield of fruit produced per plant and selective attempt in crossing the flowers. 1000-seed weight under isolation condition was marginally higher but statistically at par with those produced under controlled condition.

The number of seeds obtained from papaya fruit vary greatly according to the season in which the fruit sets and develop. Ram and Ray (1992) made a detailed study in Pusa Dwarf and Pusa delicious transplanted in the month of October. They found that first fruit setting started after eight months of trans-

Table 27. Brief items of expenditure in cultivation of papaya for seed production per hectares.

Items of operations	Expenditure (Rs)
Land preparations	250.00
Layout of field	75.00
Cost of seed	450.00
Cost of compost	5000.00
Cost of bonemeal and neem cake	10,000.00
Cost of chemical fertilizers	14000.00
Cost of labour	
Digging of pits	1562.00
Cost of application of basal manures	500.00
Cost of filling pits	600.00
Hedge sowing, pruning, and maintenance	1000.00
Nursery preparation, sowing and maintenance	800.00
Final land preparation and layout	175.00
Transplanting	500.00
Hoeing and weeding	2500.00
Top dressing of fertilizers	500.00
Preparation of irrigation channel and basins	200.00
Cost of irrigation	750.00
Watching of orchard	3150.00
Fruit harvesting and seed collection	4500.00
Seed drying, cleaning and packing	600.00
Plant protection measures	500.00
Miscellaneous	250.00
Total	47862.00
Additional cost of controlled pollination	
Cost of crossing materials	4200.00
Labour cost for hand pollination	16706.00
Total (Grand total) Rs 47862 + 20.906	68768.00

planting and continued up to 13th month in the first fruiting cycle. During severe winter months (December and January) flowering ceased completely and thus there was no fruit setting. The second flowering and fruiting cycle began in February and continued till next November i.e. up to 25th month of transplanting. Fruit that could set during rainy season (July-August) required 3 months to mature while those setting in September-October or November required longer time (4 to 5 months). Fruits that set in August, September or October were able to attain better size (growth) as compared to those set in earlier or later months. The largest size fruits were obtained from August flowering/setting in Pusa Delicious and from September setting in Pusa Dwarf in the first fruiting cycle (Ram and Ray 1992a)

The highest number of seeds per fruit was obtained in both the varieties from September setting in the first cycle. However, seeds collected from fruits set in

July-August or September showed little variation with regards to their size and germination capability. Here it is noteworthy that though the quality of seeds obtained from July set fruits was quite normal in the first cycle, the total number of seeds per fruit was quite less. Thus in the first fruiting cycle of Pusa Dwarf only August and September set fruits were able to produce better quality seeds in higher quantity. The other months produced significantly lower number of seeds. Similarly, in case of gynodioecious 'Pusa Delicious' papaya, September set fruits contained appreciable larger number of seeds than those set in other month. Higher seed yield from August/September set fruits was attributed to most salubrious environment (temperature, relative humidity and soil moisture) for fruit growth and seed development. Nakasone (1986) has also reported that temperature and soil moisture are the most important climatic factors affecting sex expression and fruit production in papaya.

Since pollination in papaya is carried out by insect, the natural crossing of the flowers in an expected consequence. Maximum insect activity is usually seen during rainy season when the plants produce abundant flowers. This provides enough scope to think that if artificial crossing by hand is done, there would be better chance of getting higher seeds during these months.

In the second fruiting cycle, the trend of seed setting in the developing fruit was little different to that of the first cycle. Fruits set in February and March were undersized and devoid of any seeds. April or May set fruits had few seeds but fruits that emerged after July possessed sufficiently large number of seeds. August and September were adjudged to be the best period for fruit and seed development in papaya as the fruits initiated during this period attained better size and contained more seeds.

Although pollination may stimulate the swelling of fruits in papaya as happened in case of February and March set fruits, the normal fruit development appeared to be dependent upon the presence of sufficient number of seeds in the fruit. Strong relationship existed between the final size of the fruit and the number of fully developed seeds it contained. The stimulatory effect of the developing seeds upon the growth of the pericarp tissue appears to be due atleast partly to the auxin which they produce.

The number of seeds per fruit was distinctly more in Pusa Dwarf but the size of seeds indicated by 1000 seed weight was markedly better in Pusa Delicious. Such variations between the cultivars have also been observed earlier. In a separate study, the author has also observed that fruits set during rainy season contained as high as 1026 ovules/fruits in Pusa Dwarf and 960 ovules/fruits in Pusa Delicious. Studies over a variety of entomophilous plants suggest that the number of pollinator visits and the number of pollen grains deposited per receptive stigma could substantially affect seed set. This explains why there is fluctuation in seed number per fruit in papaya due to change in year/or season. In other words it is the extent of pollen deposition that decides the seed count in papaya. On the basis of above results it can be summarized that for obtaining maximum seed yield, controlled pollination in papaya should be done preferably in August-September. Pollinations during these two months lead to profuse seed setting and produce higher seed yields. Hence seed multiplication of papaya on commercial scale should be taken up in isolation to meet the increasing demand. However nucleus and breeder seed should be produced under strict controlled pollinated condition in August-September to get higher quantity of seed and for maintaining the genetic purity of the variety.

Seed production method

Storey (1953) reported that the seed production was restricted to selfing or intercrossing of papaya. Purohit (1992) reported that population of hermaphrodite and female plants in 2:1 ratio resulting from progeny of selfed or intercrossed hermaphrodite flowers gave estimated seed yield of 285.2 kg/ha. The 1157 hermaphrodite and 579 female plants contributed 270.7 kg (94.9%) and 14.5 kg (5.1%) seed respectively to total seed yield. Thus in both cases female plants contributed less than 10% to total seed yield thereby establishing importance of hermaphrodite plants in seed production in gynodioecious papaya variety.

Now realising the national importance of seed production of papaya, a systematic seed production programme needs to be initiated. Depending upon the sex and parental combinations for the production of desired type of seed, papaya varieties fall under two broad groups:

Dioecious varieties: Varieties which produce male and female plants are called dioecious. The proportion of male and female plants is generally 50:50 with male population on higher side, which is a genetical character. The prevalent varieties which fall under this group in India are Pusa Giant, Pusa Dwarf, Pusa Nanha, Co1, Co2, Washington and Barwani etc.

Gynodioecious varieties: The gynodioecious varieties are comprised of female and hermaphrodite plants and the latter are also productive. Thus, all the plants of such varieties are productive and popularly known as variety without male plant. The varieties which fall under this group are Pusa Delicious Pusa Majesty, Co3, Co7, Coorg Honey and Solo (Hawaii). etc.

Technique of seed production

The seed in dioecious varieties are produced by sibmating i.e. pollinating the female flowers with male flowers of the same varieties. The seed in gynodioecious varieties are produced by crossing the pistillate flower of female plant by the pollen of hermaphrodite flower or selfing and intercrossing the hermaphrodite plants. Since variation in sex in hermaphrodite plant occurs under different environmental conditions, selection of regular and prolific bearing hermaphrodite plants for seed production in the each generation is essential in gynodioecious

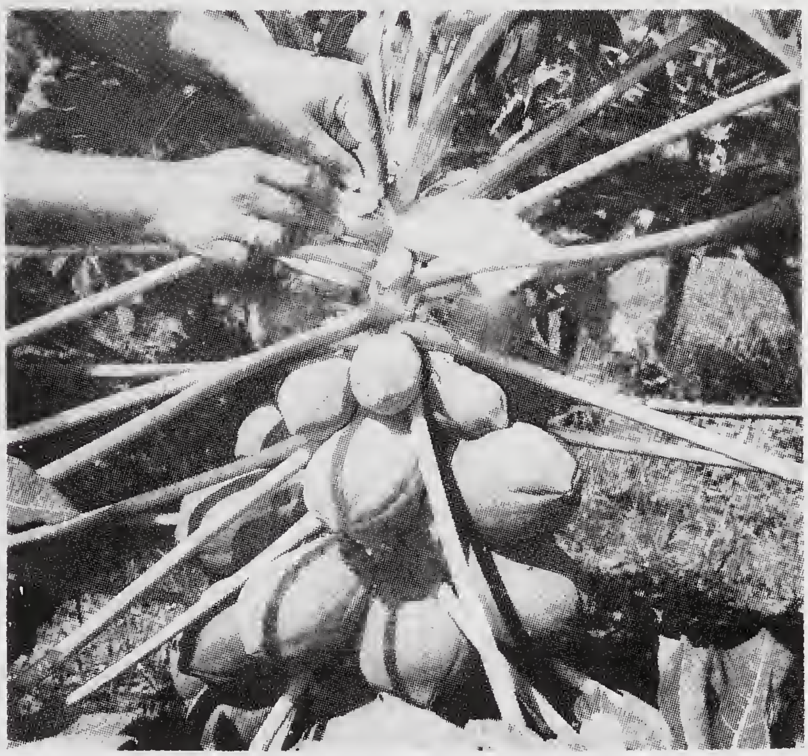


Fig.37. Seed production under controlled pollination.

varieties. The proportion of female and hermaphrodite plants will depend upon the technique used. If the female plant is crossed with the pollen of hermaphrodite plant, population of female and hermaphrodite will be in equal proportion. If the hermaphrodite plants is selfed or intercrossed, the proportion of female and hermaphrodite in the population will be 33.3:66.7. Normally in India female plant is preferred because of yield. Hence the seed is produced by crossing the female flower with the pollen of a hermaphrodite plant in gynodioecious variety. Contrary to this hermaphrodite plants are preferred in Hawaii in the variety Solo. The hermaphrodite plants of Solo produce fruits of pyriform shape which are preferred by the consumers and are also more suitable for transport. Therefore, seed in Solo is produced either by selfing or intercrossing of hermaphrodite plants. The farmers in Hawaii transplant three plants of Solo at one pit and finally thin out to one preferring hermaphrodite and remove extra female/hermaphrodite plants.

The seed production in papaya with 100% genetic purity is difficult because of dioecious nature of the plant which enforces essentially the cross-pollination. Therefore, the seed should be produced strictly under controlled conditions or in an isolated area.

Seed production under controlled condition

The breeders seeds are generally produced under controlled conditions. Under this method the stigma of female flower should be brushed with the pollen of male flower of the same variety in dioecious varieties. While crossing female flowers, care should be taken that stigma is not damaged. Only those flowers which are ready to open in each sex should be selected. This avoids advance covering of flowers against contamination with foreign pollen. Similarly for producing seed in gynodioecious varieties, the female flower ready to open should be crossed with the pollen of hermaphrodite of the specific variety in the same way. Seed production by selfing hermaphrodite is much easier because the selected flowers are only covered with glassine paper. After crossing and selfing it should be properly tagged for identification. (Fig 41).

Before proceeding with the seed production of a gynodioecious variety, knowledge of different types of flowers produced by a hermaphrodite plant is essential. Normally a hermaphrodite plant produces five different types of flowers simultaneously. These are reduced elongata, elongata, carpelloid, elongata pentandria and carpelloid pentandria. Except for the reduced elongata the other four types of flowers are bisexual i.e. male (stamen) and female (gynoecioum) organs are present in the same flowers. The reduced elongata is unisexual (male) and produces only pollen. The shape of the fruit, produced on hermaphrodite plant depends upon the type of flowers produced. The elongata flower produces a cylindrical or cucumber shape while carpelloid elongata produces deshaped or cat-faced fruits. The seed content in these fruits is comparatively low. The pentandria and carpelloid pentandria produce fruits of round oblong to round oval shape which resemble the fruits of female plant and these fruits produce plenty of seed. While crossing the flowers of female plants, pollen should be collected from the reduced elongata flower to avoid damage or injury to bisexual flower. While selfing hermaphrodite, excepting reduced elongata all the other types of bisexual flowers should be covered with glassine papers and tagged for identification.

Seed production in isolation

Under controlled conditions the seed is produced with 100% genetic purity but it is a cumbersome job and may not be feasible with most of the growers. Moreover, it requires manual labour with some technical knowledge and experience. Therefore, seed can also be produced in isolation which does not require any elaborate process in crossing and selfing. The foundations and certified seeds are generally produced by this method. The isolation distance may be kept 400 to 1000 metres. This distance depends upon the locality of pollinators. For ensuring a definite demarcation line of isolation in a locality, the simple method is transplanting of Washington or Homestead variety as a gene marker. The colour of stem and petiole in the this variety is purple which is a dominant character. If the progeny of seed do not produce any purple coloured plant, it means the isolation distance is correct. This distance may further be increased if there are some purplish coloured plants found in the progeny.

If a suitable isolated area is not available, seed can be produced in the middle of an orchard of any tall growing fruit crop like mango, litchi, sapota, *Ber* or cashewnut. These fruit trees act as a physical barrier against cross-pollination with the other varieties of papaya in a locality (Ram 1986).

The orchard in isolation generally produces 95 to 99% pure seed depending upon the local conditions. The entire fruit of the orchard can be used for seed extraction. This can be done where there is market of cut fruits or the pulp may be processed in a processing factory.

Seed crop production technology

The breeder's seed of five improved varieties can be obtained in a limited quantity from the IARI, Regional Station, Pusa Bihar or from NDAUT Kumarganj, Faizabad, U.P., and Coimbatore, and IIHR varieties can be obtained from the TNAU, Coimbatore and Indian Institute of Horticultural Research Hessargatta, Bangalore from March to June every year. The planting season may start from March to October in different climatic conditions. The following cultural schedule should be adopted for seed production in Eastern India.

Seedlings should be raised either in nursery bed or polythene bags measuring 15 cm × 20 cm filled with a mixture of half soil and half compost. While raising in polythene bags, two three seeds in each bag should be sown one cm deep. For planting one hectare land, 250–300 grams of seed is sufficient. The seed should be treated with 1% Monosan dust or 0.2% Emisan-6 solution as a prevention against "damping off" disease. A rich and well drained sandy loam land should be selected for planting. Pits of the size 60 cm × 60 cm × 60 cm should be dug in the field at a distance of 2 metres each way. The pits should be filled with the following quantity of manures/pit.

1.	Cowdung manure or compost	25 kg
2.	Neem cake	2 kg
3.	Rallismeal or Bonemeal	2 kg

Three seedlings of dioecious varieties should be planted in each pit spaced 15 cm part in a triangular fashion while single seedling planting should be done with the gynodioecious varieties. Some extra plants should be kept reserved in the nursery or in the pots for gap fillings later on.

Provision of strong wind-break must be managed around the papaya field. As soon as male plants appear in dioecious varieties, extra male plants should be uprooted. At least 10–12% male plants well distributed in the field for good pollination should be retained. Rouging of 'off' type plants should be done at this stage at the latest.

Top dressing should be done with nitrogen 200–250 g, phosphorus 200–250 g and potash 250–500 g. These chemical fertilizers should be split in two equal doses. First dose should be applied in July and the second in September. Pusa Giant is the most heavy feeder variety. Hence maximum limits for chemical fertilizers should be applied in this variety. Only one protective irrigation is required in the first year. When the plants are bearing fruits, irrigation once or twice in a month from October to May in the second year is beneficial.

Viruses like mosaic, distortion ring spot and mycoplasma (leaf curl) are observed during the rainy season when the vectors are most active. There is no practical control measure for these viruses. However, the disease can be avoided by manipulating the season of planting in eastern region of India. Seeds should be sown in the month of August-September and planting done in October-November. The juvenile plants become hardy in the ensuing winter and summer season. Profuse flowering and heavy bearing takes place in the coming rainy season, thus, the crop escapes the viruses during the first rainy season and the fruiting in papaya is maximum in the next season.

Sometimes collar-rot is noticed. It may be controlled with repeated sprays of Bordeaux mixture (5:5:50). In areas susceptible to root-rot, application of 1 kg lime and 100 gram of copper sulphate in the pits is an effective preventive measure against this disease.

Seed extraction and storage

The fruits should be harvested when they start ripening. They should be cut longitudinally and seeds should be carefully collected in a container with the help of spoon or knife. The fresh seeds should be put in water for 2–4 hours and sarcotesta should be removed by rubbing with ash and finally washed in running water. Then they should be dried in shade till the moisture content comes down to 8–9%. After drying, the seeds should be cleaned properly by removing the immature seed and other foreign materials.

The standard method of storing papaya seed is keeping it in a refrigerator at 5°C sealed in moisture proof packages. But this facility may not be available everywhere. Therefore, the seed should be kept in air tight bottles or packed in polythene bags and sealed properly. Then they should be stored in cool and dry place under room temperature.

Yield of seed

The yield of papaya seed invariably depends upon the cultural practices, sex condition and pollination. Under normal conditions the seed yields are as follows:

Gynodioecious varieties	60 to 75 kg/ha
Dioecious varieties	300 to 400 kg/ha

The seed yield is much low in gynodioecious varieties because of poor pollen production in hermaprodite plants. Contrary to this the male plants produce plenty of pollen thereby higher quantity of seed is produced in dioecious varieties. The cost of seed production is very high in gynodioecious varieties. In spite of the high cost, the farmers prefer the seed of gynodioecious varieties because of saving in raising of crops.

Among the different attributes of seed quality, its germinability is important in papaya. Due to short viability of papaya seed, its shortage has been felt at all times. Some literature is available regarding its duration and actual percentage of germination after storage which does not show uniform trend. The papaya seed is neither recalcitrant nor orthodox in its viability and germinability. The author has observed that the fresh seed has highest germination and it gradually reduces as the time passes. A norm has been fixed for germination of papaya seed i.e. 80% germination for dioecious lines and 70% germination for gynodioecious lines (Ram 1986). The work conducted by Arumugam (1974) showed that the viability of seed of two improved strain of papaya viz., Co_1 and Co_2 considerably reduced in seed when sarcotesta was intact and the effect was more pronounced in the dry seeds than the fresh one. When the fresh and dried seeds were treated with thio-urea at 100 to 200 ppm recorded a high percentage of germination (94 to 92 and 87 to 81% respectively) than those treated with G.A. (86 to 77%). Papaya seed as such stored in paper bags at room temperature showed reduction in germination after a period of 9 months suggesting the early loss of viability. Regarding the period taken for germination of seed, he found longer time to commenced germination stored under various conditions, whereas early germination occurred in seed before storage.

Veerugavathathan *et al.* (1980) conducted storage studies to restore the vigour and improve the germination in the less viable seeds (27.4%) of papaya Cv. Co_2 stored for 14 months with G.A. He observed high vigour index of seedlings from the treated seeds (100 to 200 ppm) and high germination. Vishwakarma (1991) in his study reported 92% germination with U.V. irradiation (2 minutes) in contrast to 39.33 germination under ambient condition after 8–12 months. Seed viability and vigour could be preserved for up to 4 years in the presence of silica gel (Doijode, 1996). This reduction in seed viability was associated with greater leaching of electrolytes and metabolites specially soluble sugars and free amino acids from the seed. Initial seed germination was 85% and this declined to 59% after 4 years storage with silica gel.

Leonel *et al.* (1998) studied the effect of alternating temperature and treatment with GA_3 on germination of papaya seeds. Papaya cv. Sunrise Solo seeds were soaked in 0, 50, 100, 150 and 200 mg gibberellic acid (GA_3) for 24 h, then germinated at a constant 25°C or alternating day/night temperature of 20–30°C. Germination percentage was the greatest with 100 mg GA_3 and alternating temperature gave better germination than constant temperature.

Ram and Ray (1994) studied the influence of storage condition on germination of papaya seed. The freshly harvested seeds dried up to 8 to 9% moisture content and removed their sarocotesta were stored for 20 months in (1) cloth bag (b) 400 gauge polythene bag at room temperature and (c) 400 gauge polythene bag placed in a refrigerator (5–7°C). Germination of freshly dried seeds of different papaya varieties ranged between 95 to 98%. There was little reduction in germinability after 8 months storage in all the varieties. The seeds stored for 20 months exhibited sharp reduction in germination percentage ranging from 0 to 51% under different storage conditions. Seeds kept in polythene bags placed in refrigerator showed higher germinability (35 to 51%) while in cloth at room temperature showed the lowest germination (0 to 5.4%).

21. Use of plant growth regulators in papaya

PLANT growth regulators have brought revolutionary change in all aspects of fruit production. The effect of growth regulators in papaya on seed germination, seedling vigour, flower and fruit drop, sex expression, fruit and seed set, fruit yield, quality of fruit and papain have been studied by several workers.

Chacko and Singh (1967) reported speedy germination and longer length of seedlings and higher fresh weight with 1000 ppm gibberelic acid. Palamisamy *et al.* (1992) conducted an experiment on papaya cv. Co4 to find out the effect of different chemicals and growth regulators on the germination of seeds. Seeds exhibit dormancy for a initial period of 35 days after harvest. Seeds collected from fully ripened fruits were dried for 3 days under shade temperature and treated with chemical and growth regulators viz. water, GA 100 ppm, and 500 ppm, KNO_3 0.2% thiourea 200 ppm, citric acid 0.5% and a untreated control. Their study revealed that pre-soaking of freshly harvested seeds with GA 100 ppm was found to be effective in breaking the seed dormancy recording 98% germination. The untreated control recorded very low germination of 25%. Similarly Kadam *et al.* (1992) studied seed soaking for 12 hours in various chemicals like GA (50, 100 and 150 ppm) KMO_3 (6, 120 and 180 ppm), sodium thiosulphate (40, 80 and 120 ppm) and thiourea (8, 16 and 24 ppm). Sodium thiosulphate (80 ppm) recorded the highest seed germination (96%) followed by 120 ppm KMO_3 (95%), thiourea 16 ppm (94.5%) and GA 100 ppm (93.5%) against 67% under control.

Shanmugvelu *et al.* (1984) conducted an experiment to find out the influence of GA (100, 200, 300, 400, 500 ppm, water and control) on germination of papaya seed var. Co1 and Co2 with sarcotesta in fresh and dried seeds. They found that among the various treatment seeds treated at 100 and 200 ppm of GA recorded the highest percentage of germination (76–94%). High percentage of germination in fresh seeds of both the strains was recorded at 100, 200 or 500 ppm of the GA than control.

The early flowering and fruiting in papaya has been reported to be induced by application of Benzothiazole 2-Oxy-acetate (B-2-OA), TIBA, NAA and IAA. Of these, Benzothiazole-2 oxy-acetate was found to be superior than others (Dedolph, 1962).

According to Alagimanavalan (1971) Alar at 500 ppm produced the maximum number of flowers and fruit set. He further reported that sprays with GA_3 at 50 ppm, Alar at 250 ppm and phosphon D at 250 ppm increased the femaleness over control in Co1 papaya. Similar increase in femaleness was reported by Jindal and Singh (1976) when papaya seedlings were treated with TIBA at 100 ppm. Moreover, TIBA at 25 ppm induced flowering at lower nodes, but such an effect was not noticed with higher concentration.

Padmanabhan (1970) studied the effect of photoperiodism, vernalization and certain growth regulators on the sex differentiation, growth behaviour and yield in Co_1 papya. The treatments consisted of 8–16 hours cycle and 16–8 hours cycle; two vernalization treatments; exposure of seeds to 0°C and seedlings to 10°C and treatments with NAA 100 and 200 ppm, B-9500 and 1000 ppm, GA 50 and 100 ppm and MH 250 and 500 ppm. The results revealed that (1) the percentage of germination in vernalized and untreated seeds was more or less the same (87 and 89% respectively), (2) short day photoperiodic treatment 8–16 cycle and vernalization of seedlings at 10°C resulted in 62 and 22% mortality respectively, (3) Foliar application of B-9 and MH was found to retard the height of plant and sprays repeated at periodical intervals of 40 days gave effective control of the height. GA significantly increased the height of plant over the control; NAA did not show any response, (4) Long day photoperiod (16–8 hours cycle) and GA 50 ppm were found to increase femaleness to 60% and 50% respectively as against 40% in the control, (5) All the treatments accelerated flowering and produced fruits at a lower height and lower node than control, (6) All treatments increased fruit set, B-9 significantly increased fruit set over control by 62.5% followed by GA (50%) and photoperiodic treatment by 35.4%, (7) Longer photoperiod and GA 50 ppm tended to increase femaleness.

Selvaraj (1972) evaluated the effect of GA, TIBA, CCC and ethrel on Co1 papaya in respect of morphological characters, sex, flowering, fruiting, yield, quality and papain production. The results revealed that (1) the total yield in terms of weight was higher to an extent of 16% with GA at 100 ppm, followed by TIBA at 50 ppm with an increase of 6% over control, (2) The length, diameter and girth of fruits were increased by GA markedly at 100 ppm and reduced by TIBA and CCC at 100 and 3000 ppm respectively, (3) Seed content was reduced to an extent of 52% over control by TIBA at 100 ppm, followed by at 50 ppm to an extent of 34.41% and GA at 100 ppm (17.37%), (4) The quality of fruits was improved by GA resulting in an increase in TSS to a level of 14% as against 10% in control, (5) The proteolytic activity of papain was increased by GA (100 ppm) to an extent of 17 units/100 mg against 14.5 units in control, whereas CCC at 3000 ppm recorded 12 units.

Bhattacharya and Madhava Rao (1982) studied the effect of growth regulators on the induction of early flowering in Co2 papaya. The results indicated that the differences in the time of flowering were highly significant. CCC in general, advanced flowering by about 9 days followed by TIBA (4 days), while ethrel had delayed it by a day when compared to control. The differences in the day of flowering following the application of each regulant at varying concentrations had not assured statistical significance. This is because with ethrel, flowering has been advanced by 5 days in 100 ppm treatment and delayed by about 8 days in 300 ppm treatment. They also reported that the fruit-set was increased by 200 ppm of TIBA. Ethrel was found to adversely affect the fruit-set.

Shanmugavelu *et al.* (1984) studied the influence of growth regulators on Coorg Honey Dew papaya, spraying TIBA 50 ppm, boron 2 ppm and GA 200 ppm just before flowering. The sex of the plant was unaffected, whereas it affected the fruit characters especially the size, shape, quality and seed content.

Sujatha (1986) conducted field experiments to study the influence of GA at concentrations of 5, 10 and 15 ppm and urea at 1, 2 and 3% as foliar sprays on certain biometric and biochemical characters, which contribute to the biosynthesis of papain on Co2, Co5 and Co6 papaya varieties at the growth phase of 60, 90 and 120 days fruit set. The results revealed that the biometric characters such as fruit weight, length, girth, volume, cavity size, pulp thickness and seed weight increased as the stages of maturity advanced, whereas biochemical parameters viz., chlorophyll and total titrable acidity decreased towards fruit maturity. The protein, pectin and proteolytic activity on the fruit showed a sigmoid pattern, wherein the increase was evident up to 90 days after fruit-set. Application of GA and urea at higher levels appreciably increased the fruit weight, length, girth, carotenoids and protein contents in all the three varieties. The pectin content decreased with the application of GA.

The biometric observations such as weight, length, girth, pulp thickness and the biochemical parameters like protein, pectin, proteolytic activity and nitrate reductase activity have positively influenced the papain production. But the cavity size beyond 90 days, seed weight, carotenoids, TSS, total sugars and ascorbic acid of the fruit pulp were negatively associated with the production of papain.

The large number of unsightly seeds attached with mucilagenous tissue is sometimes considered objectionable. There is a large hollow central cavity which occupies a large proportion of the fruits. Research work with plant growth regulators showed that it is possible to reduce both these undesirable features by treating the flowers of papaya with gibberellic acid. GA at 200 ppm applied to Coorg Honey Dew flowers before anthesis caused reduction in seed content considerably. GA treated fruits contained only 10 to 87 seeds as against 550–880 seeds in the control fruits. The central hollow cavity was also filled up with flesh in the GA treatment as much as 3.0 to 4.5 cm thick compared to 2.7 cm in the control fruits. The size of the treated fruits was reduced but this reduction is another advantage as this variety bears large fruits, too much big for a small family. GA treated fruits showed increased in ascorbic acid content which is important from the point of nutritive value. The ascorbic acid content of the treated fruits has been doubled to 89–100 mg/100 g from 45–48 mg/100 g in the control. In another experiment, seedlings, of Co1 papaya were sprayed with gibberellic acid and the fruits were subsequently harvested and chemically analysed. It was found that the size of the fruit was not altered but there was reduction in seed content by 32%. Fruits obtained from the GA treated plants showed increase in quality (12–13° Brix) as against 10°Brix in the control. The ascorbic acid content also increased slightly.

Spraying of NAA @ 1 ml/litre has been found to control premature drop of fruits and in incresing size of fruits in papaya (Mukherjee and Roy, 1966). The spraying of ethrel (250–500 ppm) and GA (25–50 ppm) increased the weight and volume of Co1 fruits. GA increased the ascorbic acid and reduced the seed content and the size of the internal cavity at 200 ppm. Contrary to GA, ethrel reduced the ascorbic acid content markedly (Rao and Shanmugavelu, 1971 and Shanmugavelu *et al.* 1973).

The expression of sex has been found to be altered by spraying GA. TIBA and boron (Rao and Shanumgavelu, 1971 and Shanmuguvelu *et al.* 1983). GA sprayed at 20–25 ppm increased the femaleness. GA at 200 ppm increased hermaphrodite and female flowers. Boron reduced the production of female flowers by 34%. TIBA decreased both types of flower production to a small extent.

An experiment to study the effect of certain growth regulators and urea on papain production in papaya varieties was conducted by Veerannah *et al.* (1984). Among the different treatments tried, GA at 10 ppm and urea at 2% increased the yield of papain appreciably in Co2 papaya. Such an increase was not noticed in Peradeniya which probably being a hermaphrodite type is a poor yielder of papain.

22. Papain production

THE green papaya fruits are well known for abundance of milky latex containing papain which is valued as an industrial product in preparing various digestive enzymes and food, chill proofing of bee and in meat tenderising. Besides it is also used in pharmaceuticals industry, textile, garment cleaning, paper and adhesive manufacture, dental and face cream and sewage disposal (Ram 1983c, 1986a, 1990, 1996 and 1998).

The wide range of pH over which papain is active favour its use in medicine as a protein digestant. Since, it acts equally well both in alkaline and acid medium, it is widely employed to assist both gastric and duodenal digestion. It possess the powerful anthelminthic properties, principally effectual in the expulsion of lumberici. It is an invaluable remedy in combating dyspepsia and in other digestive disorders. It enters as a component in various pharmaceutical preparations like glycin papain, liquid papain as irridin, digestive mixtures and liver tonics. In liquid preparation of post-operative adhesions, treatment of sloughing wounds, carbuncles, eschar or burns and for dissolving the membrane of diphtheria. It is used as a remedy for haemaptysis, bleeding piles and ulcers of the urinary passages. It has rebefacient properties. It is applied in psoriasis and other skin infections of a similar character and in the treatment of enlarged spleen and liver. Its action on muscular fibre is peculiarly strong, hence it can be used in a tonic and mild chologogue. It possess diabolic properties, and often reportedly been used by natives to induce criminal abortions. It is applied externally to prevent suppuration and locally for successful treatment of chronic eczema, more especially of the palms where other remedies do not prove curative. It is also used as a remedy in cases of scorpion sting. Papain preparations have been used in the treatment of peritoneal adhesions following abdominal surgery. It was used for killing bacteria during the cholera epidemic of 1943–44 in South India. It is reported to be an allergen, causing sometimes severe paroxysmal cough, vasomotor rhinitis and dyspsea. It is a powerful poison when injected intravenously. It is also exceedingly acid causing blisters and itching if applied to the skin.

Papain is used in the manufacture of proteolysed preparations of meat, liver and casein. Papain has been widely employed for degumming natural silk, especially when the latter is mixed with rayon or wool in fabric weaving. Wool treated with papain takes a silk-like sheen and becomes soft to touch. Papain treatment of wool also eliminates shrinkage and permits its being washed in the same way as cotton. Papain has been employed as substitute for rennet in cheese manufacture. Papain possesses both milk clotting and protein digestive properties. It has typical protein digestive properties and is classified as protease, proteinage or proteolytic enzyme. Papain is easily oxidized by exposure to air and is destroyed in aqueous solution by temperature above 70 degree Celcius or by some light. It is also easily inhabited by contact with metals such as iron, copper, zinc, etc. and works best at particular temperatures. The higher the specific activity or rate of catalysing per unit weight of enzyme, higher is the value. The activity of papain can be increased by refinement in proccessing. The quality and the grade of papain is determined by colour and enzyme activity (tyrosine unit) which is classified in three groups, (i) Crude papain white brown to brown, (ii) Crude papain in flake or powder referred as semi-refined, (iii) Spray dried crude papain of higher activity in powder form referred to as refined papain. The refined papain having the activity of 800–1000 units or higher is most preferred in world trade. Tapping and collection procedure, method of drying, storage and packing determines the quality of papain. The coagulated latex produces about 25% of its weight as dried powder which still contains six to ten percent of moisture. About one sixth of the dried powder is papain.

When thoroughly dried, the latex become crisp and flaky. It may then be grinded into powder. The powder is packed in air tight bottles or polythene bags. Finally the whole dried crude papain is then powdered by means of wooden mallet and passed through a 10 mesh sieve. The whole powder is packed in polythene bags and sealed air tight. Crude papain has less value if it is prepared in the desired grade of demand which is measured by the activity of enzyme. The crude papain thus prepared is exported to Europe and U.S.A. where it is further refined and sold as powder or in the tablet form under various trade names.

Papain exporting countries are Zaire, Tanzania Kenya, Israel, Phillippines, Srilanka, Cameroun and India and the major source of spray dried papain is Zaire. Principal importers are the United States, Japan, the United Kingdom, Belgium and France. Other countries import papain in small quantities. Papain is in great demand in international market particularly UK, USA and Europe. With the increase in the cultivation of papaya in various parts of India, it is highly profitable to manufacture papain where fruit production is in abundance.

Extraction of papain is simple. Green fruit after 75–90 days fruit set is suitable. Any razor blade or fine stainless steel knife may be used for lancing the fruit. Four longitudinal skin deep incision on fruit from stalk end to the fruit tip are given. The incision should be repeated on 3–4 subsequent occasions at an interval of 4–5 days. A non-metallic container should be used for collecting the latex. (Fig. 42) After collecting the latex, it should be dried in electric oven at 40 degree Celcius. Delay in the drying affects the quality of papain. The latex can

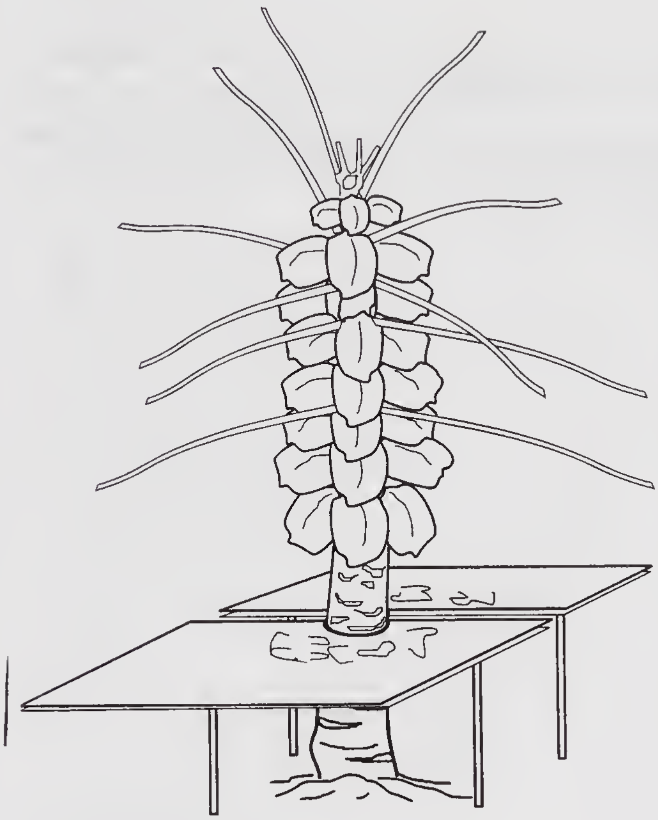


Fig.38. Papain extraction.

also be dried artificially in a home drier in a kind of drying stove constructed by building a chamber of bricks about a metre high, a metre wide and two metres long. The sides and ends are of brick with an opening at the end to admit fuel. The top is open. About 30 cm below the top an iron sheet is placed. Upon this 2.5 to 5 cm of sand is spread to modify and distribute the heat arising from the fire beneath. The coagulated juice is spread upon a brown linen stretched upon the frame which are made to fit the top of the drier. Smoking spoils the latex. Therefore, coconut shell or charcoal are recommended as fuel. The fuel is so regulated that drying is affected slowly with temperature preferably below 40°C. When thoroughly dried, the latex becomes crisp and flaky. It may then be grinded into powder and packed in polythene. Papain can be supplied and sold to Enzo-chem laboratory Yeola, Dist Nasik (Maharashtra State) and M/s Pharmaceutical and Cosmetic Promotion Council, Mumbai (Maharashtra).

Yield of papain depends on cultivar, time of taping, nutritional status of plants and region. There is positive correlation between fruit size and papain yield, rainfall and papain yield. Each fruit produces 5–8 g papain depending upon cultivar. It is reported that the variety Co_2 yielded 100–120 kg papain per acre. Yield of papain is 200–300 gm per tree with a maximum of 450 gm. The yield per hectare is worked out to 250–375 kg with high yielding papaya varieties. To increase the papain production, high yielding cultivars like Pusa Majesty Co_2, Co_5 and Co_6 have been cultivated and lanced fruits have been utilised for processing. Yield of papain increases with the increase in fruit age which is at the maximum between 60–75 days. The spacing of 1.6 × 1.6 m and application of 300 gm N are found optimum for papain yield in Co_6 papaya. Collection time of papain is morning hour and use of 10 ppm GA and 2% urea increased the papain yield in Co_2 at Coimbatore. Application of plant growth regulators like 2–4,D (10 ppm)

2,4,5T during blooming period increase the yield of papain. Urea mixed with the plant growth regulators is economical.

Utilization of scarred fruits

The extraction of latex from the fruit renders it difficult to sell, although it does not in any way impair its taste or other qualities. This fully grown but green and scarred fruit can be however he made into a candy like confectionary called petha, Petha production is itself a lucrative industry and there is every reason to believe that papaya petha will be a great success.

23. Natural compounds in papaya

PAPAYA is a rich source of several natural compounds like alkaloids, pectins, volatile compounds, proteolytic enzymes and growth inhibitors besides papain. Among the major alkaloids are carpaine, chroline, piperdine and caricacin. Raw papaya fruits, on an average, contain 0.8% pectin. Of the 160 volatile components identified in papaya fruits linalook and isothiocyanate have been found to be in abundant. Although several types of natural compounds have been reported in papaya plant but only papain, carpaine and pectins have been studied in some detail for their economic exploitation. (Singh 1990) Since papain is one of the major components of papaya and has considerable economic potential, a separate chapter has been devoted on the subject. The available knowledge about the natural compounds found in papaya are discussed in this chapter.

ALKALOIDS IN PAPAYA

Carpaine

Carpaine is the major alkaloid of *Carica papaya* L. which occurs in all of the green parts of the plant and in the seeds. It also occurs in other members of the family *Caricaceae, Vasconcellosia hasta*, and certain *Apocynaceae*. The chemistry and pharmacology of carpaine have been studied by several workers in the past. It has lead to established the absolute configuration of carpaine. However, the pharmacology of it has not been investigated enough.

Chemistry: The chemistry formula of carpaine is $C_{28}H_{50}N_2O_4$ and consists of two identical configurations of substituted piperidine rings linked together by two ester groups. In other words, carpaine contains a rather unique 26-membred ring and is far from being a simple compound as was originally thought and recorded in early literatures when Van Riju (1893) reported $C_{14}H_{25}NO_2$ as its empirical formula.

Pharmacological properties: Carpaine is reported to have quite similar properties like those of digitalis and emetine, but without most of their side effects. Because of such properties, it has been used as a heart stimulant and as a diuretic, although it is not related chemically to either digitals or emetine. Dr. Fairchaild (1943) in his book "The Garden Islands of the Great East" used pictures and words to describe how natives of the islands use the leaves of papaya for food as "vegetable greens" and brew "teas" from them to give a lift after a hard day's work.

To and Kyu (1934) reported carpaine to be an amebicide good for amebic dysentery.

This brief summary of the pharmacology of carpaine is far from complete. However, the above pharmacological properties of this important alkaloid warrant further investigations about its possible medicinal and industrial uses.

Yield: Carpaine occurs in papaya leaves in concentrations as high as 0.4% which is enough to make it available commercially at very reasonable costs. While studying the basic constituents of the leaves of *Carica papaya* L. Ogan (1971) found lower yield of carpaine from Nigerian variety than the values reported for American and Asian varieties. A final yield of 0.01–0.15% of the dry weight of the leaves of Nigerian variety, as against yield of up to 0.2% reported for Malayan plants were recorded. The yield of carpaine remained uniformly low through the twelve successive monthly estimations and it was not improved even by the use of younger leaves as suggested by Barger, Robinson and Work (1937).

Carpaine derivative and other alkaloids

Very little information is available about the several known derivatives of carpaine like methyl carpaine, ethyl carpaine, carpaine chloroauratee, carpaine hydrochloride and nitro-carpaine. Most of these derivatives were isolated in efforts to elucidate the chemical structure of carpaine. In recent studies Ogan (1971) isolated the quaternary alkaloids of papaya leaves. The Nigerian variety of *C. papaya* were found to have a relatively high content of choline which was in fact a more abundant constituent of this source than is carpaine.

Pectin

Raw papaya is a good source of pectin. The fruits on an average, contain 0.80% pectin of 150–200 grade which compares favourably with citrus and apple pectin which is usually marketed in India. The pectins from papaya are rich in ester groups and impart high jelly strength to jellies.

The pectin has been used primarily in jelly making. However, its use is rapidly increasing in a variety of other food products. It is now extensively used in modern food preparations like sweets, salad dressing, ketchups, sauces and ice creams, Pectin is an excellent emulsifier for different oils in water. It is used in flavouring extracts for codliver oil and caster oil and for liquid mineral oils in medicines. For its emulsifying properties, it is quite comparable to gums of acacia and tragacanth and is sometimes better than other emulsifying agents. Pharmaceutical pastes and ointment bases are stabilised with pectin.

Often glue and musilages are made out of pectin. As an excellent creaming agent for rubber latex, the use of viscous pectin of citrus has been successfully made. It has also been used in the hardening of steel, manufacturing of explosives, lacquers and sizing of textiles. Pectin has some uses. As a good blood-agglutinant, it is used in the treatment of intestinal haemorrhage. Cases of diarrhoea and dysentery have been successfully treated with pectin and pectin-rich fruits like papaya.

Pectin substances are complex carbohydrates usually present in all tissues and especially in fruits. They are mostly poly galacturonic acids with different degree of esterification and are differently soluble in water. The layer between the adjacent cellulose walls of the cells are almost entirely composed of pectin or pectin like substances. The forming of jelly with sugar and acid is a main feature and a useful aspect of all pectins. The presence of pectin, sugar, acid and water in right proportion and quantity is essential in the manufacturing of jelly products.

Volatile compounds of papaya

Limited attempts have been made to identify volatile component of papaya. Most of the components present are in very low concentration. Only 4 components have concentration greater than 0.5% in the sample mixture. Linalool has been found as the major component followed by benzyl-isothiocyanate. The relative proportions of the major components dependent upon the treatment received by the fruit tissues before and during volatile concentrations.

So far no commercial attempts have been made to harness the economically important volatile components of papaya although holds a great promise.

Growth inhibitors, blood anticoagulants and proteolytic enzymes in papaya

Attempts have been made to isolate and identify growth inhibiting substance in papaya. Cains (1969) isolated and identified presence of caricacin-a plant growth inhibitor in the methanolic extract of *Carica papaya* L. The growth of onion roots growing in 80 ml water solution containing latex of papaya fruit @ 0.5, 2, 4 or 6 ml was inhibited. Bulb formation took place after 18 days in all the treatments except 6 ml concentration. The latex induced damage was found to be irreversible.

A blood anticoagulant factor present in the latex of *Carica papaya* L. was reported as early as 1952 but its purification and general properties could be studied much later. The aqueous extract of papaya latex has been found to have no undesirable side effects.

The proteins of papaya and proteolytic enzyme (Chymopapain) from its latex have been separated using the technique of paper chromatography (Joahsi *et al.*, 1976). However, detailed studies are limited on the subject.

24. Papaya utilization and products of papaya

SEVERAL processed products of papaya have been developed viz. nectar, papaya beverage, papaya cake, barfi, jam, halwa, chutney, puree, slice, chunks, powder, baby food, canned papaya and tooty fruity. Among the processed products, papaya candy and tooty fruity have been commercially exploited and are produced on large scale under home industries in Bangalore, Jalgaon and Coimbatore. The product has increasing demand from bakery and other food industries. There is much scope to prepare products like toffee, nectar and canning of raw and ripe fruits of papaya. Papaya is also good source of pectin. Hence fruits after papain extractions can be utilized for pectin extraction. Uses of pectin is also on increase for various food preparation and emulsifying agent. The pectin has many industrial uses which is extracted from green fruit of papaya.

The following products which can be prepared, are described below (Ram 1981, 1981e, Ram and Singh 1996 and Singh 1990)

Pectin: Tapping of the papaya fruit for papain does not affect its pectin content and hence can be profitably be used for production of pectin. The procedure for preparation of high jelly grade pectin from papaya has also been standardised (Jain and LAL, 1955) and is as follows:

Green papaya fruits are cut, seeds are removed and the cut pieces are minced to a fine pulp of about 18 mesh size. The pulp is steeped in water to remove soluble solids such as sugars and proteins. Excess of water is drained off through wire mesh baskets. To 100 kg of drained pulp, 150 litres of 0.3 percent HCl (v/v) is added, boiled for 45 minutes and drained through muslin cloth. The hot pectin solution is immediately cooled to room temperature. The drained pulp is again extracted two times as above using 100 litres of 0.2 per cent HCl. All the extracts are combined, clarified by filtration and concentrated to ten fold under a vacuum of 27 inches and at a temperature of 40–50°C. Absolute alcohol is added double the quantity of the concentrate when all the pectin is precipitated. The precipitate is pressed free of the solvent and washed (a) with 66% alcohol, (b) with absolute alcohol and, (c) again with absolute alcohol. It is pressed and dried at 50–60°C. The resultant product is pectin.

In a second method, the dilute pectin solution after filtration is mixed with aluminium chloride to get a concentration of 0.5% or aluminium sulphate to get a concentration of 1% respectively. The pH is adjusted to 4.0 by adding ammonium hydroxide or sodium hydroxide. Coagulated aluminium pectinate is separated, pressed to remove excess water and purified as below:

(i) Concentrated HCl is added to get 5% concentration and equal volume of absolute alcohol is mixed. After half an hour, it is pressed in a basket press.

(ii) Washed with 5% HCl (v/v) and equal quantity of alcohol concentration is 50%).

(iii) Washed with 66% alcohol.

(iv) Washed with absolute alcohol containing ammonia to adjust pH to about 4.5.

(v) Absolute alcohol and finally dried.

The latter method is recommended as the consumption of alcohol is less and costly equipments like the concentrator required in the first method are not required. Pectin obtained by this method is dull white in colour and has no characteristic flavour of papaya. The yield of pectin is about 500 kg from a hectare of papaya. Cost of production of pectin is about Rs 50 per kg and market price varies from Rs 550 to 800/kg (L.R. Grade).

Petha: The unripe matured fruits are suitable for making petha. The scarred fruit from which papain has been extracted are also suitable for petha. The skin of fruit should be peeled off and then unskinned fruit cut into pieces of 8×8 cm. These pieces should be pricked with fork to permit full penetration of lime water. After keeping for 3–4 hours in the lime water, it should be washed thoroughly with 3–4 changes of water. Then, it should be boiled in 40 per cent solution of sugar so as to dip all the pieces into it. More sugar should be added to the solution in order to make it 72 per cent concentration. Sodium benzoate at the rate of 0.02% should be added to this product which act as a preservative. For making it scented, rose water or *kewara* water can also be added. The individual piece should be plump, juicy and almost transparent when ready. The product is then put in to sterilized wide mouth bottle or tin cans which are hermatically sealed, suitably labelled and packed.

Papaya jam: The matured solid fruit should be peeled off and after removing the seeds, it should be cut into small pieces. Equal amount of sugar is taken and cooked with small quantity of water. When the temperature of the product comes to 218°F then, 1 fruit of lime/kilogram of the product is added and boiled. When the temperature becomes 222°F and the product concentrated, it should be considered as a final product of papaya jam. After removing it from the fire, it should be filled in clean glass container of wide mouth bottle. The heated paraffin wax is poured into the bottle to be kept for a longer period. The sodium benzoate at the rate of 0.02% is added at the time of bottling the product.

Papaya jelly: Fully matured but somewhat raw fruits, are cleaned and pealed. After removing the seeds of such semi ripe fruit, the flesh is cut into small pieces. These pieces are immersed with water and boiled to soft consistency so that the juice is easily extracted through muslin or fine cloth. Since papaya contains less pectin, it is necessary to add 1% extra pectin purchased from the market. In the juice, equal amount of sugar is added. If extra pectin is not available, then only 3/4 sugar is added to the extracted juice. The juice along with the sugar is boiled. In the process of boiling fruit of one kagji lime is added and is boiled to a thick consistency. At this stage the temperature is also found to be 105.5°C. The product is removed from the fire and the scum is removed and the content is poured into wide mouth bottle or jar. The product in jar is covered with molten wax and closed with air tight caps.

Papaya preserve: This product has good demand in the bakery industry. The fruits after washing are cut into halves peeled and again cut into uniform size small pieces (0.9 × 0.9 × 0.7 cm) and boiled in water (1:2 ratio) for 15–20 minutes and then cooled. The small fruit bits are coloured by using approved edible colours and boiled in 40% sugar syrup for 15–20 minutes. Concentration of syrup is raised by 10. brix every day and the process is continued till the sugar concentration reaches 70–75°B. Final boiling is given for 5 minutes by adding citric acid (5 g/1 litre of syrup). The papaya bits are removed from syrup, drained and dried in the air. The finished product is packed in low density polyethylene (4000 gauze) bags and stored in biscuit tins.

Papaya kheer: The matured unripe fruit is peeled off and cut into fine shreds through iron sieves. These shreds are boiled in water to make it soft. After straining, the shred is fried in *ghee*. *Kheer*, can also be prepared without frying. About 4 times of product, milk is taken and concentrated along with the shreds. Sugar is added to the equal quantity of papaya and boiled to a thick consistency. In the final product small quantity of kissmiss, coconut, small cardamom and *chiraunji* is added to enhance the taste of the product.

Papaya halwa: The method of preparing *Halwa* from papaya is same as carrot *Halwa*. Matured papaya fruit is peeled off and seeds are removed. Then fine shreds are made through iron sieve. The shreds are boiled in water. After straining it is fried in *ghee*. Then equal amount of sugar is taken and made syrup. The fried shred is mixed in the syrup and boiled to make thick consistency. It is taken off from the fire and all the dried fruits as mentioned in *kheer* are added to this product. The edible dye is also added to make it attractive. Thus a well prepared *Halwa* can be consumed for a longer period.

Papaya sweet (Barfi): The raw fruit is peeled off and seeds are removed. Then shreds are made through iron sieve. Equal quantity of sugar is taken and syrup is made in small quantity of water. The shreds are cooked in this syrup. After cooling for sometime, one fourth of this weight, *khowa* (milk product) is mixed with it. When the final product is still warm *kewara* water is added and mixed thoroughly. Then this product is transferred in another container for final cooling. After this the final product becomes quite solid. It is cut into pieces with the help of knife and stored in suitable container. A well prepared sweet can be utilized for quite a long time.

Papaya rayata: Raw fruit is peeled off and after removing all the seeds, it is cut into pieces. Shreds are made with iron sieve and boiled into water. The shreds are strained with muslin cloth. Double the quantity of this product, curd is put into it and stirred thoroughly. After this, salt, ground *jeera,* green leaves of coriander and green chillies are mixed into it according to taste. *Rayata* thus prepared is very laxative and tasteful.

Papaya pickles: The pickles of papaya is made just like radish pickle. The fruit is peeled off and after removing the seeds, it is cut into small pieces. Then it is boiled in small quantity of water for making them soft. Different types of spices with mustard or groundnut oil is mixed in it. This type of pickle can be consumed soon after preparation. If the pickle is to be kept for longer period, instead of boiling the fruit pieces, it is dried in the sun for about an hour. Then it is mixed in different spices along with mustard oil and kept for future use.

Papaya pickles (ii) method: Raw papaya (pulp colour still pale yellow) can be used for making salted pickles by brine curing and adding spiced vinegar in the traditional way.

Peel and slice the green papaya and cover it with boiling water for 3 minutes. Strain the water and sprinkle common salt on the blanched slices. Allow the fruit slices to dry up to some extent. Place the prepared papaya slices in a jar, cover with vinegar and add one teaspoon of dehusked mustard seed to every 1/2 kg of the fruit slices. Add turmeric in suitable quantities and close the jar air tight. The slice will be cured in 2–3 weeks suitable for consumption.

Tuti-fruti: This product is made after peeling the raw fruit and making small pieces. After washing it is cooked in sugar till it becomes soft. In the process, citric acid and desired colour is added. Finally it is dried and packed before marketing.

Papaya squash: Experiment done at T.N.A.U., Coimbatore has indicated that squash can be made which is comparable to mango squash. Juice is extracted from the pulp and mixed with sugar syrup and boiled. Finally desired colour and essence is added and bottled before marketing.

Canning: Like any other fruits, papaya can be canned satisfactorily for distant transport or future need. For canning 25 mm papaya cubes are placed in a standard can containing boiling hot 40° Bricks syrup and 0.75% citric acid to a gross head space of 8 mm. Filled in cans are exhausted in steam or hot water to 71°C and then closed. Then they are again processed at 90.6°C or in boiling water for ten minutes. After that the cans are immediately cooled to 37.8°C and stored at a suitable temperature.

Canned papaya beverage: A method has been developed in Puerto Rice for the preparation of a canned beverage based on peeled and unpeeled papaya. A 1:1 mixture of papaya pulp (body weight) and sugar is passed through a stone mill and diluted with water to achieve a pulp content of 13%. About 0.4% sliced west Indian lime is added before pasteurization to enhance the flavour. The beverage is adjusted to 15° Brix pH 3.7 heated to 190°F (88°C) and canned. The beverage was stable for 1 year at 85°F (30°C).

Papaya nectar: Nectar is detained by blending the thin pulp of the fruit with sugar and citric acid, the finished product has 15–20° Brix and mild acid taste. The ripe fruit is cut into slices, peeled by hand and run through a poplar using a 1.5 mm or 1.7 mm screen. The resulting pulp is passed through a finisher using a 0.6 mm or 0.7 mm screen. The yield of pulp from the raw stock (viz. ripe fruit) is about 50%.

Recipe

Pulp	10 kg	Water	15–20 kg
Sugar	4 kg	Citric acid	125–175 g

The pulp is gradually thinned with water after which the required quantities of sugar and citric acid are added and the ingredients mixed. The nectar so prepared is filtered through muslin cloth and heated to 85–88°C. It is filled into plain or lacquered cans which are sealed, inverted for about a minute and cooled in running water to about 38°C. The cans are then left to cool to atmospheric conditions. Flash pasteurization may also be used in which case the nectar should be heated to about 84°C and filled into cans at 88°C–91°C. The cans are sealed inverted and cooled as usual. Equipment should be made of non-corrosive metal.

Papaya puree: Gelation and off odour development are major problems during the storage of papaya puree/pulp in frozen condition or at low temperature. After considering the techniques available for the prevention of these disadvantages, a process has been worked out in U.S.A. for papaya puree. It consists of the following steps:

1. Brief steaming of whole ripe fruit to coagulate the latex, inactivate the enzyme and increase puree yield by softening the fruit.
2. Cooling of fruit by water sprays and slicing.
3. Loosening the pulp and seeds (without breaking by using a crusher scraper).
4. Addition of citric acid to the pulp macerate in specific amounts to inhibit gelation, microbial activity and off odour development during storage at low temperature.
5. Separation of pulp and seeds by using centrifugal device, paddle pulper and a screen.
6. Pumping of pulp into a tank and addition of citric acid to adjust the pH to 3.4–3.5.
7. Holding the acidified pulp at 205°F (96°C) for 2 minutes and cooling quickly

to 85°F (30°C) to inactivate enzymes and stabilize puree against deterioration during frozen storage.

8. Passing the puree against a 0.02 inch (0.05 cm) screen to remove fibre and
9. Transferring the container with puree for freezing.

The puree of Solo variety of papaya grown in Honolulu showed total soluble solids 11.5 to 13.5%; total acid (after acidification) 1.05–1.10%; ascorbic acid 50 to 90 mg%; carotenoids 3.5 to 3.9; moisture 8.4 to 8.8%; and pH 3.4–3.5.

Papaya puree can be used with sugar and water to prepare a flavoured beverage (of 14°Brix). It can also be used to prepare fruit cocktails, jams and marmalades.

Post-harvest technology of latex and papaya fruits

Papain: Latex ⇒ Homogenization ⇒Centrifugation ⇒ Filteration ⇒ Ultrafiltration ⇒ Spray dry.

Pulp: Fruit ⇒ Pulping ⇒ Concentration ⇒ Mixing ⇒ Filling ⇒ ExhaustingÞ Steeming ⇒ Processing.

Slices: Fruit ⇒ Slicing ⇒Filling ⇒ Exhausting ⇒ Steeming ⇒ Processing

Candy: Fruits ⇒ Dicing ⇒ Brining ⇒ Blanching ⇒ Presyrupping ⇒ Processing ⇒ Saturating ⇒ Storage.

Powder: Fruits Pulping ⇒ Processing ⇒ Vacuum evaporation ⇒ Mixing ⇒ Spray drying.

25. Economics of papaya cultivation

A study was undertaken by the author at the IARI Regional Station Pusa Bihar during 1990–92 to know the economics of papaya fruit and seed production. The detail analysis of cost of papaya fruit and seed production per hectare is given below:

Details of operations and items	**Cost (Rs)**
One deep ploughing	125.00
One ordinary ploughing with planking	87.50
Layout and pegging	110.0
Digging pits	850.00
Manures and fertilizers	
a. Local compost	1562.50
b. Neem cake	3750.00
c. Rallismeal or Sterrameal	9375.00
d. Ammonium sulphate	12000.00
e. Single superphosphate	9375.00
f. Muriate of potash	4500.00
Initial basal manuring by labour	137.50
Pits filling	342.50
Cost of seed	250.00
Nursery management	1250.00
Final land preparation, ploughing and planking	92.50
Final layout by labourers	110.00
Transplanting	180.00
Hoeing and weeding	2750.00
Removal of extra plants	70.00
Top-dressing of fertilizers by labourers	275.00
Preparation of irrigation channel and basin	137.50
Irrigation	832.50
Land rent	250.00
Watching of orchard fruit	1750.00

Plant protection	55.00
Total	50,000,00
Total population	2,500 plants
Less 10% male plant 2,250 plants (productive)	
Yield of fruit 30 kg/plant	67,500 kg
Gross income @ Rs 2 kg	Rs 135,000
Less cost of production	Rs 50,000
Net profit/ha	Rs 85,000

Cost of cultivation for second successive crop

Weeding	1625.00
Fertilizers	
a. Ammonium sulphate	12000.00
b. Single superphosphate	9375.00
c. Muriate of potash	4500.00
Top dressing	275.00
Irrigation	555.00
Land rent	125.00
Watching	1750.00
Plant protection	55.00
Miscellaneous	125.00
Total Rs	30,385.00
Productive plants	2200
Yield of fruit 25 kg/plant	55000 kg
Gross income @ Rs 2/kg	Rs 1,10,000.00
Less cost of cultivation	Rs 30,385.00
Net Profit	Rs 79,615.00
Total net profit for two crops	Rs 1,64,615.00
Total period taken	Three years
Net profit per year per hectare	Rs 54,871.66

Cost of cultivation for seed production under controlled pollination and isolated condition

Additional cost of crossing materials	Rs 8,000
Labour cost for hand pollination	Rs 40,000
Fruit harvesting seed collection, drying, cleaning and packing	Rs 12,000
Total	Rs 60,000

Table 28. Details of seed production in different methods.

Character	Controlled pollination	Isolation
No. of fruits/plant	31	34
Seed producing fruit/plant	25	32
seeds/fruit No.	469	547
Weight (g)	7.8	9.7
Seed/plant No.	11 725	17 504
Weight (g)	194.6	311.5
Female plants/ha	2 187	2 187
Seed producing fruit/ha	54 675	69 984
Total seed produced in a hectare No.	2 56 40 000	3 82 80 000
Weight (kg)	425.62	681.38
Loss of seed during entire period (15%)	63.84	102.20
Nct seed produced in a hectare (kg)	361.78	579.18

Table 29. Cost of seed production in different methods.

Method	Common cost of cultivation (Rs)	Cost of seed production (Rs)	Total cost of production (Rs)	Total seed produced (kg)	Cost of production/ kg
A. Controlled pollination	50,000	60,000	1,10,000	362	303.90
B. Isolation	50,000	12,000	62,000	580	106,80

Table 30. Net income in different method of seed production per hectare.

Method	Total seed produced (kg)	Selling Rate of seed Rs/kg	Gross income (Rs)	Cost of produce-tion (Rs)	Net income
A. Controlled pollination	362	2000.00	724000	110000	614000.00
B. Isolation	580	1500.00	870000	62000	808000.00

Papain production

Veerannah *et al.* (1984) calculated the economics of papaya cultivation in Tamil Nadu which is based on one acre basis is reproduced as below:

Cost of production of papaya fruits and papain per acre (0.4145 ha)

Raising nursery	Rs
Cost of seed at 200 g/acre	120.00
Cost of polybags 4 kg/acre at Rs 25/kg	100.00
Cost of pot mixture 1300 polybags at 2 kg per bag at Rs 50/tonne	150.00

Cost of filling and dibbling the seed		
Four B type labourers		40.00
Watering charges for 30 days at		
Rs 5/day		150.00
	Total	560.00
Preparatory cultivation:		
Ploughing the land thrice		120.00
Cost of pitting (1200 pits 30 cm cube-		
40 A type labourers)		480.00
Filling the pits with sand, red		
earth and farmyard manure 10 tonne (Rs 500)		
Ten A type and ten B type labourers (Rs 220)		720.00
Forming beds and channels and planting		
the seedlings (10 A type labourers)		120.00
	Total	1440.00
After cultivation:		
Cost of two weedings during the first six months and four earthing up during the next two years (50B type and 80A type labourers)		1460.00
	Total	1460.00
Irrigation:		
Pot watering for one months once in three days (10B type labourers) and surface irri gations at 10 days intervals (excluding 8 rainy months) during the rest of the 21 months (Two A type labourers per irrigation for 60 irrigations)		2,440.00
Cost of water including energy charges		560.00
	Total	3000.00
Manures and manuring		
Cost of fertilizers of NPK 200:200: 200 g per tree (for the total crop period) to be given in six split appli cation (600 kg urea, 1500 kg super phosphate and 420 kg muriate of potash)		3,500.00
Application charges (Three A and five B type labourers per application for six applications)		540.00
	Total	4040.00

Plant protection

Soil drenching with Bordeaux mixture four times during the crop period (100 kg copper sulphate and 100 kg lime)	1,400.00
Labour charges (6 B type labourers per application)	240.00
Total	1,640.00

Tapping papain

Lancing fruits (100 fruitsper B type labourer in half-a-day) collection and drying of latex 500B type labourers for the crop duration.	5,000.00
Total	5,000.00

Harvesting

Harvesting fruits from the 10th month onwards for the next 20 months at four B type labourers per harvest for an average of 50 harvests and transporting the fruit to store	2,000.00
Total	2,000.00

Sundries

Charges towards thinning male trees, cost of papain collection trays/ containers and other sundries.	860.00
Total	860.00
Total expenditure on cultivation	20,000.00
Extra expenditure on seed extraction if required	
Seed extraction from 80 tonnes of fruit and drying the seed (100 kg fruits per B type labour-total 800 'B' type labourers)	8,000.00
Total	8,000.00

Receipts

For production of fruits and papain

i) Revenue from sale of papain of 250 kg at Rs 100/kg	25,000
ii) Revenue from sale of lanced fruits 80 tonnes at Rs 300 tonne	24,000
Total	49,000
Less expenditure on cultivation	20,000
Net income per are in 2½ years	29,000
Cost benefit ratio = 1:2.45	
For production of fruits, papain and seeds	
i) Revenue from papain	25,000
ii) Revenue from cut fruits 80 tonnes at Rs 300/tonne	24,000
iii) Revenue from bulk seeds 250 kg	25,000
Total	74,000
Less Expenditure on cultivation including seed extraction	28,000
Net income per acre in 2½ years	46,000
Cost benefit ratio = 1:2.64	

The economics of the cultivation of the papaya was also studied by Kumar (1952) wherein he included papain and fruit preservation under Sahavanpur condition during the period 1949–52.

The estimated average profit per acre per year from papaya cultivation was:

(i) Rs 6,413 when papain was produced and scarred fruit was sold as candied fruit.

(ii) Rs 3,021 when papain was produced but scarred fruit was sold as such and

(iii) Rs 2,522 when papain was not produced and the fruit was sold as fresh fruit.

He concluded that papaya cultivation coupled with the utilization of the fruit as a preserve and the production of papain had attractive prospects.

Recently Gadre (1997) studied economics of production of papaya for papain production. His studies were conducted in Maharashtra to determine the per ha utilization and cost of cultivating papaya and intercrops and to calculate the input-output ratio. The per ha cost and cost of cultivating papaya was Rs 16018 and 31902 respectively, whereas the per ha gross income was Rs 81203 of which Rs 55208 was from papain and Rs 26094 from papaya fruits. The net return from intercropping was Rs 14835 and the net cost of papaya cultivation was Rs 17067 per ha. The input-output ratio was 1:4.76 indicating that the cultivation of papaya for papain is financially viable.

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27. Terminology

A

Asexual propagation	Reproduction which does not invlove the union of gamet.
Aberration	Structural change in chromosome, chromosome mutation.
Abscission	Seperation from the plant.
Abortion	Arrested development of an organism in plants.
Androdioecious	Having male and bisexual flowers on seprate plant.
Androecious	Plant having male flower.
Andromonoecious	Plant having male and bisexual flower.
Anther	Part of flower containing pollen.
Anthesis	The opening of flower bud
Albino	The plant lacking chlorophyll and carotenoids
Alkaloid	A nitrogenous cyclic compound of plant origin.
Anaphase	The stage in which sister chromatids of each chromosome seperate by their movement towards opposite poles of the spindle.
Acentric	Chromosome without a centromere.
Autosomes	The chromosomes other than the sex chromosome.
Allele	A series of factors that occur at the same locus on homozygous chromosome.
Adaption	The process by which species function in such a way to better survive under given environmental condition.

B

Backcross	A cross between a hybrid and either of its parents.
Biotypes	Genetic constitution of an individual.
Biotechnology	Use of molecular tool to manipualte living organism.
Breeder seed	Seed produced by breeder.
Bivalent	Paired two homologous chromosomes (containing all the chromatids). during the first meiotic division.
Breeding	The art and science of changing plant genetically.
Bisexual	The flowers having androecium and gynoecium.

C

Cell	Smallest structural and functional unit of organism.
Carpellody	Transformation of other floral organ into carpels.
Centric	Chromosome or its fragment having a centromere.
Chlorosis	Yellowing of plant.
Character	An attribute of an organism.
Chromosome	Structural units of the nucleus which carry the genes in liner order.

Combining ability	Average performance of a strain in a series of cross.
Colchicine	An alkaloid obtained from the plant used to induce polyploidy through chromosome doubling.
Covariance	A statistical measure of inter-relation between variable.
Crossing over	The exchange of segments between non-sister chromatids of homologous chromosomes leading to recombination.
Centromere	Specialised region to which the spindle fibre is attached during cell division in a chromosome.
Cytogenetics	A branch of biology which is combination of cytology and genetics
Cytoplasm	The protoplasm of a cell excluding the cell wall and nucleus.
Cytoplasmic inheritence	Transmission of hereditary character through cytoplasm.

D

Diploid	An organism whose cells contain double sets of chromosome.
Dioecious	Plant having male and female flower on different plants.
Depletion	Reduction.
Dehiscence	Opening and discharge of pollen from the anther.
Dominance	The predominance of one pair of Mendelian character.
Deviation	Departure of an observation from its expected value.
Duplication	Occurance of a segment of chromosome twice in the haploid set.

E

Environment	The sum total of the external conditions which affect the growth and development of an organism.
Elongata	Elongated form of ovary.
Emasculation	Removal of male organs from a bisexual flower.
Embryo	The young sporophyte which results from the union male and female cells in a seed plant.
Erosion	Gradual destruction of material due to pressure.

F

Fungicide	Substance killing or inhibiting the fungus spores or mycelium.
Foundation seed	Seed stock from which further multiplication is made.
F_1	The first generation of a given mating.
Family	A group of individuals directly related by descent from a common ancestor.
Fertility	Ability to produce vialble pollen or seed.
Fertilization	The fusion of male and female gametes to produce a zygote.

G

Gamete	Cell of miotic origin specialised for fertilization.
Gene	The unit of inheritance located in the chromosome.
Genetic	The usual pattern of change in morphological character.
Genome	A complete set of chromosome.
Genotype	The genetic constitution of a plant.
Germplasm	The genetic material that provides the physical basis of heredity.
Gynodioecious	Bisexual and female flowers borne on seperate plants.

Gynomonoecious	Having female and bisexual flowers on same plants.
H	
Haploid	An organism or cell with only one set of chromosome.
Heredity	Resemblance among individual related by descent.
Heteromorphic	Homologue chromosomes differing in morphology.
Heterosis	Hybrid vigour.
Heterozygous	Homologue chromosome having different genes.
Homozygous	Possessing identical genes of any given pair.
Hermaphrodite	Reproductive organs of both sexes in 'same plant flower.
Heterogametic	The sex which produces two types of gametes in equal frequency with regard to sex chromosome.
Homologous chromosome	Chromosome which have similarity with respect to their genetic loci and visible structure.
I	
Inflorescence	Arrangement of flower on the floral axis.
Inbreeding	Mating of individuals more closely related.
Inbred pure lines	Involves inbreeding annual seed propagated materials.
Incompatibility	The inability to fertilize egg cell.
Irradiation	Exposure of seed to X-rays to increase mutation rate.
Insecticide	Substance killing insects.
Inherited	Acquired by succession.
Induction	Bringing about an electrical flow with coming into contact with an electrified or magnetized body.
Isolation	The seperation of one group from another so that mating from other group is prevented.
J	
Juvenile	Early growth stage.
K	
karyotype	The sum of the specific character of a nucleus viz. chromosome number size, and form.
L	
Larvae	An insect in the grub stage.
Leguminous	Consisting of pulse crop.
Lethal	That renders inviable an organism.
Locus	The position occupied by a gene in a chromosome.
Linkage	The tendency of genes to be inherited together due to their location close to each other in the same chromosome.
M	
Multivalent	Association of three or more homologous chromosomes during meiosis.
Mutant	An individual which has suddenly acquired a heritable variation not present in the parent form.
Mutation	A change in genes which is heritable.

Meiosis	The process proceeding the formation of chromosomes.
M_1	The first generation raised from irradiated seed.
Modifying genes	Genes that affect the expression of a non-allelic genes.
Multiple allele	A member of a series of more than two alternative forms of a gene.
Monoecious	Male and female flowers on the same plant.
N	
Necrosis	Modification.
Nucleus seed	Purest seed produced by breeder.
O	
Out breeding	(Cross breeding) Mating system in less related population.
Ovary	Female organ of flower.
Ovule	Beginning stage of seed in overy called mega sporangium.
P	
Parthenocarpy	Development of fruit without fertilization.
Proliferation	Growth.
Polygamous	Plant having different sex of flowers.
Polyploidy	More than 2n number of chromosome present in variety of plant.
Pollenizer	Plant supplying pollen.
Phenotype	Group of individual with similar appearance.
Population	A community of individuals which share a common population.
Progeny test	A test of the value of a genotype based on the performance of its offspring produced in some definite system of mating.
Primorida	The first recognisable but undifferentiated stage of developing organ within a bud.
Pedegree	A list showing the ancestral history or geneological register.
Q	
Qualitative character	A character in which variation is discountinous.
Quantitative character	A character in which variation is continous so that classification into discrete category is not possible.
R	
Recurrent parent	The parent to which successive backcross are made in back-cross breeding.
Reversal	Turning into opposite sex.
Recessive	Character marked by corresponding dominant character.
Rougue	A variation from the standard type of a variety.
Roguing	Removal of undesirable individuals to purify the stock.
S	
Self pollination	Transfer of pollen grains from anther to stigma of same flower.
Senescence	The state of growing old.
Sterility	Inability to produce seed or fruit.
Sibmating	Brother sister mating.
S_1	The first generation of sibmating.

Sample	A finite series of observation taken from a population.
Species	The unit of taxonomic classification into which genera are sub-divided.
Spindle	A bipolar collection of fibers observed during cell division in eukaryotes.
Strain	A group of similar individuals within a variety.
Satellite	A distal segment of chromosome separated from the rest of the chromosome by a secondary constriction.
Sex chromosome	The chromosome involved in sex determination and is dissimilar in heterogametic sex eg. X chromosome.

T

Trisomic	(2n+1) A cell or individual with an extra chromosome.
Triploid	An organism whose cells contain three haploid sets of chromosome.
Tetraploid	An organism whose cells contain four haploid sets of chromosome.
Test cross	A cross of a double or multiple heterozygote to the corresponding multiple recessive to test for homozygosity or linkage.
Translocation	Change in position of a segement of a chromosome to another location in the same or a different chromosome.
Teratological	Refering to a serious malformation.

U

Ultraviolet rays	A type of ray to treat the seed for mutation.
Univalent	An unpaired chromosome in meiosis.

V

Virus	A cellular organelle which contains protenious thread and causes disease.
Viability	Capable of germination.
Variation	The occurence of differences among individuals.

W

Weedicide	Substance killing weeds.
Wilt	The drooping and loss of freshness of plant foliage.
Wild type	Refers to a strain or gene commonly found in nature.

X

X-chromosome	The sex chromosome present in both sexes where female is homogemetic sex (XX=female, XY=male).

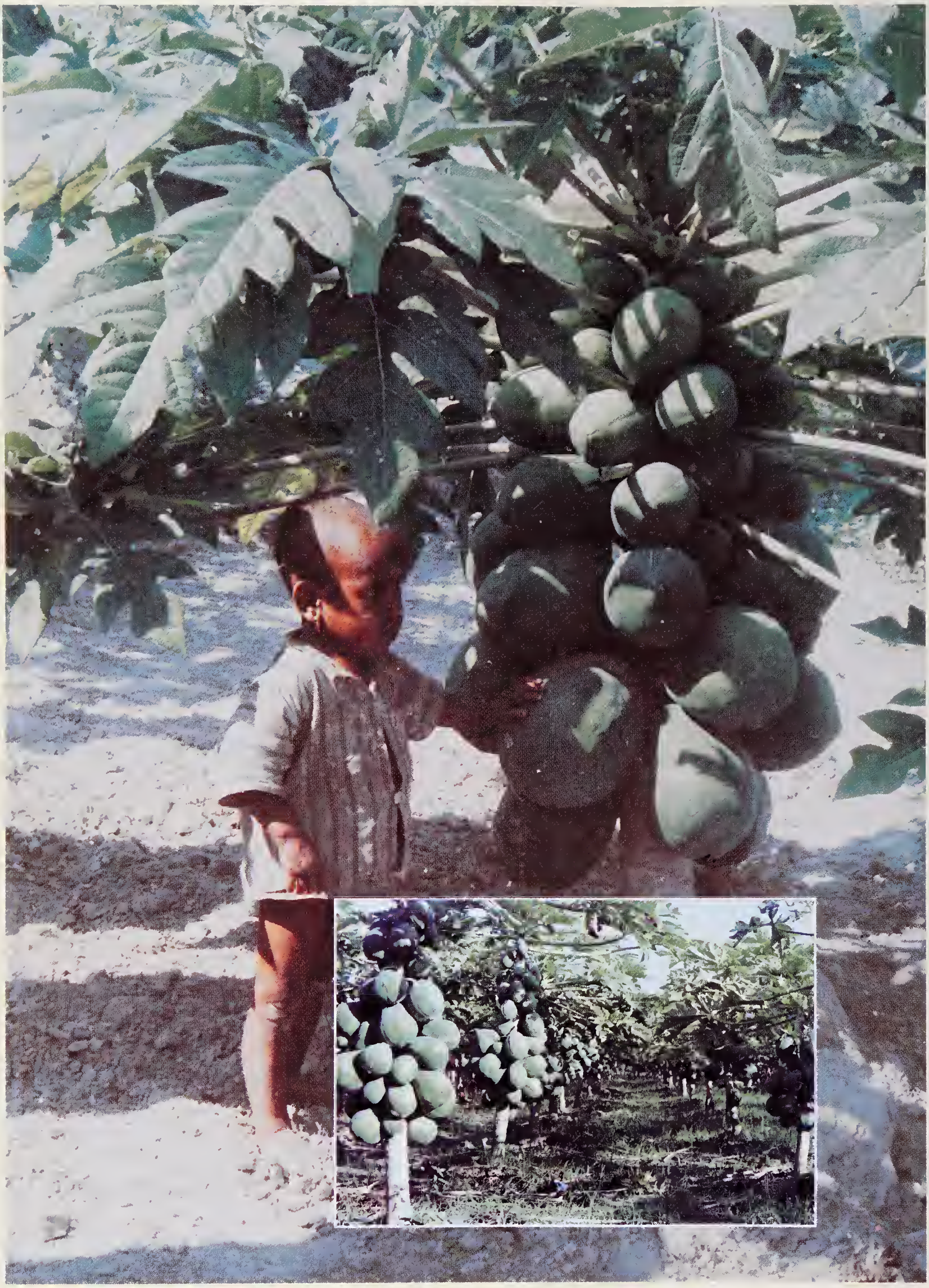
Y

Y-chromosome	The sex chromosome limited to male sex in case of male heterogamety.

Z

Zygote	A fertilized egg cell.
Z-chromosome	The sex chromosome present in both sexes where female is heterogametic sex.

28. Subject-index



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