Series of Crop Specific Biology Documents

BIOLOGY OF *CARICA PAPAYA* (PAPAYA)

Phase II Capacity Building Project on Biosafety

Ministry of Environment, Forest and Climate Change
Government of India

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Nature Protects if She is Protected

Ministry of Environment, Forest and Climate Change

Government of India

Biology of *Carica papaya* (Papaya)

Prepared by:

Ministry of Environment, Forest and Climate Change (MoEF&CC)
and Indian Institute of Horticulture Research, Bengaluru under
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सत्यमेव जयते

Message

I am happy to learn that the Ministry of Environment, Forest & Climate Change (MoEFCC) as part of the initiative under the UNEP GEF supported "Phase II Capacity Building Project on Biosafety" has developed eight crop specific biology document on Chickpea, Mustard, Papaya, Pigeon-pea, Potato, Rubber, Sorghum, and Tomato.

I am happy to note that the documents have been prepared with support from seven research institutions namely Indian Institute of Pulses Research, Directorate of Rapeseed and Mustard Research, Indian Institute of Horticulture Research, Central Potato Research Institute, Rubber Research Institute of India, Indian Institute of Millets Research and Indian Institute of Vegetable Research.

While Bt cotton is the only genetically modified (GM) crop approved for commercial cultivation in India, there are several crops under various stages of research, development and field trials. The present set of crop specific biology documents aims to provide scientific baseline information of a particular plant species that can be used as credible source of information for conducting safety assessment of GM plants.

I would like to congratulate all those who were involved in preparing these documents and those involved in steering this initiative.

I am confident that these biology documents will serve as a valuable tool for regulators, scientists, crop developers, policymakers, academicians and other stakeholders who are involved in the safety assessment of GM plants. I am also hopeful that baseline information provided in the biology document would further enhance awareness on biosafety aspects of GM crops.

(Prakash Javadekar)

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PREFACE

India is an agriculture based economy with abundance of genetic base, diverse agro-climatic zones and highly qualified manpower which provides a rich scope for technological advances in agricultural biotechnology. The shortage of healthy seeds/planting material, lack of disease resistant clones, crop damage by insects, pests etc. have often affected the Indian agricultural economy adversely and therefore the role of new technologies assumes significant importance for Indian economy.

With significant advances in the field of agricultural biotechnology the regulatory system has to deal with multiple crops integrated with multiple traits. In order to streamline the process of safety assessment, the Ministry of Environment, Forest & Climate Change (MoEF&CC) under the UNEP-GEF supported "Phase II Capacity Building Project on Biosafety" has prepared a set of crop specific biology documents namely Chickpea, Mustard, Papaya, Pigeon-Pea, Potato, Rubber, Sorghum, Tomato with support from six Indian Council of Agriculture Research (ICAR) institutions and Rubber Research Institute of India.

The biology documents provides an overview of baseline biological information of a particular plant species such as taxonomy, the centres of origin, its related species including wild relatives, general description of their morphology, reproductive biology, biochemistry, potential for gene introgression, biotic and abiotic interactions. Such species specific information is expected to serve as a guiding tool for use in risk assessment of genetically modified (GM) plants.

The documents has been prepared through a consultative approach and comments received from several organizations have been extremely useful in validating this document. I express my deep appreciation for the support provided by Indian Institute of Pulses Research, Directorate of Rapeseed and Mustard Research, Indian Institute of Horticulture Research, Central Potato Research Institute, Rubber Research Institute of India, Indian Institute of Millets Research and Indian Institute of Vegetable Research in preparing these documents. I would also like congratulate Dr. Ranjini Warrier, Advisor, (MoEFCC) and Dr O.P Govila (Former Professor, Department of Genetics, IARI) for their sincere efforts and the consultative approach adopted in finalizing the biology documents.

I am confident that these crop specific biology documents would be of immense value for researchers, regulators and industry in planning for the safety assessment of GM crops.

Hem Pande

CONTENTS

BIOLOGY OF *Carica papaya L.* (PAPAYA)

1. INTRODUCTION

1.1 General Description

Papaya (*Carica papaya*) is a fruit crop that is grown both commercially as well as in the kitchen garden of many households all over India. Ripe papaya is a favorite fruit all over India. It is used to make fruit salads, refreshing drinks, jam, jelly, and candies. Green fruits are cooked as vegetable and are also used in the preparation of tutti-frutti. It is rich in a number of nutrients (Table 1) and antioxidants and has a high medicinal value. Papain is tapped from green fruits which has industrial use.

Table 1: Nutritional composition of a ripe papaya fruit

Nutrient	All values are per 100 gms of edible portion
Moisture (g)	90.8
Protein (g)	0.6
Fat (g)	0.1
Minerals (g)	0.5
Crude fibre (g)	0.8
Carbohydrates (g)	7.2
Energy (Kcal)	32
Calcium (mg)	17
Phosphorus (mg)	13
Iron (mg)	0.5

(**Source:** National Institute of Nutrition, 2007)

Papaya is widely grown in 57 different countries of the tropical and sub-tropical regions of the world (Fig 1). India, Brazil, Indonesia, Mexico and Nigeria are the leading papaya growing countries. India is the largest producer of papaya (Table 2) with a share of 8.35% of the total world production (in 2010).

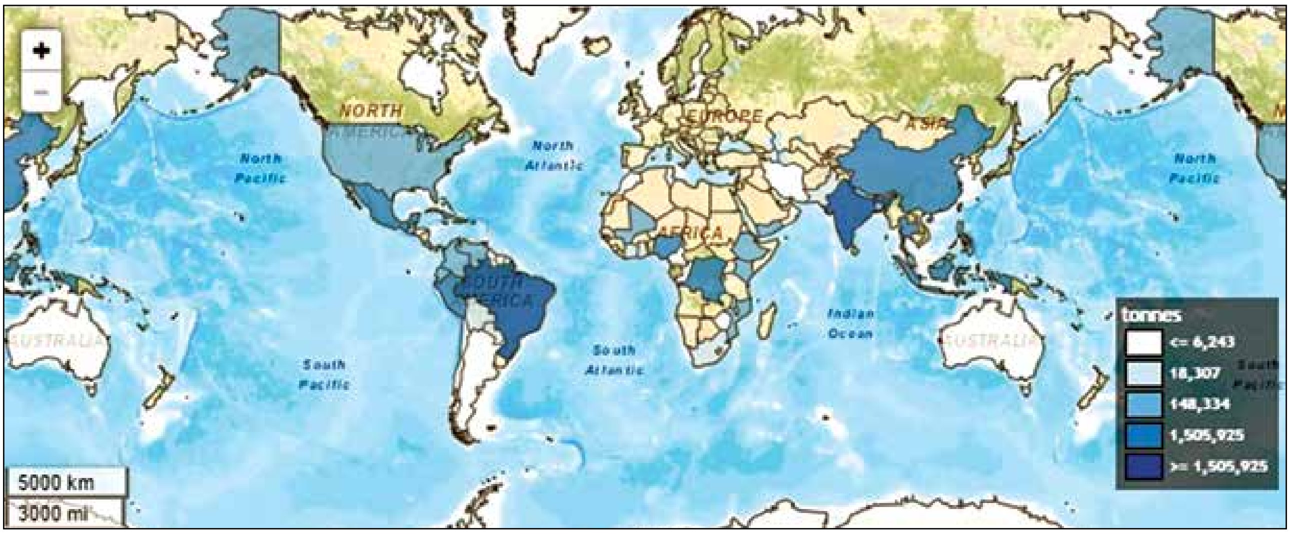
Table 2: Area, Production and Productivity of papaya in Top 5 Countries of the World

Year 2013	Value (ha) tonnes
India	5544000
Brazil	1582638
Indonesia	871275
Nigeria	773000
Mexico	764514

(**Source:** FAO, 2013)

In India it is grown in 129130 ha (FAO 2013) with a total production of 55.4 lakh tonnes. Some of the popular varieties are Arka Surya, ArkaPrabhath, Pusa Majesty, Pusa Delecious, Pusa Dwarf, Pusa Nanha, Coorg Honey Dew, Arka Surya, Solo, Red lady, Ranchi, CO. 2, CO.5, C.7, CO.6, and Barwani.

Fig 1 : Geographical Area and Production average of Papaya (1993 to 2013)



(**Source:** Reproduced from FAO [http://faostat3.fao.org/browse/Q/QC/E]).

1.2 Taxonomy

Papaya, *Carica papaya* L. (2n =18), belongs to the family *Caricaceae* (Table 3). It contains herbaceous, shrubby or arborescent plants with a well developed system of articulated laticifers. The usually sparsely branched plants are mostly dioecious and bear berry like fruits (Badillo, 2000). The taxonomic status of Papaya is as follows:

Table 3: Taxonomic Classification of Papaya

Kingdom	*Plantae*
Subkingdom	*Tracheobionta*
Superdivision	*Spermatophyta*
Division	*Magnoliophyta*
Class	*Magnoliopsida*
Subclass	*Dilleniidae*
Order	*Violales*
Family	*Caricaceae*
Genus	*Carica L.*
Species	*Carica papaya L.*

Caricaceae consists of six, relatively small genera with 35 species, all of which are American except *Cylicomorpha* which is from West Africa.

Until recently, the *Caricaceae* was thought to comprise 31 species in three genera (namely *Carica*, *Jacaratia* and *Jarilla*) from tropical America and one genus, *Cylicomorpha*, from equatorial Africa (Nakasone & Paull 1998). However, a recent taxonomic revision proposed that some species formerly assigned to *Carica* were more appropriately classified in the genus *Vasconcellea* (Badillo 2002). Accordingly, the family's classification has been revised to comprise *Cylicomorpha* and five South and Central American genera (*Carica*, *Jacaratia*, *Jarilla*, *Horovitzia* and *Vasconcellea*) with *Carica papaya* as the only species within the genus *Carica* (Badillo 2002). Apart from *Carica papaya*, none of the *Vasconcellea* spp are grown in India.

The distribution of different genera is as follows:

i. *Cyclicomorpha*: It is the only genus of the family that is restricted to humid habitat and occurs in mountainous forests of equatorial Africa.

ii. *Horovitzia*: It is a monotypic genus of hairy herbaceous plants, endemic to Mexico.

iii. *Jarilla*: This genus consists of three herbaceous species; all restricted to southern Mexico and Guatemala.

iv. *Jacaratia*: It contains seven species of trees with compound leaves, distributed from Mexico to the north of Argentina.

v. *Vasconcellea*: The largest genus of the family with 21 species, has only recently been resurrected on a generic level based on morphological and genetic characteristics (Aradhya *et al.*, 1999 and Badillo (2000).Due to their morphological resemblance to the common papaya and occurrence in higher altitudes of Ecuador, Colombia, Venezuela and North of Argentina, *Vasconcellea* spp. are often referred to as highland or mountain papayas. However the fruits are smaller, less succulent and quite different in taste. Since *Vasconcellea* seems to be a young complex network of closely related species, the following species complexes with different subspecies might be recognized within *Vasconcellea*:

Complex 1 : *V. stipulata, V. × heilbornii, V. weberbaueri, V. Parviflora*

Complex 2: *V. quercifolia, V. chilensis, V. candicans (+ V. crassipetala?)*

Complex 3: All other analyzed taxa (+ *V. crassipetala*).

vi. *Carica*: *Carica* is mono specific containing the best known and economically most important species of this family, namely papaya. *C. papaya* diverged from the rest of *Carica* species early in the evolution of this genus Kim *et.*, *al* (2002).

2. GEOGRAPHIC ORIGIN AND DISTRIBUTION

2.1 Geographical Origin and Distribution

Carica papaya is believed to have originated in the lowlands of eastern Central America, from Mexico to Panama (Nakasone and Paul, 1998). The genus *Carica* L., is presumed to have originated from natural hybridization involving *C. peltata* Hook. It spread to the Caribbean and Southeast Asia during the 16th century. It was introduced to India during early part of 16th century from Philippines through Malaysia and has only one species of papaya namely *C. papaya*. Genetic diversity studies among thirteen commercially grown cultivars of India have show that dioecious cultivars form a separate group from that of monoecious cultivars (Kanupriya *et al.*, 2012).

3. REPRODUCTIVE BIOLOGY

3.1 Growth and Development

Papaya is a small, herbaceous, semi perennial dicotyledonous plant. The plant can live up to 14-20 years, however, due to its height and susceptibility to diseases, the commercial life of a papaya plant is normally 2–4 years. The tree has a hollow trunk which is thick and spongy and is marked with scars of fallen leaves, with no lateral branches. Occasionally however, 2 or 3 branches are seen when the growing apex is damaged. The mature stem bears a tuft of leaves at the apex. Stem diameters of adult plants vary from 1m to 1.3m at the base to 5–10 cm at the crown. The plant bears 15 to 20 leaves which are large, palmate, deeply lobed with pinnately reticulate venations. Petiole is long, hollow and green, sometimes with purple pigmentation. Latex vessels are present all over the plant. The loss of leaves on the lower section of the plant and the continuous emergence of new ones at the apex gives the canopy a sort of umbrella like shape.

The root system of papaya is extensive and dense. Young roots show well differentiated epidermis, cortex and endodermis. The papaya root is predominantly a non axis, fibrous system. Healthy roots are of a whitish cream colour, and no laticifers have been observed in them (Jimenez, *et al*, 2014). Fruits are berries with seeds in the fruit cavity. The shape of the fruit can vary from oval to round.

3.2 Floral Biology

Once the plant reaches maturity, flowering occurs throughout the year in India. Papaya varieties can be classified into three types as being monoecious, dioecious and gynodioecious. The monoecious varieties have plants that bear both the male and the female flowers on the same tree. The dioecious varieties are those that have plants which bear either only the male flowers or only the female flowers. Gynodioecious varieties have plants with either a hermaphrodite flower also called the true flower, and plants with only the female flowers (Fig 2A-C).

Staminate or male flowers

The flowers are bracteolate, sessile in cluster or raceme with incomplete and actinomorphic flowers (radially symmetrical).The calyx consists of five lobes, which are united (gamosepalous) and small. The corolla consists of five petals, which are gemopetalous, (composed of partially or wholly fused petals forming a corolla shaped like a tube or funnel) elongated and yellow in colour. The androecium consists of 10 stamens in two whorls and epipetalous. The anthers are bilocular and introse (oblong) (Fig. 3 A).

Pistillate or Female flowers

The pistillate flowers are sub-sessile and bracteolate. The gamosepalous calyx consists of five sepals which are light green in colour. The corolla has 5 petals and is linear, with twisted activation. Androecium is absent in pistillate flowers and gynoecium is sessile. The style is very short with a five lobed stigma. Ovary is superior monocarpellary placentation with numerous seeds. The fruit is a berry, which is pulpy in nature. Seeds are blackish to light brown in colour, straight embryo and fleshy endosperm. The cotyledons are oblong and flat (Fig. 3 B).

Hermaphrodite or bisexual flowers

The hermaphrodite or bisexual flowers are also called as true flowers. These have both the ovary and stamens. Inflorescence is multi-flowered and contains 5-6 flowers. Corolla is gamopetalous. There are 10 and 5 stamens placed in two whorls, and sessile at the base of petals. The ovary is functional, having five locules with parietal placentation (Fig. 3 C).

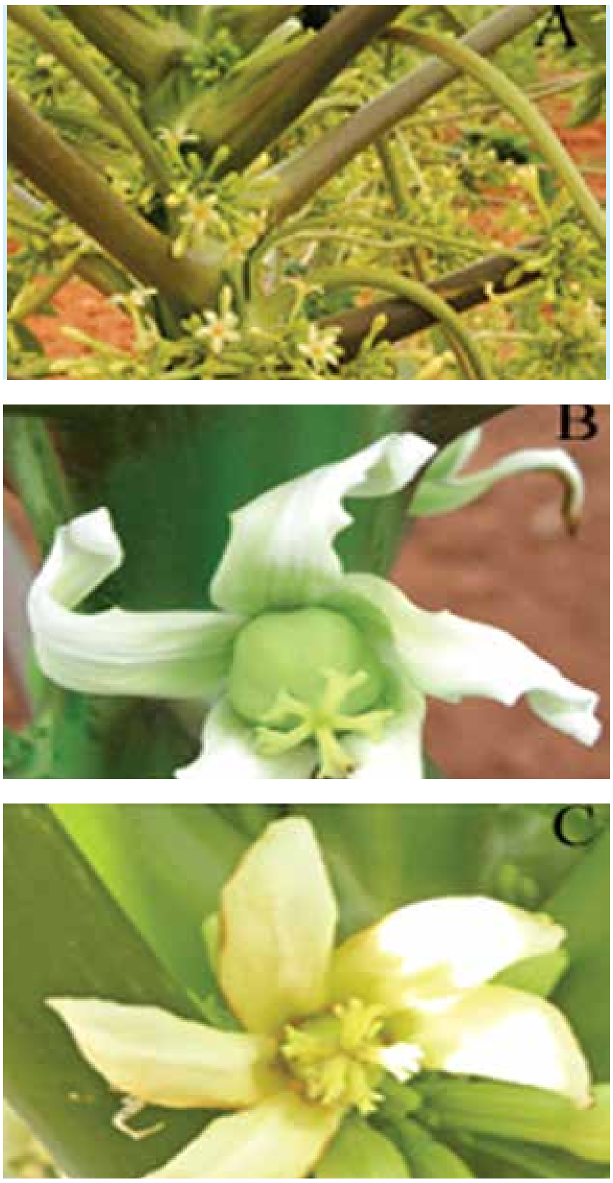


Fig. 2 A-C: View of Male inflorescence (A), close up of female flower (B) and Hermaphrodite flower (C)

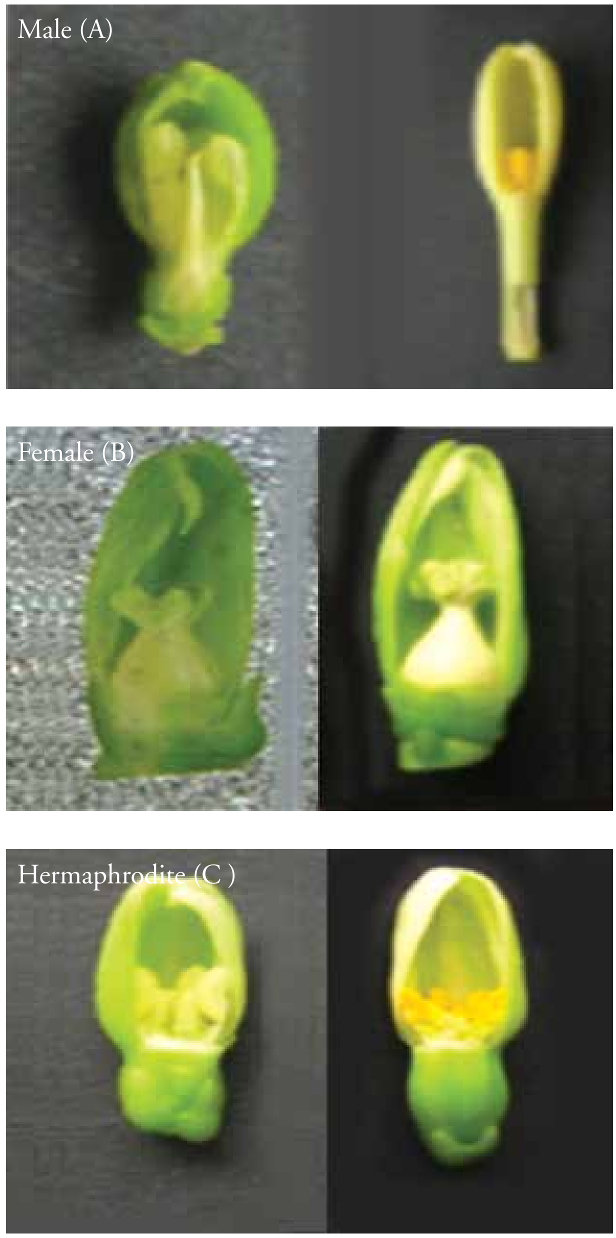


Fig. 3 A-C: Longitudinal section of Male (A), Female (B) and Hermaphrodite (C) Flowers

Variation depending on climate has been noticed with regard to dehiscence of the anther. It takes place 24 hours before anthesis in all species of *Carica*. However, there have been reports that dehiscence in staminate and hermaphrodite flowers takes place between 10 to 12 hours before anthesis. High temperature and low humidity hasten the time of anther dehiscence. Papaya is also recognized as being polygamous because in some varieties, variation in sex expression can occur with change in environmental conditions and or with the age of the plant (Blanco, 1883).

3.3 Pollination and Fertilization

Pollination by insects (hawkmoths in Australia) and by wind have been studied. Evidence in favour of wind pollination is the fact that the pollen are light and high papaya pollen count (10-18% of total aero pollen) has been recorded on the outskirts of Kolkatta (Chakraborty *et al*, 2007). Pollen remains viable for 2 days before and after anthesis, with maximum viability on the day of anthesis. At room temperature, and 50% relative humidity, pollen remains viable for 48 hrs.

The receptivity of stigma as evidenced by percentage of fruit set has been found to be maximum on the day of anthesis. Stigma receptivity of female and hermaphrodite flowers remains for two days before and after anthesis.

3.4 Studies on Pollen flow

Rodriguez *et al.*(1990) demonstrated that 90% and 94.7% of fruit set occurs in flowers that have been bagged before dehiscence in cultivars 'Sunrise Solo' and 'Kapoho solo' respectively. Out crossing can be thus limited in hermaphrodite flowers by bagging them. Here the unopened flower bud is covered with a light paper bag which is secured with a string or a plastictie until after the flower opens and can be left in place. Fruit set occurs in bagged flowers either by self pollination (65%) or by parthenocarpy (35%) in the cultivar 'Sunrise Solo'. Bagging can be resorted to in transgenic plants to prevent pollen flow.

4. COMMERCIAL SEED PRODUCTION IN INDIA

Gynodioecious varieties are preferred by seed companies for commercial seed production. These varieties do not have male plants. The female plants are removed from the farm as soon as flowering occurs since these are less productive. The hermaphrodite plants are retained and flowers are bagged 2-3 days before anthesis. Self pollination takes place and the growing fruit breaks open the bag and comes out. The bags are left in place to identify fruits with true to type seeds from those that have been self pollinated. Reproductive isolation for commercial production of fruit for consumption is not required since purity of seed is not a concern.

4.1 Gynodieocious Varieties

i) Fruit production in gynodieocious varieties for consumption

In case of gynodieocious varieties, there are 2 types of plants, namely, plants with only female flowers or hermaphrodite plants with bisexual flowers. Fruit set will occur by self pollination in plants with bisexual flowers. Plants with only female flowers can be allowed to be wind pollinated with pollen from any (not necessarily of same variety) male plants. The ratio recommended is generally 1 male plant for every 10-25 female plants.

ii) Seed production in gynodieocious varieties

When pollination has to be carried out for purposes of seed production, it is done inside protected structures such as a nethouse. All hermaphrodite plants will set fruit by self pollination. Alternatively, all hermaphrodite plants are raised in the open and flowers are bagged 2 days before anthesis. In the case of plants with only female flowers, these are generally removed by commercial seed production units.

4.2 Dioecious Varieties

i) Fruit production in dioecious varieties

In the case of dioecious varieties, fruit production for commercial purposes is straight forward. Plants with female flowers can be raised in the open and allowed to be pollinated with male or hermaphrodite plant (of any variety) as mentioned above, where one male plant can be raised along with 15-20 female plants.

ii) Seed production in Dioecious Varieties

In the case of dioecious varieties, plants with male flowers are raised in protected structures or alternatively they are raised in the open and all flowers on the male plant are covered with a butter paper bag 2-3 days before dehiscence and the flower along with the bag is harvested for pollinating female flowers. Plants with female flowers are raised in the open and bagged after pollinating with pollen from male plants. An isolation distance of 400m is maintained from the nearest papaya field.

4.3 Studies on Isolation Distance for Seed Production

Studies on genetically modified (GM) papaya have advanced our understanding of the isolation distances required for obtaining pure seed of a given variety of papaya without having to bag the flowers. Manshardt *et al.*,(2007) used a colorimetric assay for beta-glucuronidase (GUS), a marker introduced in transgenic papaya, to track pollen movement from a central 0.5-ha plot of gynodioecious transgenic 'Rainbow' plants, by seed assays on plants in surrounding border rows of non-transgenic 'Sunrise' papaya. Evidence of cross-pollination occurred in 70% of female plants (43% of assayed seeds), compared with only 13% of the predominantly self pollinating hermaphrodite plants (7% of seeds) segregating in the gynodioecious 'Sunrise' border rows. The percentage of GUS positive seeds in border row plants showed a weak negative correlation (r= -0.32) with distance from the nearest transgenic tree (30m). In a non-transgenic papaya field located 400m downwind from the 'Rainbow' source, no evidence of GUS was found in 1000 seeds assayed, clearly indicating that 400m is an adequate isolation distance and that hermaphrodite plants may be recommended for border rows. Based on these studies, various organizations and agencies have specified isolation distances for growing papaya (OGTR, 2008). The Hawaiian Identity Preservation Protocol for non GM papaya seed production specifies a minimum of 400m, isolation from other varieties. Papaya Biotechnology Network of South East Asia has proposed that non GM papaya should be separated by 400m from GM papaya. USDA-APHIS has approved an isolation distance of 500m for GM papaya field trials.

5. ECOLOGICAL INTERACTIONS

Stray cultivated open pollinated seedling derived plants are found throughout India as backyard crop. However, these have not become weedy or invasive. In managed agricultural systems, papaya is easily controlled by manual weeding and volunteer plants are not regarded as a weed problem (OGTR, 2008). With regard to factors relevant to the potential weediness of papaya in unmanaged environments, there are two types of considerations.

(i) Attributes that might predispose papaya to weediness include:

- Papaya persists after cultivation and spreads along roadsides and disturbed habitats where other plants have not established (OECD, 2005).
- Papaya fruit is consumed by a wide range of vertebrates that could potentially spread seeds into ecological habitats (OGTR, 2008).
- Papaya has a pioneer ecology due to a number of features that include fast growth, short life cycle, prolific seed production, seed dormancy, and capacity to establish significant seed banks (OGTR, 2008).

(ii) Attributes that do not favour the establishment of the plant as a serious weed include: (OGTR, 2008)

- Trees yield well for two years, after which production declines.
- The plant does not have any significant asexual reproduction mechanism.
- Because of the highly complex capability in sexual expression, sex ratios for obtaining optimal fruit (and seed) set would be unlikely to occur without human intervention.

No reports of papaya as a weed are available in India.

5.1 Crossability between Different Species of Papaya

As India has only one species of papaya, this issue is of no concern.

5.2 Wild Relatives in India

Wild species of *Carica* do not occur in India.

5.3 Potential for Gene Transfer from Papaya

There is no information on the gene transfer of papaya with other species of plants. As such it may be safe to assume that gene transfer from papaya to other species does not occur.

5.4 Natural Interspecific and Intergeneric crossing

India does not have any population of wild species of papaya. Hence there is no likelihood of genes transferring naturally to wild papaya species

5.5 Free Living Populations of Papaya

Since it is not native to India, free-living populations are not found.

6. HUMAN HEALTH CONSIDERATIONS

6.1 Allergens

Papain, a product of papaya latex, is widely used both in the food manufacturing and pharmaceutical industries. Sensitization to papain among workers in these industries is well known (Iliev & Elsner 1997). Immunoglobin E (IgE) antibodies against all four of the major papaya cysteine proteinases in latex (papain, chymopapain, *Carica* in and glycylendopeptidase) have been identified in people who show an allergic response to a pharmaceutical product derived from papaya latex (Dando *et al.* 1995).The presence of these antibodies demonstrates that all four cysteine proteinases are allergenic. *C papaya* may also have allergenic properties when ingested. For example, an allergic reaction, manifesting as a skin rash, has been reported following use of throat lozenges containing papaya extract. (Iliev & Elsner 1997) found that 50% of patients with latex allergy have hypersensitivity to certain plant foods, especially fruits; Diaz-Perales *et al.* (1999) noted that papaya fruits contain class I (allergenic) chitinases that correspond to proteins detected with a pool of sera from patients with latex fruit allergy. Latex-allergic patients may develop oropharyngeal itching (the oropharynges is a part of the pharynx at the back of the mouth) and angioederma (rapid swelling of the skin, mucosa and submucosal tissues, particularly around the mouth/ throat and hands; sometimes followed by itchiness) if they eat papaya (De Clerck. *et al.* 2007). An extreme allergic reaction to skin contact with unprocessed papaya fruit has also been reported (Ezeoke 1985). Papaya fruit pickers, manually harvesting fruit, are advised to wear gloves and protective clothing, as latex oozing from the fruit stalk may cause skin irritation (Morton 1987). Papaya pollen induces respiratory IgE-mediated allergy (Blanco1983) and one IgE-reactive, 100k Da protein component with esterase activity has been identified. The pollen can contribute significantly to the aeropollen and aeroallergen load in areas where papaya plants occur (Chakraborty *et al.* 2007).

6.2 Other Undesirable Effects of Phytochemicals

The antifertility properties of papaya, particularly of the seeds, have been the subject of significant evaluation using animal models, especially in India where there is interest in the development of a safe and effective oral male contraceptive (Lohiya *et al.* 1999). A complete loss of fertility has been reported in male rabbits, rats and monkeys fed an extract of papaya seeds (Lohiya *et al.* 1999; Pathak *et al.* 2000; Lohiya *et al.* 2002), suggesting that ingestion of papaya seeds may adversely affect the fertility of human males or other male mammals. In India and parts of south- east Asia and Indonesia, consumption of papaya fruit is widely believed to be harmful during pregnancy, since it is believed to have abortifacient properties (induces miscarriage during pregnancy) or teratogenic properties (causes malformations of the foetus) (Adebiyi *et al.* 2002). They also suggest that unripe papaya fruit may induce miscarriage in susceptible pregnant human females. But, (Eno *et al.* 2000) reported that papaya fruit extract is used for prevention of miscarriage by traditional African healers. A number of early studies, largely conducted in India had suggested that unripe papaya fruit, latex extracts or papaya seeds have deleterious effects on pregnancy in laboratory animals (Schmidt 1995). However, more recent analysis suggests that ripe papaya fruits or purified papain do not cause malformations of rat foetuses.

MEDICINAL VALUE OF PAPAYA

Papain, a proteolytic enzyme present in the latex, collected mainly from the immature green fruit, is an important commercial product of papaya. Carpine, an alkaloid present in papaya, can be used as a heart depressant, amoebicide and diuretic. In Papua New Guinea, papaya is used for treating skin rashes, sunburn and also to remove the brown spots of aging. Natives of Pacific Islands use all the parts of the papaya tree for medicinal purposes such as leaves, skin, seeds, bark, roots, flowers and the fruit. South American women massage thin slices of green papaya to stimulate milk glands. Papaya bark is used as a toothache remedy and the flowers in tea brews, to treat bronchial infections. For centuries, brews made from the roots were used to expel parasites and to alleviate bleeding, kidney colic, and jaundice. In 1875, T. P. Lucas, a British physician started a hospital in Brisbane, to treat patients solely with papaya.

7. PAPAYA CULTIVATION IN INDIA

7.1 Climate and Soil Requirements

i) Climate

Papaya grows well in tropical climate. It requires warm and humid climate and can be cultivated upto an elevation of about 1000 meters. Temperature below 10^0 C retards the process of maturity and ripening of fruits and to a certain extent the growth and setting of fruits. A dry climate characterized by a meager rainfall tends to add to the sweetness of fruit where as wet climate with heavy rainfall tends to reduce the sweetness. In North India, low temperature restricts the cultivation of papaya and also aggravates virus problem. Papaya production is possible in all parts of South India. Though it prefers humidity, papaya is affected by water stagnation and also by strong winds

ii) Soil

A well drained sandy loamy soil rich in NPK with pH 6-7 is the best for papaya cultivation (Shanmugavelu, 1987). Papaya is an evergreen plant and bears flowers or fruits for most part of the year; hence it requires a soil of high fertility. Adequate drainage and soil aeration are very important factors. Being a shallow rooted plant, papaya can be grown in soils about 45 cm deep.

7.2 Nutrition

Several trials have been conducted in different regions to determine the NPK needs of dioecious and gynodioecious varieties of papaya. A dose of 250g of N, 250g P_2O5 and 1000g K_2O given in six split applications, was found to be the best for Coorg Honey Dew variety. It has been observed that the TSS (total soluble solids) was significantly influenced by K and interaction between N and K. Application of micro nutrients like boron, zinc and iron to different cultivars of papaya has shown good response and proved to be effective for the growth and production of papaya. Boron deficiency in papaya is quite serious as it causes deformation and bumpy rough appearance on the fruits. Application of Farm Yard Manure improves the vigour of the plant and application of K increases the size of the fruit . Vesicular arbuscular mycorrhizal *VAM* coupled with vermicompost has been reported to increase yield. Experiments carried out on fertigation have shown that applying N and P by drip irrigation improves growth as well as yield.

7.3 Interculture and Weeding

Weeding should be done regularly to keep the field weed free. Black polythene mulch has been reported as giving significant increase in growth and yield of papaya. Peat and sawdust mulches are also found to be useful.

7.4 Irrigation

Papaya responds well to better water management. Adequate irrigation helps in rapid fruit development and regular yield. The plant is highly sensitive to waterlogged condition and hence it is most important to prevent water logging. In well drained soils, irrigation at shorter intervals during the early crop stages results in good establishment and also encourages better plant development. The dense root system is fairly drought resistant, but irrigation may be required in dry months. In general, irrigation to grown up plants is given once in 7-10 days.

7.5 Harvest

Mature fruits ripen within two or three days and the colour changes from green to yellowish green. Ripe fruits may also be harvested from the trees but they are often damaged by birds, so it is advisable to harvest the fruits when mature. When the latex of the fruit become almost watery, the fruit is considered ready for harvest. The fruits should be harvested individually with hand taking care to avoid all possible injuries. The first crop of fruits is harvested 12-14 months after transplanting. High relative humidity and comparatively high temperature during ripening period are not conducive to development of attractive fruit colour. The fruits tend to remain pale green even when ripe. Selvaraj *et al.*, (1982) observed that the dry matter increased at harvest while alcohol insoluble solids, starch and several minerals decreased. Ripening in papaya is characterized by an increase in the activities of invertase, cellulase, pectinesterase, catalase, peroxidase, adenosine triphosphatase, acid phosphatase, polyphenol oxidase and mitochondrial glutamate dehydrogenase and by decrease in levels of amylase, ribonuclease, mitochondrial adenosine triphosphatase, NADH diphorase and malic dehydrogenase, and of RNA, DNA, protein and mitochondrial protein contents (Pal and Selvaraj, 1987). Dramatic changes were observed when fruits reached maturity at 90 days after pollination, which corresponded to change in flesh colour from white to yellow and seed colour from white to brown or black.

7.6 Yield

Fertility of the soil, cultural conditions and cultivar are the factors influencing yield which varies considerably ranging from 50-100 tons. Each tree bears about 150 fruits, each weighing 0.45 to 7.2 kg in the first 2 years which starts declining thereafter.

8 PESTS AND DISEASES

8.1 Insect Pests and Nematodes occuring on Papaya

Very few insect pests have been reported on papaya. Among the important ones are mites (*Tetranychus cinnabarinus*), aphids (*Myzus* species) which also transmit PRSV and scale insects. Mealy bug (*Paracoccus marginatus*) occurs in Andaman Nicobar Islands and causes malformation due to toxin injected during feeding; the plant has a stunted growth and yellowing of leaves occur. Sooty mould on leaves occurs due to honey dew secretions of the bug. Two species of nematodes namely reniform nematode – *Rotylenchulus reniformis* occurring mainly in the nursery stage and Root-knot nematode *Meloidogyne incognita* occurring on papaya at all stages of its growth have been reported from India. The former causes symptoms similar to micronutrient deficiency and water stress, while the later causes stunting in the growth of the plant and fruits are insipid.

8.2 Important Diseases

Several fungal and viral diseases affect papaya. The important ones are: Damping off, Stem or Collar Rot, Powdery Mildew, Anthracnose, Leaf Spot, Fruit Rot, Papaya Ringspot Virus (PRSV), & Papaya Leaf Curl Virus

i) Damping off

Two types of damping off occur namely (a) pre emergence and (b) post emergence. Pre emergence causes complete rotting of radical and plumule. Post emergence causes toppling over of the infected seedlings. Infection occurs at ground level. Infected tissue is water soaked and becomes soft as a result of which, seedling collapses (Fig 4). The causative organism is *Rhizoctonia solani*.

Fig. 4 Damping off in papaya caused by *Ralstonia solani.*

ii) Stem Rot or Collar Rot

Stem rot is most common in trees that are 2-3 years old. It is first appears during monsoon season when the temperature is above 24°C. Black coloured girdling of the stem (Fig 5) and blocking of vascular bundles occursleading to the wilting of the plants. The causative organism is *Pythium aphanidermatum*.When the stem is cut open, dark brown discoloration is seen (Fig 6).

Fig 5: Papaya Stem rot or collar rotcaused by *Pythium aphanidermatum.*

Fig 6: Cut out of the affected portion of papaya with stem rot or collar rot to show damage caused by *Pythium aphanidermatum.*

iii) Papaya Foot Rot

In well grown mature trees of papaya, the disease caused by the same organism, namely *Pythium aphandermatum*, is often referred to as foot rot since it occurs at the base of the trunk (Fig 7). It occurs as apost monsoon disease in thetropics. Infection occurs at the base of the plant causing rotting of the infected region and collapse of the plant. In very mature trees, the disease can sometimes be seen only on one side of the stem (Fig 8) and an early intervention at this point of time, can save the plant. Neglected orchards show extensive falling of trees (Fig 9)

Fig 7: Foot rot in papaya causative organism is *Pythium aphandermatum.*

Fig 8: Close up of foot rot in papaya causative organism is *Pythium aphandermatum*.

Fig 9: Field view of papaya affected by *Pythium aphandermatum* (Note several trees have fallen down)

iv) Papaya Phytophthora Blight caused by (*Phytophthor anicotinae var. parasitica*)

This pathogen causes both fruit and stem rotting and the disease isserious during monsoon season in areas where there is poor drainage. Rotting of the roots is the major symptom whileoozing of gum from the infected stem is the characteristic of *Phytophthora*. The leaves turn pale and dull and the infected plants show wilting and sudden death (Fig 10). Purple coloured lesions are quite predominant on fruits (Fig 11).

Fig10: Papaya field affected with *Phytophthora*.
Note the dull and pale leaves and wilting symptoms on affected trees.

Fig11: Close up of papaya fruits affected with ***Phytophthor anicotinae var. Parasitica*** (Note the purple patches on fruits)

v) Powdery mildew in papaya

Powdery mildew occurs on papaya during dry cloudy weather. There are two causative organisms for powdery mildew in papaya.

Powdery mildew caused by *Oidium carcicae.* White powdery patches appear on both sides of the leaf (Fig 12a-b). As the disease progresses, the leaf becomes dull and looses turgidity and eventually falls off. The disease also occurs on flower buds causing fruit drop.

Fig12 a: Powdery mildew in papaya caused by *Oidium carcicae.*

Fig 12b: White patches on the leaf, abaxial side on the left and axial side on the right.

vi) Papaya Powdery mildew caused by *Laveillula taurica*

Powdery mildew caused by *Laveillula taurica*, a obligate pathogen is more serious than Oidiumcarcicae. The disease occurs mainly on the upper surface of the leaf which is covered with pale olive spots while the lower surface has greyish submerged patches with water soaked boundaries (Fig 13). This disease causes extensive defoliation anddeath of the plant.

Fig 13: Powdery mildew in papaya caused by *Laveillula taurica.*

vii) Papaya Anthracnose (*Colletotrichum gloeosporioides*)

This disease occurs on fruits while they are still on the tree, the disease develops into large scars on the fruits as they ripen after harvest (Fig 14).

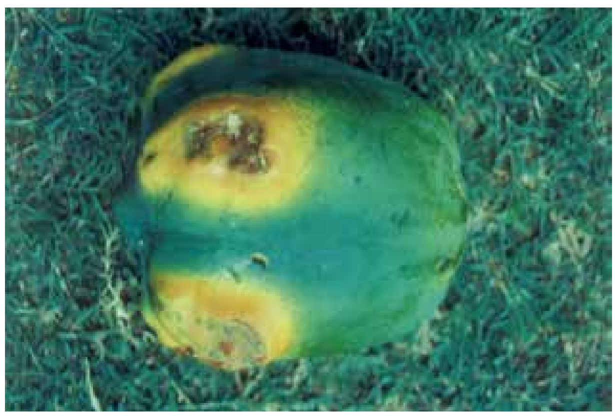


Fig 14: Papaya Anthracnose caused by *Colletotrichum gloeosporioides*

viii) Papaya Black Spot caused by *Asparisporium caricae*

This is a serious post monsoon disease on papaya and is characterised as dark black spots on the underside of the leaf (Fig 15).

Fig15: Black spot of papaya caused by *Asparisporium caricae*

ix) Leaf and fruit blight of papaya

This is a serious disease occurring on leaves, fruit and stem. In severe cases it affects the crown of the plant causing it to rot and die (Fig 16). The disease is common in winter months and is caused by *Alternaria alternata*.

Fig 16: Leaf blight in papaya caused by *Alternaria alternate*. Note the death of the crown.

x) Grey leaf spot of papaya caused by *Ascochyta caricae*

This disease occurs in peninsular India. The leaf has greyish white spots with necrotic lesions (Fig 17).

Fig 17: Grey leaf spot of papaya caused by *Ascochyta caricae.*

xi) Brown spot of papaya caused by *Cercospora caricae*

The disease is seen on the leaves as well as fruits. It is characterised by dark brown spots on the leaf & fruit (Fig 18 a-b)

Fig 18 a: Brown spot disease of papaya caused by *Cercospora,* symptoms on leaf

Fig 18 b: Brown spot disease of papaya caused by *Cercospora*, symptoms on fruit.

xii) Other fruit rots and Boron deficiency

Post harvest fruit rots cause considerable yield loss in papaya. Some of the important diseases occurring in India are caused by Botyodiplodia, *Curvularia lunata*, *Rhizopus* & Yeast (Figs 19-22). Among mineral deficiencies in the country, Boron deficiency is notable and causes a fruit deformity called mumps (Fig 23).

Fig 19: Fruit rot caused by *Botyodiplodia*.

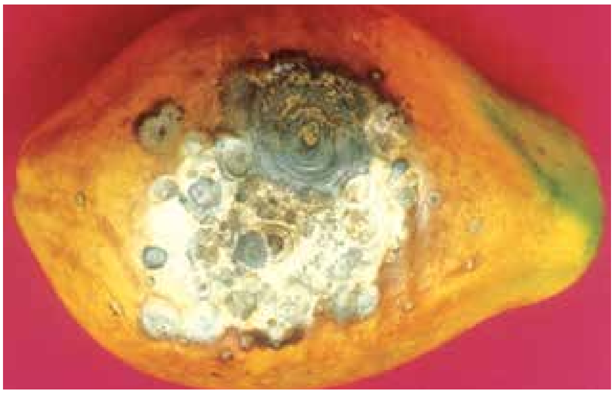


Fig 20: Fruit rot caused by *Curvularia lunata*.

Fig 21: Post harvest disease of papaya. Fruit rot caused by *Rhizopus*.

Fig 22: Fruit rot caused by Yeast Infection.

Fig 23: Papaya Mumps caused by Boron deficiency.

xiii) Viral diseases of papaya

Among viral diseases, Papaya Ring Spot Virus (Fig 24)and Papaya Leaf Curl Virus are two most important diseases. These not only cause unmarketable fruits during early stages of infection but also cause reduction in yield and death of the plant.

Fig 24: Papaya Ring Spot Virus (PRSV) symptoms on leaf

9 BREEDING OBJECTIVES IN INDIA

Hybridization work was taken up in different research centers throughout the country with the following objectives:

- To evolve varieties, which are gynodioecious
- To evolve varieties with high total soluble solids (TSS), small cavity and good keeping quality
- To evolve varieties, which are resistant to papaya ring spot virus and leaf curl virus.
- To develop varieties suitable for both papain extraction and high fruit yield

Most of the breeding programs in earlier times involved inter varietal crosses with introduced cultivars from Hawaii, Africa etc of *Carica papaya*. Attempts to cross cultivated varieties of papaya with *Vasconcellea cauliflora* to transfer resistance to PRSV were not successful due to embryo abortion at 70-90 days. Embryo rescue helped establish some crossed progeny but level of resistance was not high (Iyer *et al.*, 1987)

10 BIOTECHNOLOGICAL INTERVENTIONS

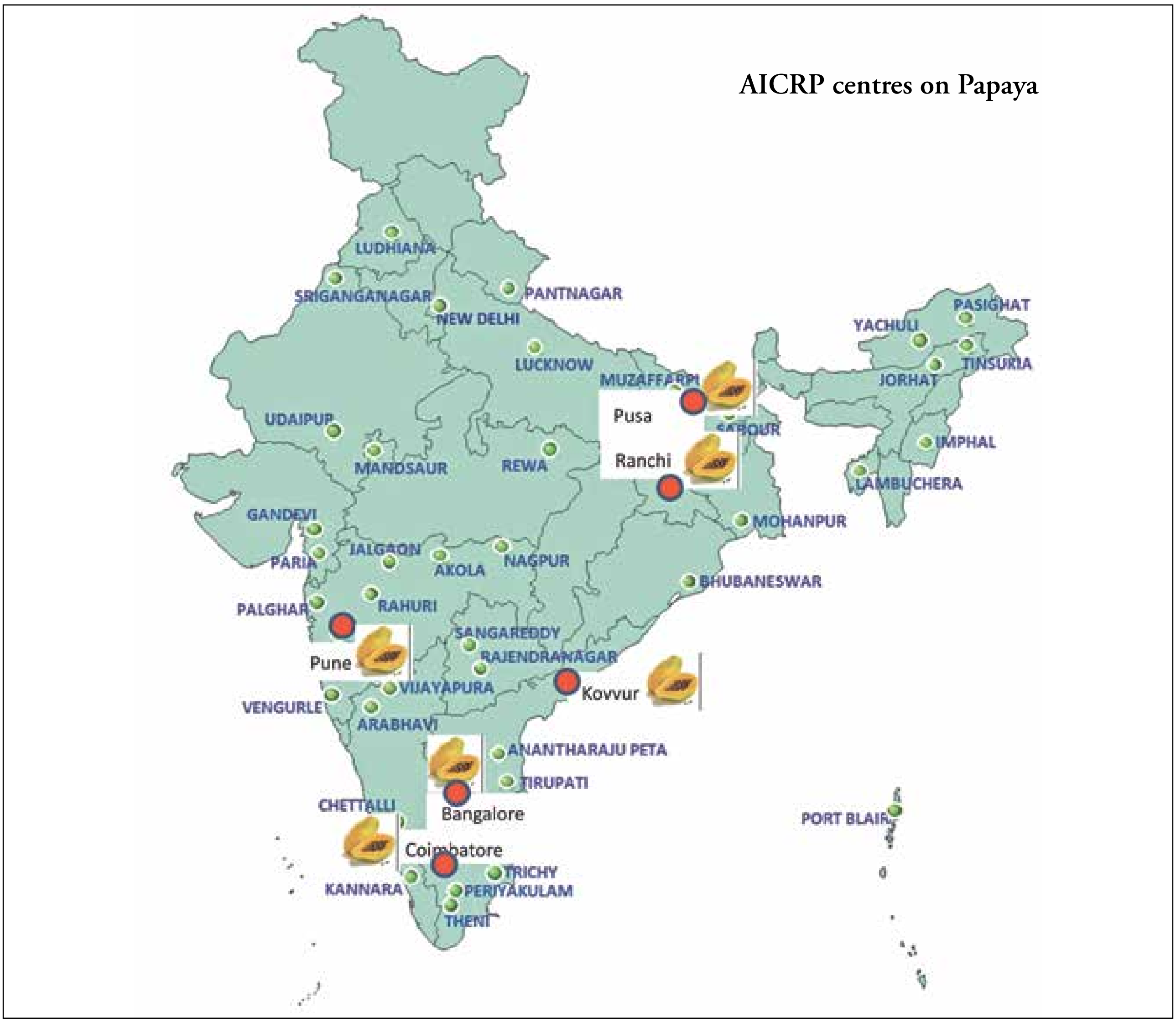
The use of pathogen derived resistance has been successfully demonstrated against Papaya Ring Spot Virus by expressing coat protein gene of the virus in transgenic Rainbow variety of papaya in Hawaii. Subsequently other countries have also adopted this technology. Since the resistance offered by coat protein is only against the cognate strain of the virus from which the gene has been derived, attempts through RNAi and DsRNA against multiple strains of the virus have been initiated in a number of labs in the country.

11 VARIETAL TESTING SYSTEM IN INDIA

Varietal testing in papaya is carried out under the 'All India Coordinated Research Programme' of Fruits (AICRP). Research and evaluation is carried out in various institute located in different agro climatic zones.(AICRP) was initiated during Fourth Five Year Plan. Testing is carried out both by the State Agricultural Universities (SAUs) and ICAR research institutes co-ordinatedly to find solutions to various problems and to evaluate the suitability, adoptability and transferability of the technology in different ecological regions of the country. At present there are 6 centers on papaya. In the east it is being carried out at Fruit Research Station, Kovvur, in the West at the ICAR-IARI center of Pune, in the North at Pusa and Ranchi and in the south at TNAU, Coimbatore and at Indian Institute of Horticultural Research (ICAR-IIHR), Hessaraghatta. Germplasm collection of cultivated varieties and different species of papaya are being maintained at both TNAU and ICAR-IIHR

The broad objectives of AICRP are:

1. Collection, conservation and evaluation of germplasm for its utilisation in hybridisation programme.
2. Evaluation of varieties developed in the country for its suitability in different Agro-climatic zones.
3. Standardization of production technology, population density, nutrition, cropping system, weed control and water management under different ecological regions.
4. Standardization of crop protection techniques through efficient management of insect pests and diseases. AICRP on Tropical Fruits is head quartered at ICAR-IIHR, Bangalore and its centres .



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