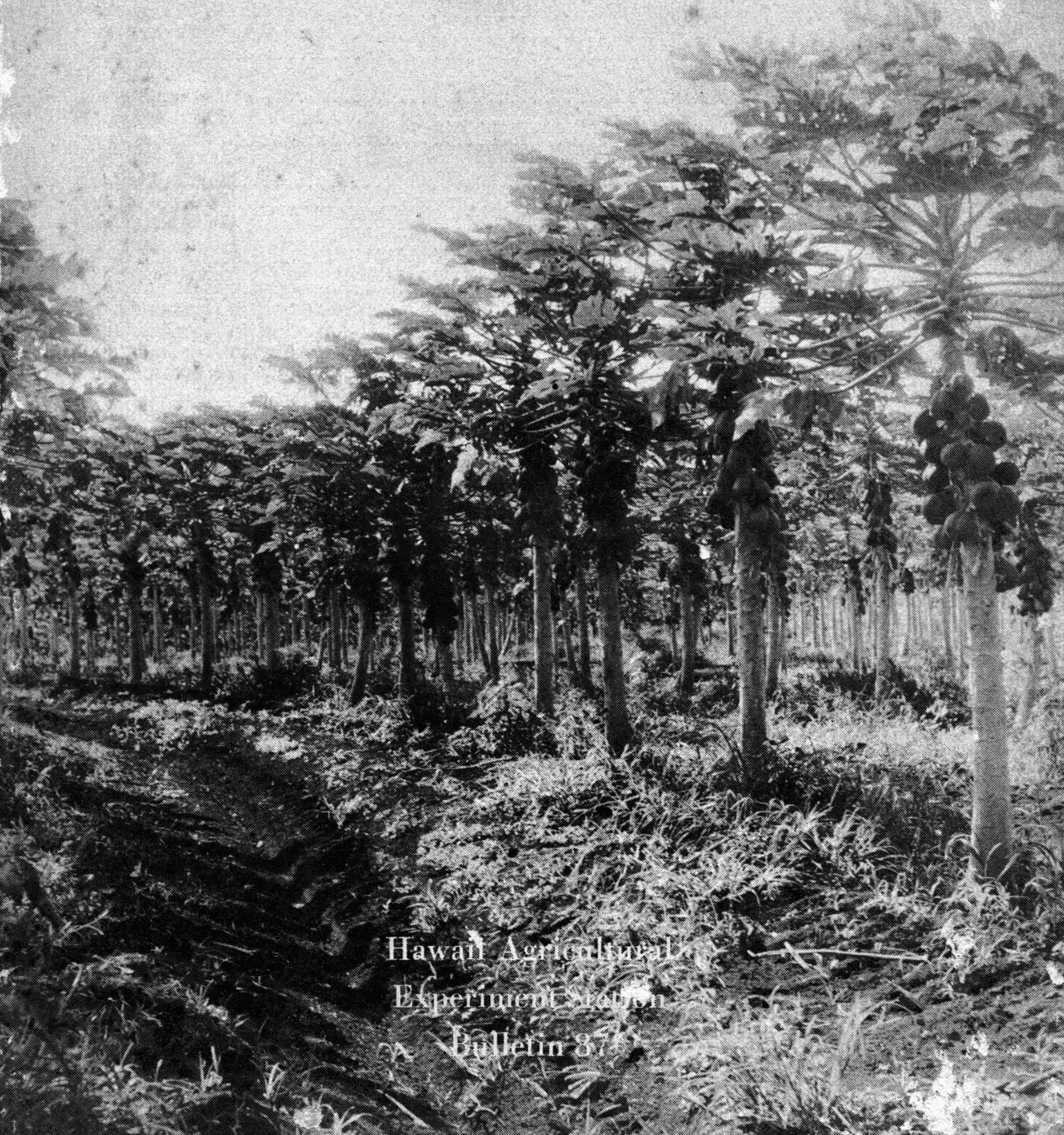
PAPAYA PRODUCTION IN THE HAWAIIAN ISLANDS



Hawaii Agricultural
Experiment Station
Bulletin 87

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HAWAII AGRICULTURAL EXPERIMENT STATION
of the
UNIVERSITY OF HAWAII

BULLETIN NO. 87

PAPAYA PRODUCTION IN THE HAWAIIAN ISLANDS

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HONOLULU, T. H.
June 1941

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THIS BULLETIN is designed to take the place of two previous bulletins on papaya culture (*18, 40*), now out of print, and in addition to present results of subsequent experimental studies, particularly those on sex determination and on treatment of fruits for mainland shipment.

PART I. THE BOTANY AND SEX RELATIONSHIPS OF THE PAPAYA

by W. B. STOREY

The papaya, as well as other species of *Carica,* is native to tropical America, though the country of its origin has not been determined. De Candolle (*5*) advanced evidence to support his contention that the species must have originated in the West Indies or in Central America near the shores of the Gulf of Mexico. Solms-Laubach (*49*) believed that the cultivated papaya arose as a hybrid between two species of *Carica* native to Mexico. Popenoe (*41*) calls attention to evidence indicating that the species originally came from Mexico.

During the seventeenth and eighteenth centuries the papaya spread rapidly and was brought into cultivation in all parts of the tropical world. De Candolle (*5*) mentioned the statement of Sloane that it was taken from the West Indies into Asia and Africa early in the eighteenth century. Popenoe (*41*) made reference to the writings of the Dutch traveler Linschoten, who, in 1598, stated that the papaya was transported from the Spanish Indies to Malacca and thence to India. Watt (*58*) reported that seeds were taken from India to Naples, Italy, in 1626. From either Malacca or the Philippine Islands the papaya is believed to have been spread rapidly by seed through the islands of the South Pacific Ocean. Sturtevant (*53*) stated that it had been widely distributed in the islands of the Pacific by the year 1800. It appears to have been introduced into Hawaii from the Marquesas Islands some time between 1800 and 1823 by Don Marin, an early Spanish settler.

At the present time the papaya is found in cultivation in all of the tropical countries of the world and in some subtropical regions as far north and south as 32 degrees of latitude. In continental United States it is grown principally in Florida but also to a limited extent in the relatively frost-free areas of Texas and California (Wolfe and Lynch, *59*).

Botanical and Common Names

The binomial *Carica papaya* L. is now generally accepted by botanists as the valid specific name of the papaya. Other designations such as *Carica mamaja* Velloso, *C. hermaphrodita* Blanco, *Papaya vulgaris* de Candolle, and *P. sativa* Lussac are synonyms whose use is no longer justified.

The American word papaya, a corruption of the Carib *ababai,* is the common name most generally used for the species. In some English-speaking countries the name papaw (or pawpaw) is in common use; the use of this term is unfortunate since it serves to confuse *C. papaya* with the unrelated species *Asimina triloba* Lunal., to which the name papaw has long been applied in North America. Other corruptions of *ababai* in use are *papaia, papeya,* and *papia.*

In Cuba the papaya is known as *fruta bomba* and in other restricted regions as tree melon, *melon zapote, lechoso, maneo,* and *mamoeiro.* Of local application only are the Hawaiian *milikane* and *he-i,* the Tahitian *iita,* and similar terms in other Polynesian dialects.

Botanical Relationships

The genera *Carica* and *Jacaratia* are now considered by botanists to constitute the family Caricaceae. The characters of *Carica* are so varied that botanists had previously classified it with the families Passifloraceae, Cucurbitaceae, Bixaceae, and Papayaceae (De Candolle, *4*).

Harms, in his monograph of the Caricaceae (in Engler and Prantl, *7, pp. 510–522*), stated that there are about 40 species of *Carica.* All of these are indigenous to the American tropics and are described as dioecious except *C. papaya,* in which hermaphrodite forms exist. Most of the species are single-stemmed, erect, herbaceous plants of relatively short stature, but in the genus are some species which branch freely and some which attain a height of 20 feet or more. Several species are found in cultivation, according to Heilborn (*17*), but only *C. papaya* has become of economic importance.

A chromosome number of 2N=18 appears to be uniform for the genus, judging from the species already examined cytologically. This number has been reported for *C. candamarcensis* Hook. fil., *C. cauliflora* Jacq., *C. chrysopetala* Heilborn, *C. papaya* L., *C. peltata* Hook. and Arn., *C. pentagonia* Heilborn, and *C. quercifolia* Benth. and Hook. The chromosomes of the several species, although apparently never studied in detail on a comparative basis, appear superficially to be more or less uniform as to size and morphology, suggesting a fairly close relationship among species. This is indicated further by the limited but nevertheless evident cross-compatibility, as illustrated by the production of a number of interspecific hybrids (*18*).

General Description

The papaya is a large, herbaceous, dicotyledonous plant, commonly referred to as a tree, consisting usually of a single erect stem surmounted with a crown of large leaves (see *cover illustration*). A number of ascending lateral branches may arise from vegetative buds in the leaf axils, either following injury to the growing point of the main stem or, in most strains of papaya, as natural growth after 2 or 3 years. The main stem and the branches are hollow. The wood is fleshy but quite firm. The bark is smooth and grayish, and is marked by large, prominent leaf scars.

The crowning clusters of leaves at the apexes of the trunk and branches comprise the foliage of the tree. The leaf itself consists of a large, flat, palmately lobed, pinnatifid blade at the end of a long, stiff, hollow, cylindrical petiole; the blade is often 2 or 3 feet in diameter, and the petiole 2 to 3½ feet long. New leaves are constantly being formed at the apex of the cluster, and, as the stem grows upward, the older lower leaves dry and fall. The normal life of a leaf is generally but a few months, the period varying somewhat with the age of the tree and its environment.

The flowers are borne in modified cymose inflorescences, which first appear in the axils of the leaves immediately below the growing point. The type of the inflorescence depends upon the sex of the tree and the types of flowers represented. The structure of fruit-producing flowers is such that pollination is readily accomplished both by wind and by insects. Flowers and fruits occur in progressive stages of development from just below the apex to 3 or 4 feet lower on the stem.

The fruit is melonlike in its superficial characters, is generally spherical to oblong in shape, and comprises five longitudinal sections or carpels with parietal placentation. The carpels are so united as to leave a large central cavity in which the seeds are packed. The skin is thin and smooth, green when the fruit is immature, yellow to orange when the fruit is ripe. The flesh is yellow to deep orange, or in some strains salmon-pink to red, and is from 3/4 inch to 2 inches thick. The fruit ranges in weight from a few ounces to 25 pounds, depending upon the strain.

The seeds, which are attached to the placentae by fleshy seed stalks about 1/2-inch long, are black in color, roundish and wrinkled in form, and each is enclosed in a thin, gelatinous aril, or envelope. A well-pollinated fruit may contain as many as 1,200 seeds.

When cut or scratched, the green fruits, the flowers, and the vegetative portions of the plant yield a thin milky juice, the papain-containing latex, which at first flows freely but rapidly thickens and finally coagulates.

Under favorable conditions, the papaya tree may live for 25 years or longer and attain a height of 25 feet or more. The tree grows rapidly and requires but 10 to 14 months from the germination of the seed to the production of the first ripe fruits. If environmental conditions are suitable, it will continue to bear throughout its life.

Flower Types and Fruit

The numerous combinations of flower types which appear in the papaya are the foundation for the concept of sex forms which was expounded by Higgins and Holt; the length of the inflorescence also played a part in this classification.

It has been noted more recently (*51*) that certain flower types are characteristic of certain sex forms, and, furthermore, that some correlation exists between the gross structure of the flower and the shape of the resulting fruit.

A knowledge of the existing flower types is pertinent both to an understanding of the present concept of sex in papaya and to a recognition of the role played by the flower in predetermining, to a great extent, the shape of the fruit. Descriptions of the principal flower types are given below.

Type I. Pistillate or female flower (fig. 1, *A, left*). This flower is unisexual, as it possesses a functional ovary but lacks stamens. It depends upon an outside source of pollen for fertilization.

Superficially, the petals appear to be completely free from one another; actually they are inconspicuously fused not only together but also with the base of the ovary.

The five-carpellate pistil is generally smoothly circular or slightly undulate in outline. The fruits formed from type I flowers are more or less spherical to obovoid (fig. 1, *A*, *right*), the particular shape being a racial characteristic. At the base of the fruit five distinct scars may be seen, arranged in a circle, where the petals have fallen away from the area of fusion with the ovary.

Type II. Pentandria bisexual flower (fig. 1, *B*, *left*). This bisexual form of flower is called "pentandria" because it possesses five stamens (*18*). The stamens, which are fairly short, appear to be arranged alternately with the petals.

The petals are free for most of their length but are more fused to each other and to the base of the pistil than are those of the type I flower. The stamen filaments are fused with both the pistil and the petals below the throat of the short corolla tube.

The pistil, as in the type I flower, is five-carpellate but is deeply furrowed. Normally the stamens lie along the furrows.

The fruit is globular or slightly oblong with five deep longitudinal grooves (fig. 1, *B*, *right*). At the basal end lies a glossy disk, on the margin of which a continuous circular scar attests the former presence of the fallen corolla.

Type III. Intermediate or carpelloid bisexual flower (fig. 1, *C*, *left*). This type of flower has previously been designated "intermediate" because of its apparent lack of definite arrangement (*18*). It is characterized by considerable distortion, which can be detected externally in the young bud.

The petals may be nearly free to their base or fused together and with the pistil for as much as two-thirds of their length; various degrees of fusion may be encountered in a single flower.

The stamens are variable in number, two to ten having been observed. The degree of their fusion to the petals, the pistil, or both may vary considerably. The stamens commonly exhibit carpelloidy; that is, they tend to become carpel-like in structure. The carpelloid stamens may be found in different stages of transition, and often both antherlike and stigmalike tissues develop in contiguous regions.

The pistils are frequently distorted, and the carpels, which may vary from five to ten, are faulty in fusion. Exposed ovules are often found on the carpelloid stamens as well as on carpels which have failed to unite into a closed ovary. The fruits which develop are usually misshapen and may assume grotesque forms (fig. 1, *C*, *right*).

Type IV. Elongata bisexual flower (fig. 1, *D*, *left*). Because this type of flower possesses an elongate pistil and the resulting fruit is, in general, long-cylindrical, it has been called the "elongata" flower (*18*).

The petals are fused together for one-fourth to three-fourths of their length and form a fairly rigid corolla tube, quite free from the pistil except obscurely at the base. At the throat of the corolla tube are ten stamens

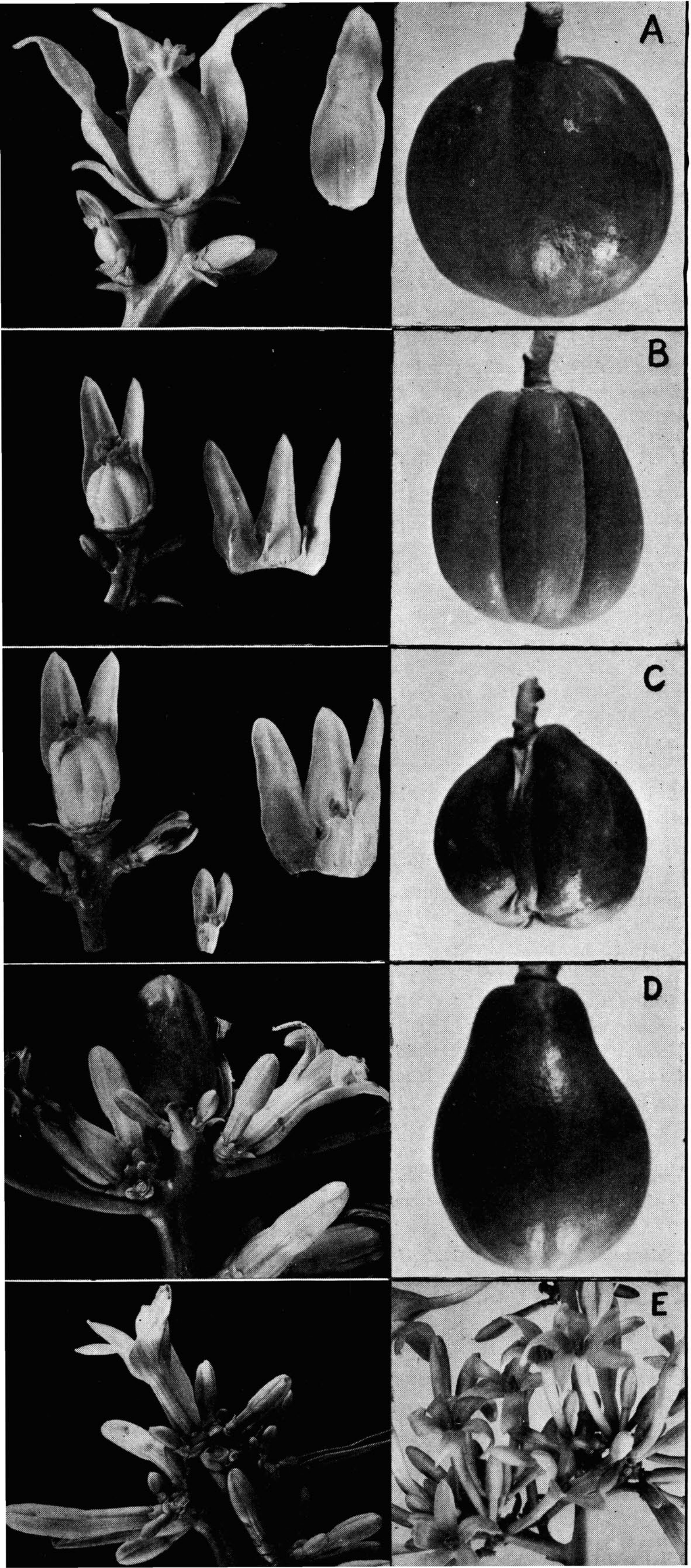


Figure 1. Flower and fruit types of the Solo papaya:

A, left, pistillate or female flower (type I); right, fruit from type I flower.

B, left, pentandria bisexual flower (type II); right, fruit from type II flower.

C, left, intermediate or carpelloid bisexual flower (type III); right, fruit from type III flower.

D, left, elongata bisexual flower (type IV); right, fruit from type IV flower.

E, left, type IV+ flower (non-fruit-producing); right, staminate or male flower (type V, non-fruit-producing).

arranged in a double series, one series being opposite the petals and subsessile, the other being alternate on short stalks. In the flowers of some races the anthers and the stigmas of the pistil are at one level, often touching one another; in the flowers of other races, particularly those with short corolla tubes, the anthers are located well below the stigmas. These differences undoubtedly affect self-pollination to some degree.

The pistil is generally five-carpellate, but the number of carpels may range from one to ten. Fruits which are unicarpellate or composed of only a few carpels are long and slender and may be likened in shape to a banana; fruits which are made up of five or more carpels vary from long-cylindrical to pyriform (fig. 1, *D, right*).

Type IV+ (fig. 1, *E, left*). During certain seasons in Hawaii, due to conditions as yet undetermined, the type IV flower fails to develop a functional pistil, although a vestigial ovary lacking stigmas is always present. Aside from its failure to function as a female flower in pollination and its slightly reduced size, it does not differ structurally from the female functional type IV. It does differ structurally from the type V flower, even though it can function only in the production of pollen. This barren hermaphrodite form has come to be known as "type IV+," which serves to imply that it is perhaps intermediate to types IV and V.

Type V. Staminate or male flower (fig. 1, *E, right*). In this flower type the numbers and arrangement of the petals and stamens are the same as in type IV. The corolla tube is long and slender, but it lacks the thicker, firmer structure of types IV and IV+.

This type of flower can produce no fruit, for the pistil, though present, is reduced to a rudiment, lacking stigmas. It can produce only pollen and, in this role, is considered to be the complement of the pistillate or type I flower.

Tree Forms

Depending upon the type or types of flowers it bears, a papaya tree belongs to one of three sex forms: (1) Pistillate or female; (2) bisexual or hermaphrodite; or (3) staminate or male. The species is usually described as dioecious, but because bisexual flowers and hermaphroditic trees are also represented it is more properly referred to as polygamous. Earlier publications (*18, 21, 40*) have referred to the "monoecious" type. However, a true monoecious type (one which bears both unisexual pistillate and staminate flowers) does not seem to occur in the species.

Higgins and Holt (*18*) described 13 sex forms in the papaya and Kulkarni (*30*), a fourteenth. Haigh and Fernando (*10*) recognized only six. However, studies of the flowering characteristics of the sex forms combined with genetic studies have shown

Figure 2. Pistillate or female papaya tree (form A) flowering and beginning to set fruit; for female tree bearing fruit, see figure 9.

that the papaya probably consists of only four distinct heritable sex forms, one pistillate, one staminate, and two hermaphroditic, characterized by the type or types of flowers produced in different environments. Many of the previously described sex forms are, therefore, only seasonal variations of the basic sex forms.

The grower should learn to recognize the four basic sex forms, for by so doing he can readily distinguish productive from unproductive forms when he comes to select seed for a new planting. Brief descriptions of these forms[1] are given below.

Form A. Pistillate or female tree (fig. 2) [corresponding to form 1 of Higgins and Holt]. This tree bears flowers that are characteristically and constantly of the type I previously described. In contrast with other sex forms it is remarkably stable and is not materially affected by seasonal and environmental changes.

The spherical or oblong fruits are borne singly, rarely in two's or three's, on peduncles which seldom exceed a few inches in length.

Form B. Continuously fertile hermaphrodite tree (fig. 3, *A*) [including forms 7, 8, 11, and 12 of Higgins and Holt]. In Hawaii from July to December the continuously fertile hermaphrodite form bears preponderantly type IV flowers in the terminal position of the inflorescence. The lateral flowers are mostly of the same type, although type V flowers are observed frequently. Flower types II and III are observed only infrequently at this season, and type IV+ is rare or absent at any time.

With change of season from summer to winter, there is a shift from the preponderance of type IV flowers to types III and II. The transition is most noticeable in the terminal flowers, which often are the only ones to produce fruit. The progression in forms of fruit, therefore, is from the cylindrical or pyriform through the distorted types to the more or less spherical with deep longitudinal furrows (fig. 3, *B*) ; with return to summer the order reverses. By midwinter (January and February) the terminal flowers are mostly type II while the laterals are mostly type III, but

[1] These tree forms have previously been designated "types I, IV, IV+, and V" (*15*). However, the term "form," with alphabetic designations, is being adopted to minimize confusion between classifications of trees and flowers.

some type IV's are still present. Type V flowers appear infrequently at this season.

Very often the failure of the terminal flowers to produce fruits causes one or more of the laterals to come into production. The curious admixture of fruit shapes often found on a single tree is due to the functioning of lateral and terminal flowers of different types.

The seasonal shift described above is best exemplified by the Solo variety, but nearly every hermaphrodite strain under observation has behaved somewhat similarly. A few strains, however, do seem stable and produce fruits more or less of uniform shape throughout the year.

Form C. Summer-sterile hermaphrodite tree (fig. 4) [forms 4 and 5 of Higgins and Holt]. This hermaphrodite tree looks like form B but can be distinguished by the absence of type II flowers at any time and by the production of occasional fruits with a reduced number of carpels, as well as by the large proportion of type IV+ flowers in the summer months. During the balance of the year the terminal flowers and most of the lateral flowers are type IV. Fruits are often set to the point of serious crowding along the trunk. Such sterile flowers as occur laterally are mostly type IV+, but a few type V flowers may occasionally be present. Type III flowers also occur but are less numerous than on the form B hermaphrodite.

Figure 3. A, Continuously fertile hermaphrodite tree (form B) of the Solo papaya, which has produced fruits of a good shape over a period of 6 months or longer; B, stem of continuously fertile tree, showing change in shape of fruits (note the few staminate flowers in the inflorescence).

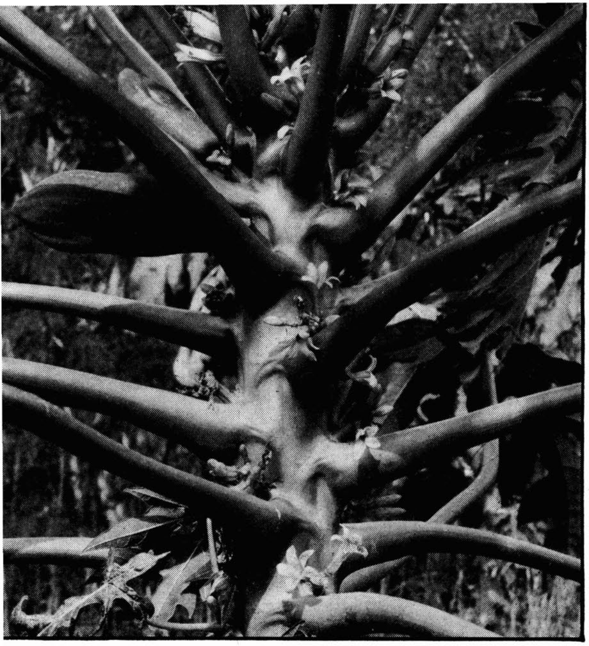


Figure 4. Upper portion of stem of a summer-sterile hermaphrodite tree (form C), showing resumption of fruiting after a barren period (note bananalike fruits produced at transition season).

From July on, a shift in the direction of maleness takes place, and in the course of a few weeks the transition from the bearing of fruit-producing type IV flowers to the bearing of female-sterile type IV+ flowers is accomplished. Occasionally during this period a type IV will be produced and set a fruit. In midsummer the tree shows a well-stocked fruiting region 3 or 4 feet long, with an equally long, barren length of stem just above.

The bananalike fruits so often seen on this form of tree develop from flowers produced at the season when the tree is undergoing transition from productivity to barrenness and vice versa.

It may be said of form 5 of Higgins and Holt (*18*), an extremely barren form, that it represents a variant of form C which is less susceptible to external influences than the typical form. This form has often been spoken of as a "short-stemmed male" and is undoubtedly one of the so-called males which can be "shocked" into productivity as a "female" by "cutting off its head." Differences in location and in the treatment accorded such trees may affect the nonproductivity to a limited extent, but the change is not permanent.

Form D. The staminate or male tree (fig. 5, *A*) [forms 2, 3, 6, 10, and 13 described by Higgins and Holt and the form described by Kulkarni (*30*) are variants of form D]. The male tree is easily identified by its long, pendulous inflorescence, composed, during the summer season, entirely of type V flowers. As in form C, seasonal conditions affect the female functionability of this form (fig. 5, *B*). Generally only the terminal flowers of the ultimate peduncles are affected by a change of environment, although in some stocks a very high percentage of the flowers become female functional. The shift in flower type is generally from V to IV or vice versa. However, in a few exceptional strains, type III and II flowers may be found, and some type I's have even been seen; characteristic type IV+ flowers have never been observed.

As in the hermaphrodites, the extent to which transition will take place seems to depend upon the race, the age of the tree, and the environment. In some races the male may fruit only in its first year of blossoming; in others it may fruit continually from year to year; and in others it may never fruit at all. It has been noted that the fruiting of the male papaya takes place most freely in cool climates outside the Tropics and at high altitudes (*18*).

An understanding of the behaviors of the different sex forms described above is sufficient for the reader to appreciate how and why a single tree, or even a single flower cluster, can give rise to fruits of contrasting shapes.

Sex reversal, which has been widely discussed by various workers (*18, 21, 30, 35, 40*), can best be interpreted as the response of the male (form D) and the barren hermaphrodite (form C) to physiological changes. Under natural conditions this is most evident as a response to seasonal change, but comparable effects result from the practice of beheading (Iorns, *22*; Reyes, *42*).

In selecting fruits for seed, it is recommended that trees in their second year of fruiting be examined during the months of December, January, and February. At this time the form C trees will have been nonproductive for several months and their detection in the orchard offers no difficulty.

The possibility of eliminating nonproducing or low-producing forms by a system of controlled pollination is best appreciated when the genetics of sex in the papaya is understood.

Figure 5. A, Typical staminate or male tree (form D) of the Solo papaya; B, lower portion of fruit-bearing male tree (most of the fruits have developed from type IV flowers but the one at the extreme left is from a type III flower).

Genetics of Sex in Papaya

Genetical studies carried on independently in South Africa by Hofmeyr (*19, 20, 21*) and in Hawaii (*52* and unpublished data[2]) have clarified sex determination in papaya in terms of simple Mendelian factors. The data on intersexual crosses and self-pollinations made by these two investigators with *C. papaya* are presented in table 1.

Table 1. Cross- and self-pollinations made, sex segregations, and sex ratios obtained in studies of *Carica papaya* carried on independently in Hawaii and in South Africa[1]

Cross	Sex segregations			Sex ratios				
	Females	Hermaphrodites	Males	♀	:	☿	:	♂
A, HAWAII								
1. Female × male	2,614	0	2,420	1	:	0	:	1
2. Female × hermaphrodite	1,925	1,901	(1)[2]	1	:	1	:	0
3. Male selfed	155	0	296	1	:	0	:	2
4. Hermaphrodite selfed	1,196	2,343	(16)[2]	1	:	2	:	0
5. Hermaphrodite × hermaphrodite	299	580	0	1	:	2	:	0
6. Hermaphrodite × male	99	115	98	1	:	1	:	1
B, SOUTH AFRICA								
1. Female × male	2,501	0	2,745	1	:	0	:	1
2. Female × hermaphrodite	754	762	0	1	:	1	:	0
3. Male selfed	38	0	129	1	:	0	:	3[3]
4. Hermaphrodite selfed	118	265	0	1	:	2	:	0
5. Hermaphrodite × male	23	33	32	1	:	1	:	1

[1] The author wishes to express his appreciation to Dr. Hofmeyr, who has given his permission for use of data, and who has been most cooperative at all times.

[2] Probably resulting from contamination during pollination or mechanical mixture of seeds or seedlings.

[3] Hofmeyr (*21*) later expressed the opinion that the true ratio is probably 1 to 0 to 2.

Using the Mendelian factor symbols which were first proposed by Hofmeyr, the scheme for sex determination in the papaya is given below. The numbers assigned to the crosses and self-pollinations correspond with those in table 1, *A*.

[2] STOREY, W. B. A GENETICAL INTERPRETATION OF SEX DETERMINATION IN CARICA PAPAYA L. 1940. [Unpublished doctor's thesis. Copies on file in Cornell University Library and in the Library of Plant Breeding Department, Cornell University.]

Scheme for Sex Determination in *Carica papaya*

M_1=dominant factor for maleness
M_2=dominant factor for hermaphroditism
m=recessive factor for femaleness

M_1m=the male or staminate tree; form D
M_2m=the hermaphrodite tree; forms B and C
mm=the female or pistillate tree; form A

1. $mm \times M_1m \rightarrow 1\,mm : 1\,M_1m$
2. $mm \times M_2m \rightarrow 1\,mm : 1\,M_2m$
3. M_1m selfed $\rightarrow 1\,mm : 2\,M_1m : (1\,M_1M_1)$
4. M_2m selfed $\rightarrow 1\,mm : 2\,M_2m : (1\,M_2M_2)$
5. $M_2m \times M_2m \rightarrow 1\,mm : 2\,M_2m : (1\,M_2M_2)$
6. $M_2m \times M_1m \rightarrow 1\,mm : 1\,M_2m : 1\,M_1m : (1\,M_2M_1)$

By genetical tests (*21*) and by examination of seeds from fruits of male and hermaphrodite trees (*52* and unpublished data[3]), it has been demonstrated that the Mendelian factors involved are allelomorphic and that the genotypes enclosed by parentheses in the above scheme are nonviable.

In reviewing the crosses outlined above, it is evident that in a strictly dioecious race—the condition commonly but erroneously considered to prevail in the papaya—only female (mm) and male (M_1m) trees are represented; sex determination in such a race is as indicated by cross 1 (table 1).

The cross of a female tree with a hermaphrodite, illustrated by cross 2, yields a progeny which segregates in the ratio of one female to one hermaphrodite. This type of cross is important from a practical standpoint because all of the offspring are fruit-bearing.

The occasional occurrence of flowers with functional pistils on male trees makes possible the self-pollination of this form (cross 3, table 1). The offspring segregates in the ratio of one female to two males, which obviously is undesirable from the grower's point of view. It serves to show, however, that the male tree is always heterozygous for the factors m and M_1.

The progeny of a self-pollinated hermaphrodite or of two hermaphrodites crossed (crosses 4 and 5, table 1, *A*) segregates in the ratio of one female to two hermaphrodites. If a form B hermaphrodite is self-pollinated or if two form B hermaphrodites

[3] STOREY, W. B. Op. cit.

are crossed, all of the hermaphroditic offspring will be form B. If form B is crossed with form C, then one-half the hermaphroditic offspring are of one kind and the remainder of the other. In commercial practice, it is obviously of advantage to self-pollinate the fruitful form B for seed. The above crosses are as important as cross 2, in that every tree will produce fruit, and actually they are better adapted to Hawaii, where the shape of fruit is of prime consideration. They yield 67-percent pyriform-fruited trees to 33-percent round-fruited in the seedling population. As pointed out earlier, the M_2M_2 genotype, which theoretically should be a pure-breeding hermaphrodite, is nonviable; this accounts for the fact that all hermaphrodites are heterozygous.

The cross of a hermaphrodite and a male (cross 6, table 1, *A*) yields a progeny segregation for females, hermaphrodites, and males in the ratio of one to one to one, obviously undesirable because of the high percentage of males. Cross 6 further illustrates the heterozygosity of hermaphrodites and males, for among the offspring appears the female form which did not originally enter the cross.

Regardless of the races of the parents, the proportions of the sex forms which appear among the progeny are consistent with the ratios given in table 1, *A*. For instance, if a female of the race called Haiti is crossed with a hermaphrodite of the Solo variety, the sex forms appearing in the progeny will be 50 percent female and 50 percent hermaphrodite although there may be blending of the fruit and tree characteristics of the two races.

Because male and hermaphrodite trees are always heterozygous, pure-breeding races, in the sense that they produce their own sex form exclusively, have never been obtained. The only homozygous form, the female (*mm*) which theoretically would breed true to type if self-pollination were possible, is precluded from doing so by its lack of stamens. However, what might be thought of as pure-breeding strains of hermaphrodites from the standpoint of racial characteristics, can be maintained by self-pollinations in succeeding generations. The fruits will generally be uniform in size, shape, and quality. Round-fruited female trees will also be present, but they too will approach uniformity in fruit size and shape.

It is easy to see how, with open pollination, different races growing in close proximity to one another become mixed and blended into a trioecious group in the course of a generation or two. The proportions of the sex forms in this mixed group depend entirely upon the proportions of pollen from males and hermaphrodites which chanced to fall upon the stigmas of the flowers whose fruits are destined to serve as sources of seed.

Application of the genetics of sex to seed selection. A knowledge of the genetics of sex in the papaya is of practical application if appropriate cross- or self-pollinations are made, with care taken to exclude foreign pollen. Seed can be obtained for a new generation of trees with full assurance that no undesirable sex forms will be present. Uniform types of hermaphrodite and female fruits can be produced from generation to generation by successive self-fertilizations.

In Hawaii the pyriform Solo fruit is preferred, and maximum production of this type can be assured by self- or cross-pollination of hermaphrodite forms (crosses 4 and 5, table 1, *A*). The fruits of the female trees which arise from these pollinations have a low market value but are not wasted, for they can be converted into juice or other products. In South Africa, on the other hand, where a round fruit shape is preferred,[4] cross 2 would probably be best because 50 percent of the plants (the highest percentage possible for the type) are round-fruited form A; the remainder are hermaphrodite and productive, and the long fruits, though not readily accepted by the consumer, can be used for other purposes.

For the production of seed it is recommended that the appropriate cross be made by hand and the pollinated flowers be bagged, regardless of whether or not the orchard is isolated or free of male trees. Only by following these recommendations can the planter be certain as to what forms of trees will appear and make plans for maximum production of the desired type.

It should be pointed out that, while the various cross- and self-pollinations enable one to predict the sex forms which will appear in the progenies and the proportions in which they will appear, no satisfactory means of predicting the exact sex form of a single individual has ever been discovered. Various methods have been tried, such as separation of darker seeds from lighter because of

[4] Personal communication from J. D. J. Hofmeyr.

a presumed sexual difference; discard in the seedling flat of the larger, stronger plants which were thought to be males; selection of seeds only from certain portions of the fruits; and separation of pistillate from staminate seedlings on the basis of certain juvenile vegetative characters. These methods have proved to be wholly unreliable when tested by competent investigators (*6, 21, 40, 42, 43*) but the need of such prediction is obviated by the simple expedient of producing seed that will yield progenies 100-percent fruit bearing.

Varieties

There are too many variations among the numerous types of papaya in Hawaii to allow for varietal stabilization by seed selection when the seed is the product of open pollination. Just as the sex forms appear in mixed proportions under free pollination, varietal characters likewise become mixed or blended, and races and strains previously distinct lose their identity. The only remedy for such a situation appears to be inbreeding with controlled pollination.

In Hawaii the term "variety" is used with restraint (*18, 40*), for strictly speaking there are few, if any, true varieties of papaya. In many papaya-growing regions arbitrary names are assigned to certain strains, the names adopted usually corresponding to the country from which the seed was received, to well-known growers, or to some conspicuous character of tree or fruit. Types that have retained their names for any appreciable time have done so because of certain easily recognized characters which are reproduced in the offspring with a reasonable degree of fidelity; to illustrate, the Solo papaya is known by its small size and pyriform shape, the Watermelon by its red flesh and large size. Often, however, several very different strains have developed from a single new introduction, and these have all continued to be known by the name of the country of origin. The development of pure-breeding strains, each of which possesses a name no other may have, seems highly desirable.

Recognizable among so-called varieties are such contrasting characters as short versus tall stature; low-borne versus high-borne fruits; stubby versus long lateral branches; green versus red or variously pigmented stems; drooping versus ascending leaves; yellow versus red fruit flesh; and small fruits (less than 1 pound) versus large fruits (15 to 20 pounds). That varieties possessing various combinations of reproductive and vegetative characters may be established seems foreshadowed by the persistence of a type such as Solo, by present knowledge of the relationship between flower type and fruit shape, by the understanding of the inheritance of sex forms bearing different flower types, and by studies of the genetic factors which affect fruit size and shape (*12, 13, 19*). Whatever variety or varieties are finally established, be they for the fresh-fruit market, for canning, or for the production of papain, they must breed true for the characters desired of the sex forms represented. It has already been pointed out that at present a variety consisting of and breeding true to a single sex form is impossible of attainment.

At this station the Solo papaya is considered to be the only one in Hawaii deserving of varietal rank. It is the only papaya that has persisted in essentially its original form over the years. This constancy is undoubtedly due to continual selection by growers for the pyriform fruit shape associated with hermaphroditism; the bisexual flowers of Solo are capable of a high degree of self-pollination under field conditions. Furthermore, a few, well-isolated growers have maintained seed stocks and have been the source of seed for most of the commercial plantings.

The Solo papaya probably originated in Barbados, British West Indies, where the late Mr. G. P. Wilder of Honolulu purchased a single fruit and sent the seed to Hawaii. Because of its small size and excellent flavor, the variety quickly attracted attention as a fruit desirable both for home use and for market. It was named Solo by the late Mr. J. E. Higgins, according to a report of the station (*11*), the name implying that the fruit is adequate for one individual. In subsequent years it has risen to first rank as the commercial papaya of Hawaii.

The Solo papaya is typified by the small, pyriform fruits borne on hermaphrodite trees. These fruits are approximately 6 inches long and 4 inches wide, and weigh about 1 pound. Fruits borne on female trees, present in all plantings, are spherical in shape and slightly larger. The trees are usually single-stemmed; lateral branches seldom develop beyond spurs 6 or 7 inches long that soon lose their leaves. The Solo reaches maturity in 12 to 14 months, a slightly longer time than is required by many other types. The first fruits are borne 4 or 5 feet from the ground.

In the development of new, improved varieties of papaya for commercial production, the Solo papaya is being employed as the basis of breeding work. The station is attempting to combine its excellent flavor and convenient size with the greater disease resistance and earlier maturity of some recently introduced races.

Several Mendelian characters which might serve as distinguishing marks of new varieties are already known. Hofmeyr (*21*) has shown that yellow flower color (Y) is dominant to white flower color (y), purple stem color (P) is dominant to green stem color (p) and yellow flesh color (R) is dominant to red flesh color (r). The inheritance of other characters which might desirably be incorporated into new varieties should come to light as genetical and breeding work is continued.

PART II. PROPAGATION AND CULTURE OF THE PAPAYA

by W. W. JONES and W. B. STOREY

The papaya is adapted to and thrives only in the Tropics. In Hawaii it grows well along the coastal plains and in the foothills to an elevation of about 1,500 feet, producing the best fruits in hot localities where water is not lacking.

The plant may be grown upon almost any kind of well-drained soil. Groves in Hawaii thrive upon sandy littoral soils as well as upon the lateritic lava soils of the foothills. Like most other fruit trees, the papaya yields its best crops when grown in deep, rich soil, but it can also be grown successfully in soils too shallow, too rocky, or otherwise unsuited for most fruits.

In waterlogged soils the tree makes a spindling growth and drops its lower leaves prematurely, the remaining foliage turning yellow (fig. 6). Terminal growth is reduced and, if flooding of the roots is prolonged, the tree dies. On the other hand, too dry a soil may produce effects just as deleterious as flooding, for the papaya's root system is fairly shallow and the tree literally starves to death.

Under conditions of optimum moisture, sunlight, and temperature, papaya trees make stocky growth, mature at an early age, and produce an abundance of fruits. Under less favorable conditions, the trunk may be slender

Figure 6. Injury to papaya trees resulting from poor soil drainage (note spindling growth and shedding of leaves).

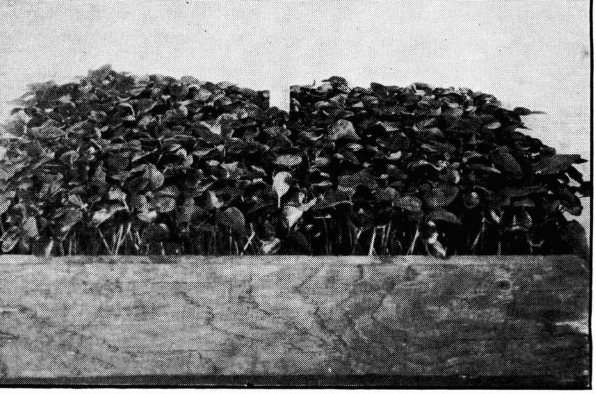


Figure 7. Papaya seedlings growing in germination flat; the seedlings are ready to be transplanted to cans or other individual containers.

and spindling, fruiting may be deferred, and the fruits borne may be few. The lack of sunlight, and probably of warmth, during the cool season in Hawaii is usually reflected in retarded growth and in the setting and maturing of fruits. This is particularly true at high elevations and in cloudy, rainy localities. Fruit setting is undoubtedly curtailed by rain, which reduces the activities of pollen-carrying insects and inhibits wind movement of pollen. Fruits that do set usually fail to attain their natural skin coloring, and their flesh is pale in color and insipid to taste. Under extremely unfavorable circumstances the fruits may be destroyed by fungi before they ripen.

Propagation

The papaya has been propagated successfully on a small scale by means of cuttings and grafts by Fairchild and Simmonds (*9*), Pope (*40*), and Traub and Marshall (*55*), but the time and labor involved for a plant with so short a commercial life preclude the use of asexual methods in commercial plantings.

With seed propagation, quick, uniform, high-percentage germination may readily be secured. Only seeds from fully ripened fruits should be used. In order to break the gelatinous envelopes in which they are enclosed, the seeds may be squeezed in a piece of cheesecloth or they may be placed on a sheet of rubber (a piece of inner tubing from an automobile tire) and rubbed with a piece of sponge rubber. The seeds should then be washed free of the broken envelopes, thoroughly dried in the shade, and planted immediately or stored in well-capped glass jars or in a seed storage container with a little calcium chloride. Under proper storage, seeds will retain their viability for 2 or 3 years.

Of the several methods employed in germinating papaya seeds, the use of germination flats seems to be the most satisfactory (fig. 7). Many types of boxes may serve as germination flats, but probably the most convenient are relatively small, shallow boxes, about 18 inches long, 15 inches wide, and 3 inches deep, in which fancy and dried fruits and candies are often packed. After small holes have been bored in the bottom of the flat to provide drainage, a 2-inch layer of sifted soil, steam-sterilized if possible, is leveled into it. The seeds are sprinkled over the surface of the soil and pressed in with a flat piece of wood. A one-fourth-inch layer of soil or sand is sifted over the seeds, and the flat is watered lightly and placed in a greenhouse or outside in partial shade. With suitable temperatures the seeds should germinate in about 2 weeks.

Soon after germination, while the cotyledons are still large and green and before the foliage has made much growth, the seedlings should be placed in full sunlight; too long a delay often results in excessive wilting and sunburn when the plants are finally exposed.

Some 3 or 4 weeks after germination the seedlings are transferred to individual containers, in which they make further growth before being set out in the field (fig. 8). In earlier years the transfer was made to 4-inch clay pots, but more recently it has been found that empty cans, collected from the discard piles at local canneries or gathered at hotel kitchens, school cafeterias, and restaurants, suffice when six or seven holes are punched in the bottom of each to permit drainage. The young seedlings are easily removed from the germination flat with a pointed stick or a narrow pot label and are planted in a hole made with a dibble or a round, pointed stick in the center of the soil in the can. In another 3 or 4 weeks the seedlings will have attained a height of 6 or 8 inches and be ready to plant in the orchard.

If cans are not available, an improvised container can be made by bringing together the ends of a rectangle of light roofing paper, about 10 inches long and 4 inches wide, and fastening them with a hand stapling machine. The resulting cylinder has a diameter

Figure 8. Papaya seedlings ready to be transplanted to the field.

of about 3 inches and a depth of 4 inches. These cylinders are placed side by side on planks or in flat boxes, filled with soil, and then planted with seedlings.

Similar containers made of 15-pound asphalt-felt paper, with corrugated roofing nails instead of staples holding the edges together, have been described by Wolfe and Lynch (*59*) for Florida growers.

Some growers simply fill up the requisite number of cans with soil and plant two or three seeds in each, thinning out the extra seedlings after growth has commenced. Little seems to be gained by this method, however, over the one previously described. Other commercial planters germinate their seeds in a specially prepared seedbed in a convenient part of the field, transplanting the seedlings when they have attained a height of 4 to 6 inches. This practice is not generally satisfactory because of the difficulty of disentangling the roots of many seedlings, growing close together. Moreover, soil may be lost from the roots during transplanting, and in the bright sunlight of an open field, the plants will wilt and often die.

Planting

The land for a papaya orchard should be cleared, thoroughly plowed, and harrowed. It should then be staked for rows at right angles to one another. The planting distances should be determined after consideration of the spread of the tree, the available water supply, and the labor involved in cultivating and harvesting. On sloping land it is advisable to run the rows on terraces following the contour of the terrain in order to reduce the danger of erosion and to permit the laying of furrows in areas where irrigation is needed.

For Hawaii, Pope (*40*) has recommended planting distances of 10 feet by 10 feet, or 435 trees to the acre. For South Africa, Van Elden (*6*) has recommended 9 feet by 9 feet, or 538 trees to the acre. Other investigators have recommended planting distances of 12 feet by 12 feet, 12 feet by 10 feet, and 12 feet by 8 feet. Factual data on the best interplant distances in Hawaiian orchards are not available, but investigators and growers are generally agreed that the trees should never be planted closer than 8 feet by 8 feet.

If the plants have been growing in roofing-paper containers, the containers may be lifted or slid from the plank into holes just large enough to receive them and the soil made firm around them. If the seedlings are in cans, they must be removed before planting. Squeezing the sides of a can will loosen the soil, which can then be tapped out as a unit without injury to the roots.

Immediately after planting, the young trees should be watered. This is particularly true if soil has been lost from around the roots in making the transfer from pot to ground. Unless rainfall is adequate, water should be supplied subsequently every 4 or 5 days, until root systems capable of supplying the needs of the plants have developed.

It is generally accepted that the papaya tree grows and produces best when planted singly. However, in some localities, two or more seedlings per hole are planted, in order to secure a greater number of trees of a particular sex form than could be expected from seedlings planted singly. For example, in Hawaii where the market prefers the pyriform Solo fruit to any other, most growers plant two trees in the hole and later thin the orchard, favoring hermaphrodites. However, even with trees planted singly, all are fruitful when seed is obtained from self-fertilized hermaphrodite trees, and 67 percent will produce pyriform fruit. The percentages of hermaphrodite and female trees which will remain in multiple plantings after thinning are given in table 2.

Table 2. Percentages of female and hermaphrodite trees remaining in multiple plantings after thinning to one tree per hole, favoring hermaphrodites (seed from self-fertilized hermaphrodites)

Number of trees planted per hole	Proportions after thinning	
	Females	Hermaphrodites
	Percent	*Percent*
1	33.3	66.7
2	11.1	88.9
3	3.7	96.3
4	1.2	98.8

Sometimes growers desire to plant trees of a dioecious race in which the normal expectancy is one female to one male. The percentages of each sex which will remain in the orchard, after multiple planting and subsequent thinning, are given in table 3.

Table 3. Percentages of female and male trees remaining in a planting of a dioecious race of papaya after thinning to one tree per hole, favoring females

Number of trees planted in hole	Proportions after thinning	
	Females	Males
	Percent	*Percent*
1	50.0	50.0
2	75.0	25.0
3	87.5	12.5
4	93.7	6.3

If seeds from a female by hermaphrodite pollination were planted and the trees thinned to favor females, the proportions of females to hermaphrodites would be as females to males in table 3. However, if hermaphrodites were favored, the proportions would be reversed.

Principal objections to multiple plantings are that the amounts of propagating material and numbers of seedlings required are greatly increased, and that maintenance of the trees in the orchard until the appearance of flowers (at least 6 months) involves extra time, labor, and water.

In any planting, but particularly if many of the trees are pistillate, it may be advantageous to have a few male trees interspersed with the fruiting trees to insure pollination and fruit production. Male trees can be obtained by planting a small number of seedlings germinated from the seeds of a fruiting male; about a dozen such trees per acre should suffice. For obvious reasons, fruits produced in the orchard should not be used as sources of seed for a new planting unless bisexual buds have been bagged and the fruits marked and saved.

The time of planting deserves some consideration, from the standpoint of economics. During the summer months, development and ripening of the fruit are generally rapid and, consequently, the market supply is plentiful. During the winter months, on the other hand, development and ripening are retarded, often to the point where trees which produced an oversupply in the summer fail to supply normal local demands. However, Solo papaya trees set out in August or September of one year should be yielding a crop by October or November of the following year and producing their best fruits just at the season when the production of older trees is slowing down.

Irrigation

With uniformly distributed rainfall of from 50 to 60 inches a year, the papaya grows naturally and fruits continuously and abundantly. Irrigation is not necessary unless the plant is growing on sandy soils with low water-holding capacity or in an area where rainfall is either light or poorly distributed.

In many groves on dry, leeward lowlands, water is applied in shallow basins or in furrows between the rows. Hillside groves are watered in somewhat the same manner, but the plant rows should be arranged along contour lines to accommodate both irrigation and cultivation. The irrigation interval is best determined by experience. Probably thorough irrigation once each week is sufficient under most conditions.

Water should be supplied in quantities just sufficient for the normal requirements of the plant. If seepage is slow, care should be exercised to prevent waterlogging by irrigating at less frequent intervals or by draining off excess water. However, dryness is to be avoided as much as flooding if the trees are to maintain growth and productivity.

Cultivation

Cultivation of the orchard is generally limited to control of weeds. A shallow, spike-tooth harrow is not only effective for weed control but also aids in conserving moisture by increasing the absorption power of the loosened ground. Since most of the feeding roots of the papaya plant lie close to the surface, harrowing should not exceed a depth of about 3 inches.

Fertilization

Many Hawaiian soils require fertilization, particularly with nitrogen and phosphorus, for optimum growth and production of papayas, although the growth of the tree is limited as much by inadequate water and sunlight as by lack of fertilizer. Fertilizer deficiency can usually be determined by the type and amount of growth; for instance, plants grown in sand gave definite size variations, depending on fertilization, as shown in table 4.

Table 4. Effects of fertilizer elements on size of papaya plants grown in sand (12 plants per series)

Fertilizer formula	Average height of plants	Average number of leaves per plant	Fresh weight of plant
	Inches		*Grams*
Complete	37.5	19.3	1,059.4
Minus phosphorus	28.6	16.6	960.3
Minus nitrogen . .	18.5	10.9	306.4

As shown in table 4, if the nitrogen or phosphorus element is deficient, a marked reduction in growth occurs, and the number of leaves per plant is greatly reduced. In addition, deficiency of either element produces a characteristic appearance of the leaves (figs. 9 and 10). If nitrogen is deficient, the leaves are small, stiff, and light yellow in color, and the petioles are short. The normally horizontal or ascending petioles of the Solo variety tend to grow downward from the trunk. If phosphorus is deficient, the leaves are dark green with a purplish-red coloration on the veins and petioles.

The deficiency symptoms described above are also likely to develop if water is insufficient or excessive, since the plant is unable to absorb the required elements in either case.

Figure 9. Female papaya trees growing under similar conditions, but A, without nitrogen, and B, with nitrogen; note the cessation of fruiting and the downward slope of the petioles in the tree lacking nitrogen.

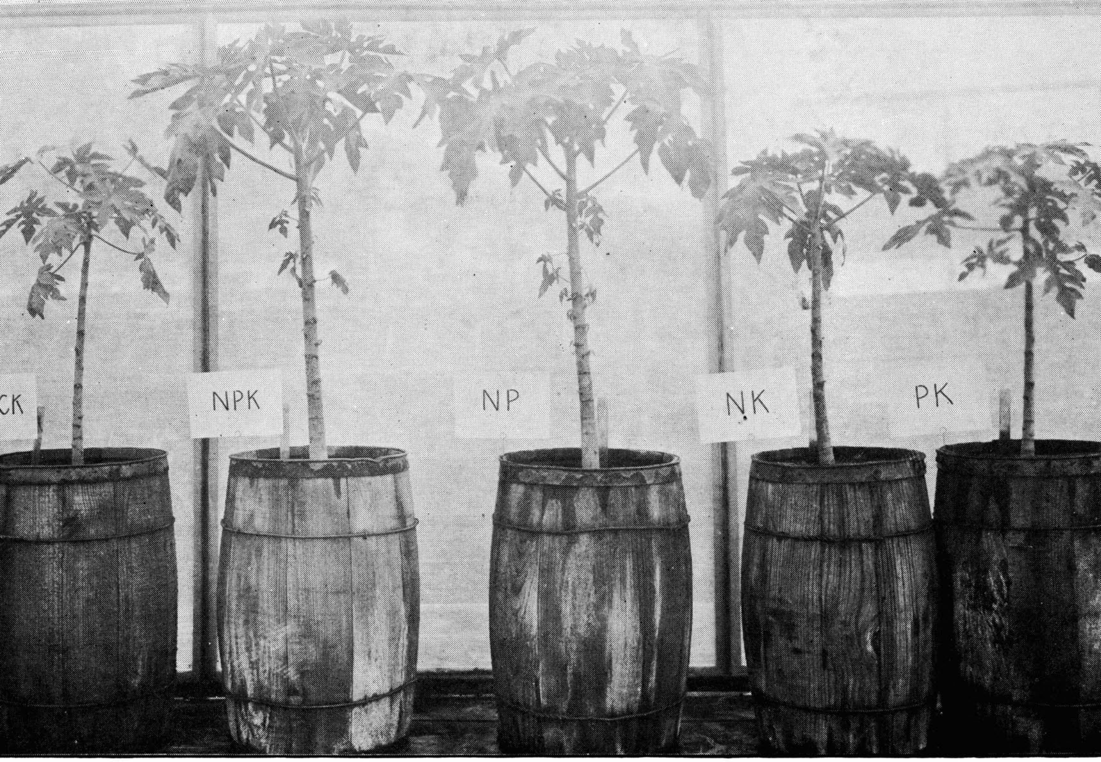


Figure 10. Five-month-old papaya trees in a fertilizer experiment with treatments as indicated.

Preliminary field experiments indicate that the effect of phosphorus on yield is greater than that of either nitrogen or potash. However, this work is not complete. In the meantime, where fertilization is necessary, a formula high in phosphorus (6-12-6 or 8-12-6) is recommended, at the rate of approximately 1,000 pounds per acre. With 435 trees per acre (planted 10 feet by 10 feet) this rate would provide 2.3 pounds per tree per year, or approximately 0.6 pound per tree in quarterly applications. Young trees should receive only half this amount, or 0.3 pound, 3 to 4 weeks after the seedlings are set in the field. Thereafter, the full rate should be applied at 3-month intervals. Care must be exercised in the first fertilization to place the fertilizer within the root zone of the seedling and yet not so close as to cause injury to the trunk.

PART III. DISEASES OF PAPAYA IN HAWAII AND THEIR CONTROL

by G. K. PARRIS

The papaya is very sensitive to unfavorable growing conditions. Too little or too much moisture or disturbance of the root system by soil erosion renders the plant susceptible to disease attack.

Anthracnose Fruit Rot

Symptoms. The first signs of this disease appear on fruits that are almost ready for picking, or just prior to the so-called firm-ripe stage of maturity. Superficial, small, circular, slightly sunken, brown spots surrounded by normal green tissue appear on the skin. As the fruits mature, these spots enlarge and become distinctly sunken and saucer-shaped. They vary from one-quarter to one inch in diameter. With aging, the spots become progressively darker, ultimately black, and the center of each is covered with a salmon-yellow or light pink deposit, somewhat shiny when wet, scaly when dry. White mycelium may also be present, associated with the lesions (fig. 11, *A*). On a mature fruit the spots may retain halos of green color which stand out sharply against the chrome-yellow of unaffected parts.

The fungus body penetrates the skin of the papaya fruit to enter the flesh, where considerable decay may take place, and eventually complete collapse, especially if fruits are kept at room temperature past maturity. Breakdown is due in part to anthracnose, but secondary organisms commonly contribute to a large share of the decay. These saprophytes enter by way of the anthracnose spots and flourish in the soft, sugar-laden tissues of the ripe fruit.

Any part of the fruit may be attacked by anthracnose, but in general the lower or blossom end is first affected.

Cause and life history. A fungus, *Colletotrichum* sp. (probably *gloeosporioides*) is the cause of anthracnose. Its life history is relatively simple. Each spore is capable of germinating in the presence of moisture to produce a tiny germ tube, which may penetrate the skin of a papaya fruit. The time of initial penetration is not accurately known at present, but preliminary studies by Wardlaw et al. (*57*) indicate that the germ tube enters the fruit while the latter is one-quarter to one-half its ultimate size. Once beneath the skin, the germ tube forms a few strands of hyphae, which are threadlike, colorless, and probably well-branched. Further development of the fungus takes place only after the fruit has matured considerably. Then the hyphae enlarge, spread through adjacent epidermal cells, and finally break through to the surface of the fruit, where the organism produces millions of tiny spores which form the salmon-yellow or light pink deposits previously mentioned (fig. 11, *B*). This completes the life cycle of the fungus as it occurs in Hawaii.

The spores are transported from fruit to fruit within a planting and from planting to planting by various means, most important of which are wind, splashing rain, and insects. Probably man, in handling and transporting fruit from the orchard to the packing house, is also responsible for considerable transfer of spores. Partly or completely rotted fruits on the refuse heap are potent sources of spores; the same is true of overripe fruits still attached to the tree.

Control. Control of anthracnose is very important in Hawaii, particularly at present, due to the keen interest in shipping fruits to mainland United States. Before fruits can be shipped, they must be treated to kill larvae of the Mediterranean fruitfly (*Ceratitis capitata*). Fruits that have been treated, particularly with methyl bromide, are more likely to show anthracnose lesions than untreated fruits similarly handled and stored (*24, 25*). Moreover, the grower cannot determine by inspection in advance of treatment whether his fruits will be sound or spotted with anthracnose after treatment. Fruits for local consumption are not treated, and if they show no spots when picked, seldom decay before they are consumed.

Removal and complete destruction of diseased fruits will reduce the sources of infection in a planting.

The anthracnose can be further controlled by spraying the fruit at 7- to 10-day intervals with a fungicide.[1] The fungicide best

[1] KIKUTA, K. ANTHRACNOSE OF PAPAYA AND ITS CONTROL. Hawaii Agr. Expt. Sta. Prog. Notes 18. 5 pp. 1941. [Mimeographed.]

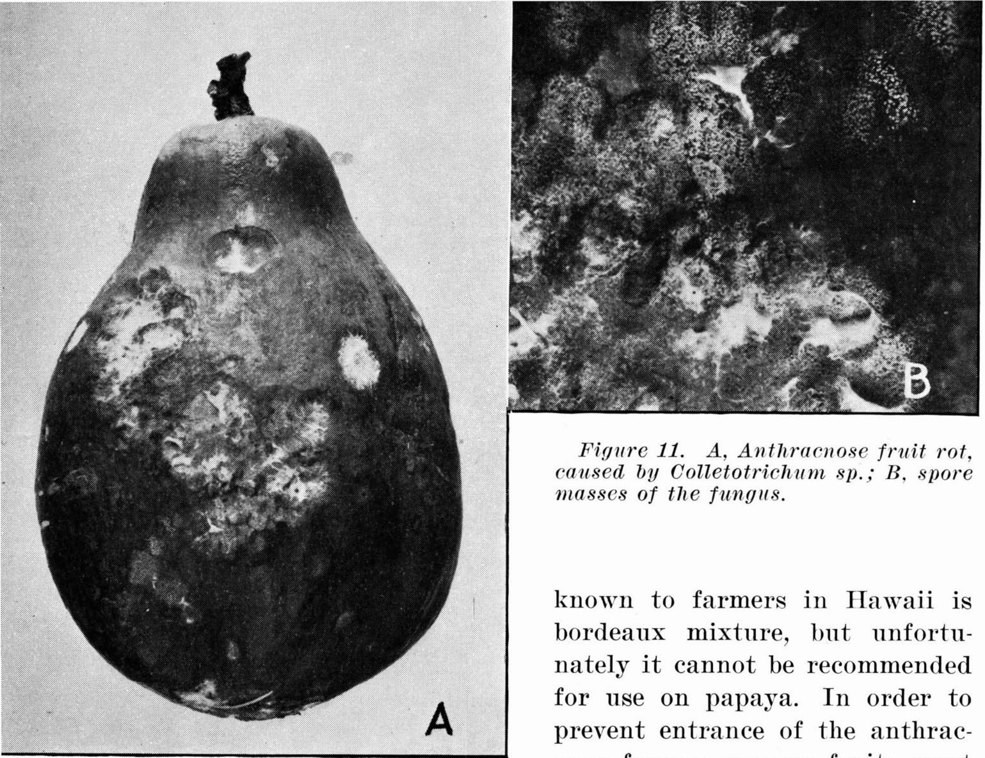


Figure 11. A, Anthracnose fruit rot, caused by Colletotrichum sp.; B, spore masses of the fungus.

known to farmers in Hawaii is bordeaux mixture, but unfortunately it cannot be recommended for use on papaya. In order to prevent entrance of the anthracnose fungus, papaya fruits must be sprayed regularly, from the time when they are very small. In a juvenile condition, the papaya fruit is burned by bordeaux, the fungicide causing the death of a few cells wherever it enters the skin. As a sprayed fruit enlarges, appreciable areas of the surface are roughened or "russetted." Russetted fruits are unattractive and have a low sale value. Furthermore, it has been found that trees sprayed with bordeaux exhibit burning of the foliage and actually produce less fruit per tree than unsprayed plants.

Two additional copper fungicides, Cuprocide 54 and Cuprocide 54-Y, have been tested by Kikuta,[2] and were found to give up to 98 percent control of anthracnose without injury to the tree or fruits. It is unnecessary to spray the stems or the leaves of the plant. The under side of the fruit should be well covered, at a spray pressure of 150 to 300 pounds. The amount of fungicide to apply is indicated on the container. The addition of a spreader to the fungicide is of some benefit, for the papaya fruit is not easily wetted. It is also well to include a sticker, especially in rainy areas.[3]

Alternaria Fruit Rot

Symptoms. The blossom end of an affected fruit is discolored and darkened; when the fruit is cut open a considerable portion

[2] Kikuta, K. Op. cit.
[3] For discussion of spreaders and stickers, refer to Parris (*38*, pp. 21–22).

of the lower end is seen to be blackened and shrivelled. The flesh may be covered with a greenish mold (fig. 12). On internal parts that are only slightly discolored, a white, fluffy mycelium may be present. A dry rot is produced, in contrast to that of anthracnose, which is a soft rot.

Cause and life history. The cause of this disease is a fungus, a species of *Alternaria* (*citri?*), which gains entrance to the fruit through imperfectly closed blossom scars. The greenish mold mentioned above consists of the spores of the fungus. These spores are probably spread by wind, rain, and insects.

Alternaria rot is relatively unimportant in Hawaii.

Control. Control measures directed specifically at this fungus are usually not necessary; spraying for anthracnose should also control alternaria rot.

Powdery Mildew

Symptoms. This disease is best known to growers by the symptoms produced on the papaya leaf, but it may also cause appreciable damage to the fruit.

On the leaf: The presence of powdery mildew may be suspected when the older leaves of the papaya plant show dead areas between the main veins and when they wither more rapidly than normal, hang downward, and finally drop prematurely. Younger leaves show blotches or islands of yellow or pale green, usually near the veins, surrounded by normally colored tissue (fig. 13, *A*). Careful examination of foliage will reveal less advanced symptoms—tiny, pale yellow spots, somewhat water-soaked in appearance, near the veins.

On the under side of a diseased leaf, associated with the discolored spots of the upper surface, are found patches of mealy, whitish

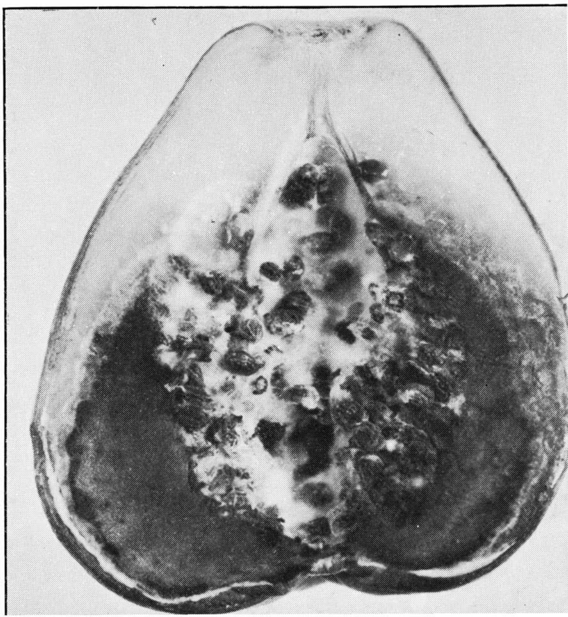


Figure 12. Fruit rot caused by Alternaria species.

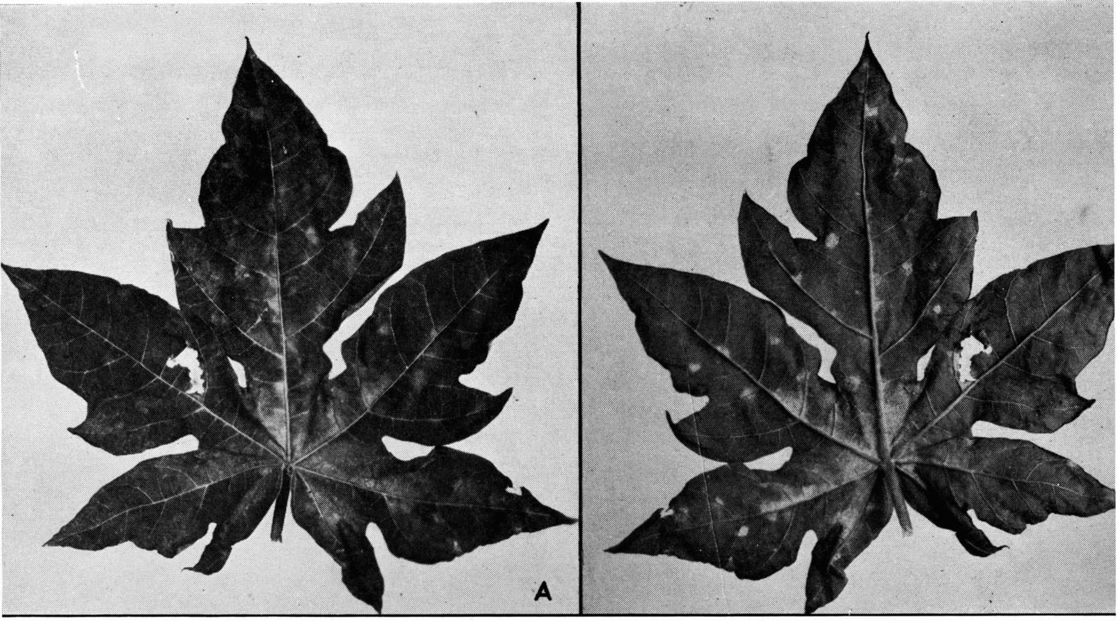


Figure 13. Effect of powdery mildew on papaya leaf: A, upper surface; B, under surface.

material, which rub off easily when handled (fig. 13, *B*).

On the fruit: Patches of this white, floury deposit may also appear on young papaya fruits. Fruits are not so severely injured as leaves, and the deposit soon disappears. However, the skin of the young fruit is superficially scarred by the infection, and when the fruit reaches maturity, this blemish may be of considerable size (fig. 14) or the fruit may be unevenly shaped due to restriction in growth of areas previously diseased. Affected fruits have little market value.

Cause and life history. Powdery mildew of papaya is caused by *Oidium caricae* Noack, a fungus which produces its spores on diseased spots on the leaves or fruits. These spores, en masse, give to the lesions the floury, mealy, whitish appearance previously described.

The spores are blown from plant to plant by the wind. They may also be transported by insects or splashing rain. In the presence of moisture they germinate and enter the plant tissue, from which the fungus derives its nutriment. Once established, the fungus soon causes yellowing of the tissues and reproduces.

The powdery mildew fungus needs moisture for spore germination and consequently is more common in the rainy months than in drier weather. Once established on the plant, the organism grows most rapidly at high temperatures.

Control. Powdery mildew can easily be controlled by a copper or a sulfur fungicide, sprayed directly at the diseased parts. If the fungus is abundant, burning of sprayed parts is likely to follow the application of copper. Fungicides should be applied when necessary, once a month or more often if the disease recurs sooner. Apply at the rate cited on the fungicide container.

Phytophthora Rot

This disease has been observed in several localities on the island of Oahu, at Aiea Heights, at Kailua, and at Kaneohe. It possesses all of the characters of a virulent disease and may, at some future date, become important.

Symptoms. The rot usually attacks the stem and the fruits, and occasionally the collar and roots of the plant. It has not been found attacking the papaya leaf in the field, but laboratory studies show that this plant part is susceptible under optimum conditions for infection.

On the stem: The disease first appears on the stem as water-soaked, discolored spots, about the size of a fifty-cent piece, which enlarge until they may produce a girdling of the affected part (fig. 15, *A*). Lesions are usually located in the region of fruit production, though they have been seen near the soil level and at intermediate points. When the stem is girdled, the top of the plant wilts, the leaves droop and fall prematurely, and finally the entire top of the plant is killed (fig. 15, *B*) or is snapped off by the wind. In some instances the plant seems able to withstand the onslaught of the disease, the lesions dry out, and infection stops. However, the death of a strip of tissue may so weaken the stem that the top of the plant will be snapped off by the wind. These decapitated plants eventually send out suckers, whose growth may be normal for a time, later becoming diseased, or may remain healthy indefinitely.

On the fruit: This disease causes a rotting of the young to medium-

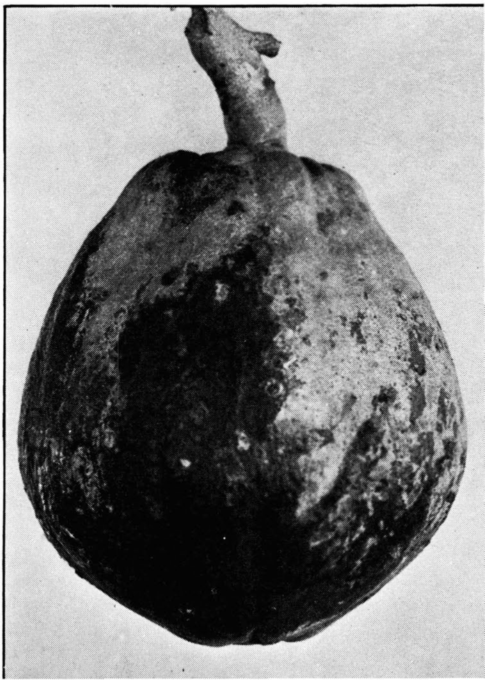


Figure 14. Scarring of young papaya fruit by powdery mildew.

sized fruit as it hangs on the tree. Any part of the fruit may be attacked: infection of the stem end is usually followed by infection of the stem at the point of attachment of the fruit to the stem. Diseased fruits show a whitish deposit (fig. 16, *A*) that adheres rather firmly to the surface of the fruit but can easily be removed with the fingernail or with a pen-knife. It may be confused with powdery mildew, although usually the latter is less extensive.

As the disease progresses, the fruit shrivels, turns dark brown, and falls to the ground, where further shriveling takes place until the fruit is blackened, very hard and mummified, and perhaps one-fourth its former size (fig. 16, *B*). Mummified fruits may show the whitish deposits noted on normal-sized diseased fruits attached to the tree. Unlike papaya anthracnose, phytophthora rot is not associated with secondary organisms which cause soft rotting of fruits: the rot is always a hard rot.

On the collar and roots: When the collar and roots are attacked, as occurs infrequently, the plant may topple over or be blown down by the wind. Such plants usually show a wilting and yellowing of the leaves, but this may also be produced by plants suffering from malnutrition, too much or too little rainfall, or root injuries associated with soil erosion. Seldom is the plant

Figure 15. Effect of Phytophthora parasitica on papaya plant: A, Water-soaked, discolored spots on stem; B, severely diseased plant, with the top killed.

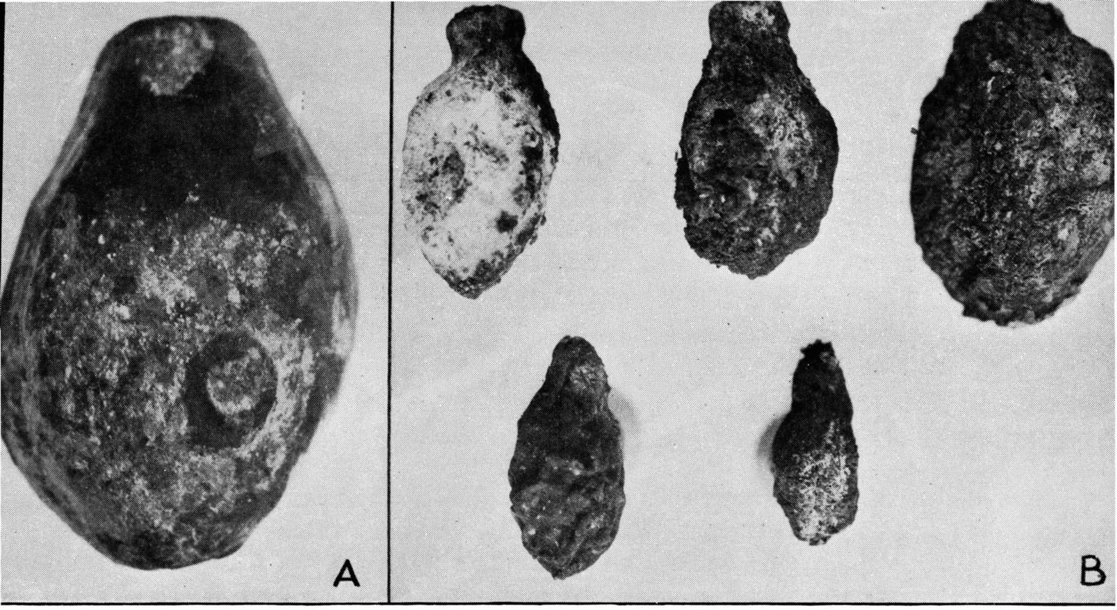


Figure 16. Effect of Phytophthora parasitica on fruits: A, Whitish deposits caused by downy mildew attacking fruit on tree; B, diseased fruits which have fallen to the ground, shriveled to one-fourth their size, and mummified.

killed by rotting of the collar. The diseased parts slough off, and the plant, in a recumbent or semi-recumbent position, slowly recovers.

Cause and life history. The cause of this disease of papaya is *Phytophthora parasitica* Dastur. The whitish deposit on the fruit is due to the formation of millions of spores (called sporangia) by the fungus. The sporangia are blown by the wind to healthy parts where, in the presence of moisture, they germinate to produce threadlike, colorless strands or hyphae which enter the skin of the plant. The organism is a virulent parasite if introduced through a wound; on unwounded parts, less damage is caused. Once within the cells of the plant, the pathogene develops in all directions to produce more of the previously described spots or cankers.

Within mummified fruits, thick-walled spores are formed, capable of withstanding considerable desiccation. These chlamydospores, as they are called, undoubtedly survive in the soil, but their presence in the tropical climate of Hawaii is probably not necessary to perpetuation of the fungus since sporangia are so abundantly produced on stems and fruits.

Control. The disease may be controlled by spraying with a copper fungicide. As pointed out for control of anthracnose, bordeaux mixture is not recommended for the papaya plant.

Many growers decapitate the stem below the diseased regions; suckers develop from the beheaded stems, and fruit formation is resumed earlier than when young trees are planted.

Root Rot

Symptoms. Diseased plants are retarded in their growth, the leaves turn light green or yellow and fall prematurely, and the apex of the plant is small and spindly in appearance. Root-rotted plants are poorly anchored in the soil and can be pushed over easily. Examination shows the root system to be scanty, and the surviving roots are discolored and decayed for a portion of their length. The stem at or just below the soil level may also be affected, and show a soft, spongy rot which extends upward in the pith and woody parts for several inches. The skin of the stem may be darkened or slightly water-soaked, but this symptom is seldom observed.

Cause and life history. Root rot of papaya in Hawaii may be caused by members of the genera *Pythium*[4] and *Fusarium*.[5] The latter genus is probably not so important a cause of disease as the former. The fungi are soil inhabitants, capable of living as saprophytes. Any factor or factors which weaken the plant, such as improper irrigation or soil erosion, may increase plant susceptibility.

The fungi enter the papaya roots through wounds, or directly if the roots are unthrifty. There the organisms multiply, causing decay and ultimately death of the affected parts. The fungi then live saprophytically in the soil on partly or completely decayed vegetable material.

Control. The uprooting and burning of diseased plants has been recommended by Simmonds (*45*). The soil in the holes vacated by dead plants should be dug apart and left exposed to the sun, or a weak bordeaux solution may be poured directly on the soil in and around the holes. It is best not to replant in the same hole for some time. When papayas are cultivated, care should be

[4] One species has been identified by J. T. Middleton as *P. aphanidermatum*.
[5] PARRIS, G. K. A CHECKLIST OF FUNGI, BACTERIA, NEMATODES, AND VIRUSES OCCURRING IN HAWAII AND THEIR HOSTS. U. S. Bur. Plant Indus., Plant Dis. Rptr. Sup. 121, 91 pp. 1940. [Mimeographed.]

taken to avoid injuring the root system. The plants should be maintained in a vigorous condition, and flooding should be avoided. Papayas with "wet feet" are particularly subject to root rot.

Damping-Off

This disease is confined to the seedbed, but losses are often so severe as to merit attention by growers.

Symptoms. Young plants, soon after they emerge, wilt rapidly, topple over at the soil level, turn brown, dry out, and eventually die. A wilting plant shows a darkened, water-soaked spot on the stem near the soil level; the stem is also constricted and wrinkled. Dead plants may become covered with a darkish or light gray mold.

Cause and life history. The fungi *Pythium* and *Rhizoctonia* are the causes of damping-off of papaya. These organisms live in the soil as saprophytes but can also attack the young seedling as it emerges from the soil, or some time after it has become well established in the seedbed. Local findings have shown that these fungi do not cause the death of germinating papaya seeds; that is, they do not produce pre-emergence damping-off.[6] After the death of the seedlings, the fungi return to the soil to attack future plants grown therein.

Control. Seed treatment with Semesan or red copper oxide (Cuprocide) will not control post-emergence damping-off of papaya,[7] but soil sterilization by heat or by formaldehyde before planting will destroy the pathogenic organisms. Steam is the most effective sterilizing agent, but the equipment required is expensive. Details of soil sterilization with formaldehyde are described in a previous publication (*38*). Seeds should not be planted in formaldehyde-treated soil for at least 10 days, and preferably not for 2 weeks.

Root Knot

Injuries so severe as to cause stunting of papaya have been attributed to nematodes (*50*); however, this pest is not believed to be of much consequence in papaya production in Hawaii.

[6–7] Unpublished data from M. Matsuura, assistant in plant pathology at this station.

Symptoms. The roots are the only parts of the plant attacked by nematodes, but injuries to the subterranean parts are usually reflected in stunting and generally poor growth of aerial parts. Enlargements (galls, or knots, as they are variably called) are produced, due to the feeding activities of the nematodes within the cells and tissues. The young roots are usually attacked most severely, and the normal intake of water and soil nutrients by the plant is thereby limited. The plant is retarded in growth, turns yellow or yellowish-green, and exhibits all the features of a plant suffering from malnutrition. The leaves may fall prematurely, and fruits produced are small and insipid in taste. There is some evidence that nematode-injured papayas are more subject to root rot than healthy plants. In cases of severe infection the papaya may be killed (*50*).

Cause and life history. The cause of root knot is the nematode *Heterodera marioni* (Cornu) Goodey, which attacks a wide range of plants. This pest is omnipresent in the soils of Hawaii and causes severe damage to pineapple, tomato, peppers, beets, and various ornamentals.

H. marioni is a small worm, just below the range of visibility of the naked eye, which lives in the soil and feeds on the roots of plants. Eggs are laid in the plant tissue. The adults live in the galls and also migrate freely through the soil. The larvae can subsist in the soil without food for at least 1 year, and produce as many as 12 generations in Hawaii within that period. The nematode spreads from place to place by means of infested soil, by water movement, or associated with the roots of living plants.

Control. Carbon bisulfide and chloropicrin have been recommended by various workers, including the writer (*38*), but these chemicals are expensive, difficult to apply, and not lasting in their effect.

Papaya seeds should not be planted in nematode-infested soil. If the young seedlings are affected with this pest, the subsequent development of root knot on the transplanted papaya is assured.

In the field the effect of root knot can be largely counteracted by keeping the plant in a thrifty condition. Proper fertilization and irrigation to keep the root system abundant and functioning actively will tend to overbalance the deleterious effects of nematodes on the roots.

Papayas should not be planted following crops known to be susceptible to nematodes or where damage by nematodes has been recently observed.

Papaya Mosaic

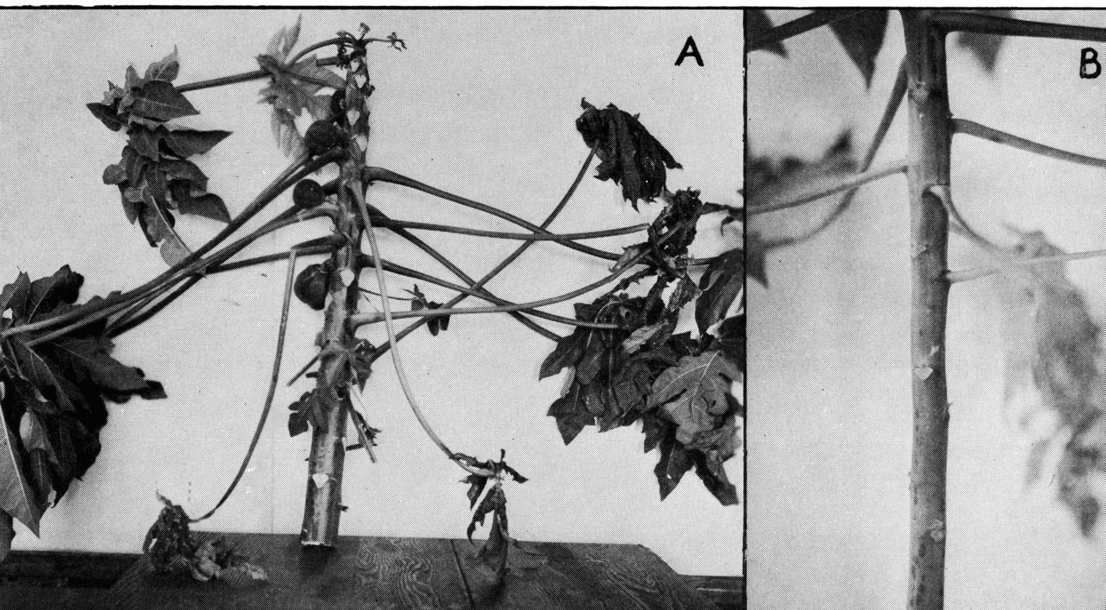
This virus disease, first reported in Hawaii in July 1937, caused considerable damage on the island of Oahu for several years, but since February 1939 has been conspicuous by its absence.

Symptoms. Affected plants (*39*) are stunted and the foliage is yellowed or mosaiced, the normal green color being mottled with dark and light green patches. The petioles of diseased leaves bend downwards, whereas the petioles of healthy foliage leave the stem at an angle above the horizontal. Usually only the upper two-thirds of a tree shows symptoms.

Diseased leaves abscise rapidly; 4 to 6 weeks after appearance of initial symptoms, only a few badly distorted, undersized leaves remain, clustered at the apex of the plant (fig. 17, *A*). Leaves which were mature prior to the appearance of symptoms are conspicuous as a fringe of normal green foliage around the lower part of the plant.

Linear, darker green than normal, slightly raised streaks or "oil spots," water-soaked in appearance, may be present on the petioles of diseased leaves or on the stem of a diseased plant (fig.

Figure 17. Effect of papaya mosaic: A, Close-up of diseased plant (note drooping of petioles and distortion of growing point and leaves); B, stem of diseased plant with streaks or "oil spots."



17, *B*). Streaks consistently precede the appearance of symptoms on the leaves. They may be isolated and few in number or quite extensive; occasionally definite ringlike patterns may be produced on the stems.

Fruits on diseased trees are undersized and somewhat distorted, and their surfaces may be rugose. On some trees the fruits bleed excessively, but this is not generally true.

The stems and petioles of diseased plants are much harder and somewhat more brittle than those of healthy plants, due to the excessive development of thick-walled tissue (sclerenchyma).

Cause and life history. The cause of this disorder is a virus, or ultramicroscopic principle capable of reproducing disease when the juice of a diseased plant is injected into a healthy plant. In the case of the present papaya virus, transmission has been obtained by mechanical abrasion and by inarch grafting of a diseased on a healthy plant, but not by scion grafting. No insect has been found which will transfer the virus from a diseased to a healthy papaya. The source of the virus in the field in Hawaii is not known.

Control. Little can be done to control this disease until more facts are available as to the method by which it is spread in the field, or the plant reservoirs from which it moves to the papaya.

As soon as the disease appears in a planting, the diseased portions of the plants should be cut off. Care should be taken to remove all parts of the stem showing oil spots. If some of the suckers that develop are diseased, further decapitation is called for, until all the suckers on a plant are normal. According to local observations the uprooting of diseased plants and their burning does not seem to be necessary.

The grower should never handle healthy plants after he has touched diseased plants, without first washing his hands with soap and water or a weak solution of formaldehyde. The same is true of pruning shears, saws, or other decapitating instruments.

PART IV. INSECT PESTS OF PAPAYA AND THEIR CONTROL

by F. G. HOLDAWAY

The most important pests of papaya in Hawaii are mites. Three species have been recognized: two are "red spiders" of the family Tetranychidae, the third is a "white mite" of the family Tarsonemidae. Next in importance are various sucking insects, of which thrips and aphids are the most abundant. Mediterranean fruitfly (*Ceratitis capitata* Wied.) will oviposit in ripe and overripe fruits but does not attack fruits in the mature green stage in which they are normally harvested (*34*). A large number of other species of insects have been found on papaya trees, but at the present time they have the status of either minor or casual insects. However, one or more species may be found to be vectors of papaya mosaic. Ladybird beetles and spiders are commonly found on papaya trees, and they and occasional lace-wing and syrphid-fly larvae undoubtedly do much to keep down the number of insects on the trees.

Mites

Red spiders are the commonest pests of papaya. The identities of the species and their relative abundance is still a matter of investigation. To date two important species of Tetranychidae are recognized, the common red spider *Tetranychus telarius* (so-called), probably *Tetranychus althacae* v. Hanst., and *Tenuipalpus bioculatus* McGregor.[1] The former species exhibits whitish, reddish, and orange forms; the latter is scarlet-colored.

All stages of *Tetranychus telarius* (*althacae*) occur on the under surface of the leaf but also may be found on the trunk of the tree. Heavily infested leaves exhibit webbing along the veins and in the angles between the veins. Attacked foliage takes on a yellowish-green color and may exhibit a whitish stippling which

[1] Identification by E. A. McGregor, who considers that there may be three or even four species of tetranychid mite on papaya in Hawaii.

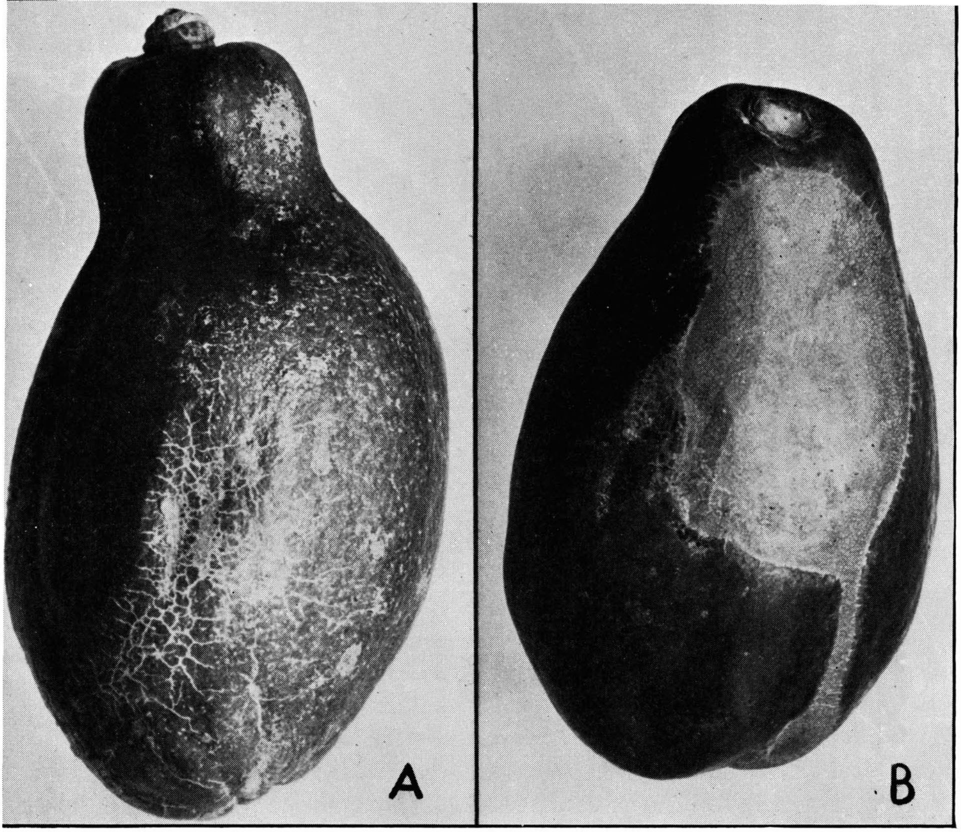


Figure 18. Papaya fruits attacked by the "red spider" or privet mite. Tenuipalpus bioculatus: The fruit on the left exhibits typical scaly, cracked areas; the fruit on the right shows the large, sunken area.

shows on the upper surface. The mites are wind-borne, according to Klein (*29*), who records 63 host plants in 25 families in Palestine; 60 percent are economic plants.

Tenuipalpus bioculatus McGregor, referred to by McGregor (*32*) as the privet mite, is capable of serious injury to the fruit (fig. 18). Affected fruits exhibit callouslike, grayish, scaly or cracked areas which may be sunken below the normal level of the skin. Affected areas are most common at the point of contact of the fruit with the trunk.

McGregor has recorded occurrence of this mite on ten host species of diverse taxonomic relationships. In addition to privet (*Ligustrum amurense* and other species), he includes garden mint (*Mentha spicata*), strawberry, the palm (*Phoenix humilis*), orange, and lemon. He says "This host list . . . indicates that the privet mite is to some extent a general feeder." It causes serious damage to citrus trees in California (*16*) and may be one of the species of mite on coffee in Hawaii.

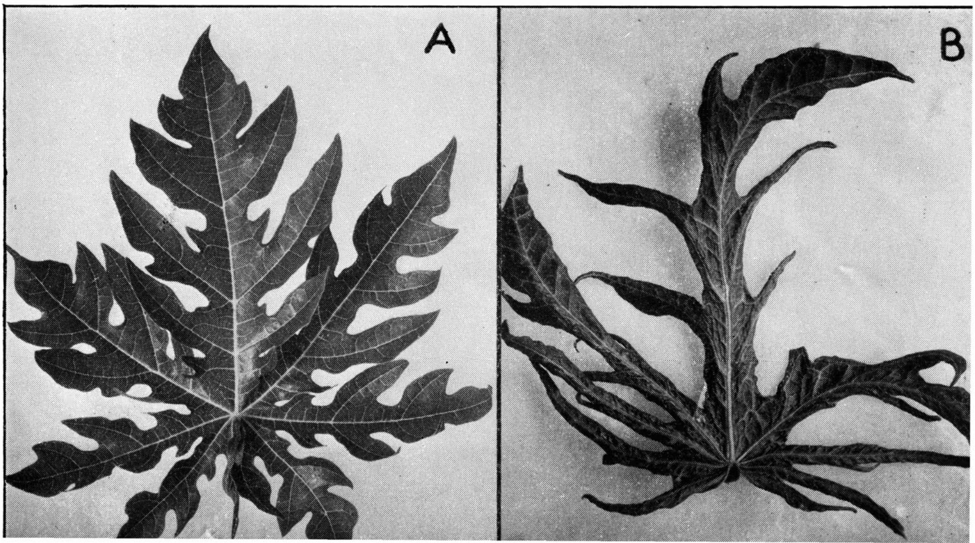
The third important species of mite on papaya is the tarsonemid species, *Hemitarsonemus latus* (Banks).[2] This species can be seen only with difficulty with the naked eye. The adult females, the largest individuals, are between one-fifth and one-fourth of a millimeter in length. The mites, which occur on the under surface of the leaf, are translucent white in color. Ewing (8), in his description of the species, apparently made from individuals taken on mango, gives the color of the females as "translucent yellowish green, the legs having a whitish hue." Individuals observed on other hosts conform more to this description but on papaya they are white. The common name for this mite in mainland United States is broad mite.

Infested leaves are reduced in size and are yellowish-green to yellow. The lamina, instead of being flat, blade-like, and pliable, is distorted and leathery, with the tips often curled in the direction of the lower surface. The surface, instead of being smooth, as in a normal leaf, is rough (fig. 19). Infested trees produce progressively smaller and more markedly distorted leaves. Infestations allowed to go unchecked may result in the death of the leader and the production of multiple stems, or may even cause the death of the tree.

Hemitarsonemus latus has been recorded in Hawaii causing injury to the young foliage of string beans and jimson weed (*Datura stramonium* L.). Ewing (8) lists 37 hosts, which include

[2] Identification by H. E. Ewing.

Figure 19. A, Normal papaya leaf; B, papaya leaf infested with white mites (Hemitarsonemus latus).



a wide range of ornamentals, vegetables, fruit trees, and weeds. Of these, mango, avocado, beet, potato, tomato, pepper, and parsley are economic plants grown in Hawaii. Mite injury suggestive of that caused by *H. latus* has been observed on tomato, Irish potato, sweetpotato, pepper, Swiss chard, beet, and avocado, but exact determination of the species has not yet been secured.

Smith (*46*) states that at 70° to 80° F., temperatures characteristic of regions in Hawaii where papayas are grown, *H. latus* completes its life cycle in 4 to 5 days and may deposit seven eggs daily. Such a rapid life cycle no doubt accounts for the speed with which the trees become deformed and the infestation spreads from plant to plant.

Tetranychus telarius and *Hemitarsonemus latus* may attack papaya trees at any stage of their growth. (It is not yet known whether *Tenuipalpus bioculatus* attacks young trees.) Papayas in the seedbed and nursery should be kept under observation and treated as soon as the presence of mites is detected. The young trees will thus be kept thrifty, and new fields will not be infested with mites from the nursery. Clean cultivation should be practiced, since weeds are often a source of infestation. The effect of weeds on mite incidence has been observed in a sloping papaya

Figure 20. A, Typical distortion of leaves caused by infestations with white mite; B, a tree, formerly infested, which has resumed healthy growth after spraying with sulfur.

field, where weeds were left to prevent erosion. Jimson weed became abundant in the field, and the source of infestation by *H. latus.* In parts of the field where jimson weed was most abundant, over 90 percent of the trees were severely attacked by the mite.

Mites are most abundant and injury is most severe during periods of dry weather.

Control. Experience has shown that sulfur will control all the species of mite attacking papaya in Hawaii (see fig. 20). Although sulfur dust has been reported to give almost 100-percent kill of *Tenuipalpus bioculatus* on citrus in California (*16*), to give effective control of *H. latus* on gerbera (*46, 47, 48*), delphinium (*28*), and greenhouse plants (*37*), and to give best results against *Tetranychus telarius* on vines (Ruzaev, in Vasil'ev, *56*), experience has shown that sulfur sprays are more effective than dusts for mites on papaya in Hawaii. Several factors undoubtedly contribute to this result. It is easier to secure satisfactory coverage of the under surface of the broad horizontal papaya leaf with a spray than with a dust. Winds, which are frequent in Hawaii, make dusting difficult. The open nature of the foliage of papaya is not conducive to efficient or economical use of dusts. Wettable sulfur at the rate of 5 pounds per 100 gallons has given good results, and finely divided sulfur of the colloidal type in paste form has given even better results. The price of the latter type is higher than that of ordinary wettable sulfur, and it is not known yet whether the increased effectiveness is sufficient to justify the extra cost. In applying wettable sulfur spray for the control of mites, particular attention should be given to the under surface of the leaf. For control of the white mite, *Hemitarsonemus latus,* attention should also be given to the growing point.

Aphids and Thrips

While aphids and thrips do not infest papaya trees as commonly as do mites, they sometimes cause quite serious damage in the first few weeks after the young papaya trees are placed in the field, especially if conditions are such as to prevent or slow up normal growth.

Several species of aphid have been found to attack papaya trees. *Myzus persicae* Sulz. is the most abundant, and *Macrosiphum gei*

Figure 21. Egg masses of nutgrass armyworm, left, and beet armyworm, right, on papaya leaves; the deformity of the leaves was probably caused by Thrips tabaci when the leaves were much younger.

Koch and *Aphis gossypii* Glover are next in importance. Over 450 individuals of *Myzus persicae* have been found on a young papaya tree, only 7 inches in height, recently transplanted to the field. The aphids occur on the under surface of the leaf. With heavy infestations the leaf curls at the edges and turns yellowish-green. The leaf petiole hangs down below the horizontal in a manner characteristic of the petioles of trees affected with mosaic, whereas in normal uninfested trees the petioles are directed upwards as they leave the trunk.

The onion thrips, *Thrips tabaci* Lind., breeds readily on papaya and may cause serious deformity of the foliage of young trees. Infested leaves become mottled with whitish blotches. Leaves which are infested when very young may become markedly distorted. One hundred thrips (80 adults and 20 nymphs) have been recorded on a young tree only 13 inches in height.

Control. A nicotine-sulfate spray at a strength of 1 to 400 (2 tablespoons to 3 gallons or 1 quart to 100 gallons), to which soap has been added (1 cubic inch per gallon or 6 pounds per 100 gallons), will usually control aphids and thrips on papaya. Nicotine sulfate is compatible with wettable sulfur and, when necessary, may be included with the sulfur spray for mites.

Miscellaneous Insects

Egg masses of beet armyworm [*Laphygma exigua* (Hub.)] and nutgrass armyworm [*Laphygma exempta* (Walk.)], are often found on the foliage of papaya trees (fig. 21). The larvae of these insects do not normally complete their life cycles on papaya. Larvae of nutgrass armyworm do not feed on the foliage at all. Larvae of the other species are capable of completing part of their development if constrained to feed on papaya foliage, but in the field readily leave the tree when they are about one-half inch in length, if they have remained to that stage of development.

PART V. HARVESTING, MARKETING, AND USES OF PAPAYA

by W. W. JONES

In harvesting papayas for local markets, the fruits should be removed from the tree as soon as the first traces of yellow color appear on their skins (firm-ripe stage). Such fruits will ripen in the course of 4 or 5 days, with as good flavor as those ripened on the tree. If the fruits are allowed to ripen on the tree, it is practically impossible not to bruise them in handling. In addition, ripe fruits are frequently damaged by birds.

Care must be exercised in harvesting, even with firm-ripe fruits. Gloves should be worn, not only to prevent injury to the fruits but also to protect the harvester from the latex. As soon as the fruits are removed from the tree they should either be wrapped in paper and placed in a field box lined with excelsior or placed in a box lined with excelsior which has been covered with paper. Fruits placed directly on excelsior become scratched. A field box should hold 24 to 36 fruits in a single layer, and there should not be more than one layer to the box. With the fruits wrapped and in properly lined field boxes, they can then be transported to market without bruising.

The harvesting and marketing should be so timed that the fruit is almost fully colored but still firm when it reaches the consumer. Under ordinary conditions fruit for local markets should not be cold stored.

Before the fruits are transported to market, they should be graded as to size and maturity and all cull fruits discarded. This can be done in the field at the time of harvest or just before the boxes are loaded on a truck for transport to market. Any box of fruits should contain only one fruit shape (sex type), one degree of maturity, and one approximate size. Under ordinary conditions only the pyriform (type IV) and the round (type I) fruits should be marketed. The misshapen, bruised, or overripe fruits should be discarded.

Harvesting for Mainland Shipments

Shipment of papayas to the mainland was in the experimental stage in 1914, when certain island fruits and vegetables were placed under quarantine (Quarantine No. 13) because of the presence here of the Mediterranean fruitfly (*Ceratitis capitata*). All shipments ceased, and papayas were marketed only locally until November 1938, when the quarantine laws were modified. The modifications were based on treatments known to kill all stages of the Mediterranean fruitfly and of the melonfly (*Bactrocera cucurbitae*).

Careful harvesting and handling are especially important when fruits are destined for distant markets. The firm-ripe papayas should be removed from the tree with a sharp knife: fruits that are broken or twisted from the tree, especially the riper ones, are frequently bruised around the point of stem attachment. They should then be placed in a padded, paper-lined box, not more than one layer deep, and transported to the treating plant.

Maturity of the Fruits

An understanding of the ripening process in the papaya fruit is necessary before marketing problems can be appreciated. With advent of maturity, the first noticeable change is the development of yellow color in the seed stalks. The color then spreads outward, and full ripeness is attained when the external surface of the fruit is completely yellow. During the same period the flesh, previously tough and rubbery, becomes very soft and easily crushed. Associated with these visible evidences of maturation are changes in the chemical composition and respirational activity of the fruit.

Table 5. Chemical composition of the papaya fruit in relation to maturation

Stage of maturity	Water (fresh-weight basis)	Calculated on dry-weight basis—						
		Soluble solids	Glucose	Sucrose	Total sugar	Total nitrogen	Calcium pectate	Acid-hydrolyzable material
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Green	86.1	10.49	40.70	30.98	71.68	0.59	6.53	9.33
Firm-ripe	86.1	10.67	62.23	12.41	74.64	.66	5.99	4.74
Ripe	85.3	11.56	62.64	14.40	79.04	.53	6.35	4.36

The outstanding change in chemical composition (table 5) is in relationship of sucrose to reducing sugars. In the immature fruit 42 percent of the total sugars occur as sucrose, while in the ripe fruit the sucrose content drops to 18 percent of the total sugars.

Acid-hydrolyzable material is reduced from 9 percent of the total dry weight in the immature fruit to 4 percent in the ripe fruit. As no starch is present in the papaya, this decrease represents a change in cell-wall constituents and accounts, at least in part, for the change in consistency of the flesh during ripening.

As the fruit ripens, the rate of respiration, as measured by carbon-dioxide elimination, rapidly increases, reaching a peak simultaneously with full color development (fig. 22). Later the

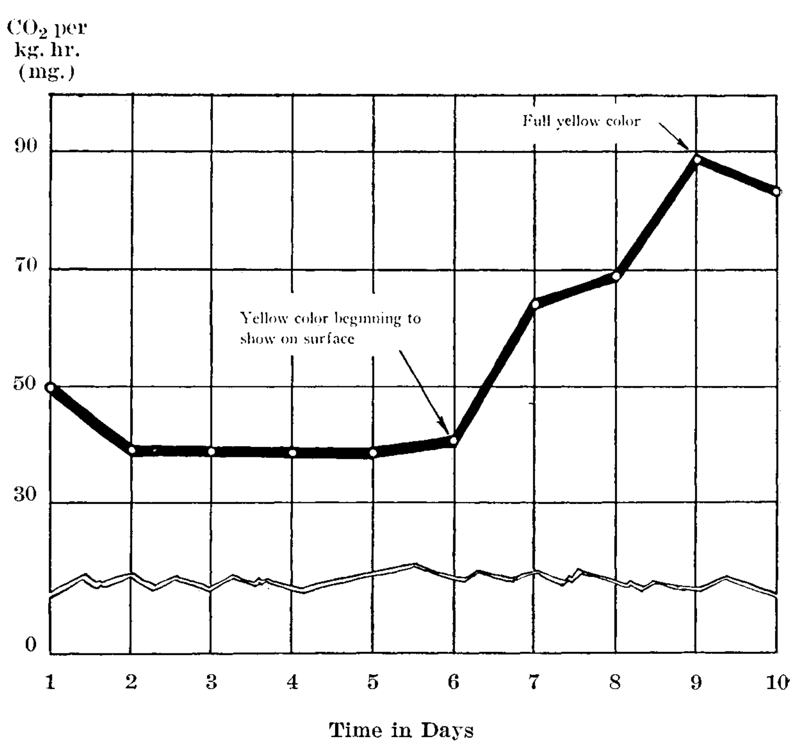


Figure 22. Respiration of papaya fruits during ripening process (held at a temperature of approximately 77° F.).

rate of respiration usually falls. In some instances it may rise again, but the second rise is caused by growth of fungi on the overripe fruit and by leakage of carbon dioxide from the interior of the fruit through the openings caused by the fungi. Even before the development of external color and the increase in elimination of carbon dioxide, concentration of carbon dioxide in the internal cavity of the fruit, and in the flesh as well, has begun and continues throughout the ripening period. No peak is reached. As the internal carbon dioxide increases, the oxygen decreases.

Tolerance to Disinfestation Treatments

Before papayas can be shipped to the mainland, they must be treated to kill all stages of the Mediterranean fruitfly. Three methods have been approved—cold treatment, vapor-heat treatment, and for certain specified fruits, methyl-bromide fumigation. The tolerance of the fruit and the cost of the treatment determine the commercial method.

Cold treatment. The cold treatment consists of holding the fruit for 15 days at a temperature of 35° F. Unfortunately many tropical fruits, including the papaya, are "chilled" by this treatment. The papaya may be stored at 50° F. for 10 to 15 days but not at 35° F. Storage at 35° F. prevents the hydrolysis of sucrose and cell-wall constituents and retards respiration of firm-ripe papayas (*14*, *27*). After removal to room temperature, small surface pits develop and the fruit decays without ripening. Even in ripe fruits, the characteristic papaya flavor is lost after 15 days at 35° F.

Methyl-bromide treatment. This method consists of treating the fruit with 2 pounds of methyl bromide per 1,000 cubic feet for 3.5 hours at a temperature of not less than 80° F. It has been shown (*25*) that papayas do not tolerate this treatment well, chiefly because of decay caused by *Colletotrichum* sp. (*gloeosporioides* ?). Until fruits free of this fungus are available, methyl-bromide should not be used on papayas. (See the section on diseases, p. 32, for a more complete discussion of this organism.)

Vapor-heat treatment. In this treatment the *inside* temperature of the fruit must be maintained at 110° F. for 8 hours in an atmosphere saturated with water vapor. The method was first used for control of Mediterranean fruitfly on citrus fruits in Florida (*26*). It has also been applied to control of narcissus-bulb pests in the Pacific Northwest (*31*).

In commercial papaya treatments the fruits must be held in the heat room for about 8 hours (known as the approach or conditioning period) before the specified temperature is reached. This period, plus the 8 hours required for disinfestation, gives a total treatment time of 16 hours. It was soon found that the papaya would not tolerate a 16-hour treatment in an atmosphere saturated with water vapor. However, by holding the relative humidity between 55 and 60 percent during the approach period, papayas were found to tolerate an 8-hour disinfestation at 110° F. and 100 percent relative humidity (*23, 26*).

Equipment and Operation of Heat-Treatment Plant

Vapor-heat treatment requires a room equipped with a machine to heat, control the relative humidity of, and circulate the air in the room. The air is withdrawn through a false floor, passed through the conditioning machine, and reintroduced into the room through the ceiling (fig. 23). The conditioning machine must be provided with water sprays, steam sprays, and a steam radiator. With these three units, the temperature as well as the relative humidity can be controlled. The essential point in designing the treating room is to insure even distribution of the circulating air and steam mixture. In a square room this can only be done by apportioning exactly the amount of mixture drawn from each part of the room by a system of channels leading to the suction outlet.

The room should be just large enough to contain the maximum quantity of fruits to be sterilized at any one time. A room 9 by 9 by 8 feet to 12 by 12 by 8 feet should be large enough for the average commercial plant. The former would accommodate about 5 tons of papayas and the latter, about 9 tons. The conditioning machine for the smaller room would consist of a 4-horsepower boiler and a variable-speed fan with a maximum capacity of 1,000 cubic feet per minute. The mixing chamber should be a sheet-metal box, 5 by 3 by 3 feet. Within this box are located the water sprays, steam sprays, and steam radiator. The air enters one end

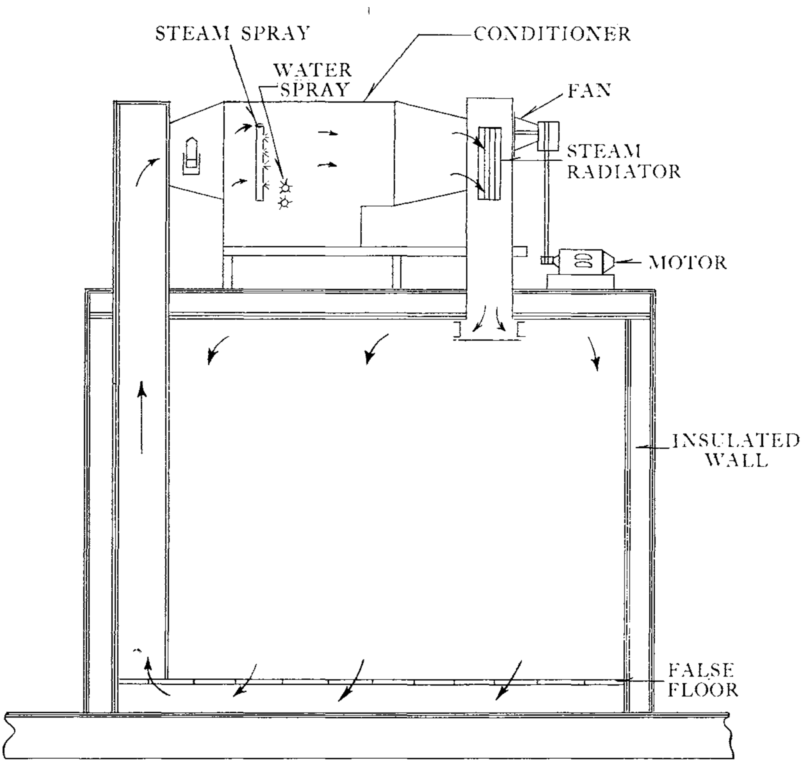


Figure 23. Vertical section of vapor-heat chamber, with equipment; arrows show direction of circulation. [*Basic design was taken from Latta (31); provisions for preconditioning equipment have been added.*]

of the mixing chamber, passes over the radiator, through the water and steam sprays, through baffles, into the fan, and thence into the treating room. Both the room and the mixing chamber should be insulated to prevent loss of heat.

Before treatment, the fruits should be graded. Only bruise- and blemish-free, firm-ripe fruits of a desirable size and shape should be treated. They should be carefully placed in slatted-bottom boxes and the boxes stacked in the treating room. After the 8-hour approach period, when the temperature of the fruits is raised to 110° F. with the relative humidity maintained at 55 to 60 percent, and the 8-hour disinfestation period, with the relative humidity maintained at 100 percent, the room should be opened and the fruits allowed to cool to room temperature (about 12 hours).

The fruits should be individually inspected, and any bruised or overripe fruit removed. Each fruit should then be wrapped in a paper, similar to that used for grapefruit wraps, and packed in excelsior in a "Jumbo avocado flat" (fig. 24). The number of fruits per lug varies from 9 to 18, depending on size. The size should be uniform in any given lug, and the size and number of fruits should appear on the label. As soon as the lugs are packed and lidded, they should be moved to the boat and loaded into a refrigerator hold adjusted and maintained at 50° F. On reaching the coast the fruits should be removed from cold storage and allowed to ripen at a temperature above 65° F. The ripe fruit may then be replaced in cold storage at 40° to 45° F. and held for 2 or 3 weeks.

Uses of Papaya

Food products. A large percentage of the papayas grown in the islands are consumed as fresh fruit and as such are an economical source of vitamins A and C and of calcium and a basic ash (*36*). Pope (*40*) has reported that the papaya contains little nourishment. Calculations from chemical constituents as shown in table 5 and an estimated yield of 30 tons of fruit per acre (*33*) show that a yield of 6,000 pounds or 3 tons of sugar per acre per year may be obtained.

In addition to the consumption of fresh papaya, some fruits and considerable quantities of papaya juice are canned. The papaya is also used in the preparation of such products as jam, marmalade, pickle, cocktail, etc. (*36*).

Medicinal value. Any medicinal value that may be possessed by the papaya can be attributed largely to the high pectin content of the fruit, the papain (very little to none in the ripe fruit), the sulfur-containing volatile oil of glucosidal nature of the seed, and the alkaloid carpain of the seed and leaves. No factual data are available at this station, however, except on the production of papain.

Figure 24. Papayas which have been treated in a vapor-heat chamber, regraded, wrapped, and packed for shipment. This box is a "Jumbo avocado flat" (inside dimensions 13¾ × 16½ × 4½ inches).

Papain. Papain, one of the most powerful plant proteolytic enzymes, is known to occur in all parts of the papaya plant except the roots (*2*). It is possible that it occurs in the roots also, but Balls and his coworkers at this station were unable to extract it. Consumption of commercial papain, or the dried latex from the fruit, is increasing in the United States; 222,675 pounds were imported in 1938, according to the chemical division of the U. S. Department of Commerce. There is no domestic production of papain in the United States, although the trees grow in Puerto Rico, Canal Zone, and Florida, as well as in Hawaii.

The collection and preparation of the latex for market is a simple process. Usually only the fruits are tapped, but papain may be obtained from other parts of the tree, as will be pointed out later. The yield is greatest from fruits on a vigorously growing tree during warm weather, early in the morning, after a rain. Large, mature-green fruits are selected, and four or five shallow, lengthwise incisions, not over one-eighth inch deep, are made in each fruit. Latex flow is rapid at first, but coagulation soon occurs, and the coagulated latex is then scraped from the fruit. The lancing may be repeated several times at intervals of 3 or 4 days; it leaves the fruits badly scarred and unfit for the fresh fruit market, but the quality is not impaired and the fruits can be used for making juice. The latex should be dried promptly to prevent fermentation. Commercial papain is usually sun-dried; however, drying at 50° C. under vacuum has been found to give a white or light brownish powder, somewhat more active than the commercial sun-dried papain (*2*). As soon as the latex is dried and ground, it should be sealed in air-tight containers since it becomes inactive on exposure to air (*54*).

The yield of dried latex at one bleeding usually amounts to about 0.1 percent of the fresh weight of the fruit (see table 6).

Table 6. Amount of latex obtained from papaya fruit[1]

Weight of fruit	Weight of fresh latex	Proportion of fresh latex to fresh fruit	Weight of dried latex	Proportion of dried latex to fresh fruit
Grams	*Grams*	*Percent*	*Grams*	*Percent*
1150	7.5	0.65	1.35	0.12
1000	10.0	1.00	1.00	.10
1565	5.2	.30	....	....
733	5.6	.77	.73	.10
1470	8.6	.58	1.60	.11
1225	5.1	.42	.92	.07

[1] Data obtained in a cooperative experiment between the Bureau of Agricultural Chemistry and Engineering of the U. S. Department of Agriculture and the Hawaii Agricultural Experiment Station, and previously published by Balls et al. (*2*).

Sen (*44*) finds that the first exudation of juice gives the greatest yield and best quality of papain. He further notes that potash starvation is disastrous to papain yield, while the effects of phosphate starvation are not marked.

The enzyme can also be separated from press juices of the stems, leaves, and petioles by the addition of alcohol or ammonium sulfate. The product thus obtained is about equal in enzyme activity to the dried latex from the fruits. This method is not used at present, but it offers possibilities and could be adapted to machine preparation.

Recently crystalline papain has been isolated (*1*). It has an isoelectric point of about pH 9.0 and a molecular weight of 27,000, and contains 15.5 percent nitrogen and 1.2 percent sulfur. The proteolytic activity is three or four times as great as that of the commercial latex, and is comparable to that of pancreatic enzymes. It has a very marked anthelmintic activity in test tubes (*3*).

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