

Breadfruit

Artocarpus altilis (Parkinson) Fosberg

Diane Ragone



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Foreword

Humanity relies on a diverse range of cultivated species; at least 6000 such species are used for a variety of purposes. It is often stated that only a few staple crops produce the majority of the food supply. This might be correct but the important contribution of many minor species should not be underestimated. Agricultural research has traditionally focused on these staples, while relatively little attention has been given to minor (or underutilized or neglected) crops, particularly by scientists in developed countries. Such crops have, therefore, generally failed to attract significant research funding. Unlike most staples, many of these neglected species are adapted to various marginal growing conditions such as those of the Andean and Himalayan highlands, arid areas, salt-affected soils, etc. Furthermore, many crops considered neglected at a global level are staples at a national or regional level (e.g. tef, fonio, Andean roots and tubers etc.), contribute considerably to food supply in certain periods (e.g. indigenous fruit trees) or are important for a nutritionally well-balanced diet (e.g. indigenous vegetables). The limited information available on many important and frequently basic aspects of neglected and underutilized crops hinders their development and their sustainable conservation. One major factor hampering this development is that the information available on germplasm is scattered and not readily accessible, i.e. only found in 'grey literature' or written in little-known languages. Moreover, existing knowledge on the genetic potential of neglected crops is limited. This has resulted, frequently, in uncoordinated research efforts for most neglected crops, as well as in inefficient approaches to the conservation of these genetic resources.

This series of monographs intends to draw attention to a number of species which have been neglected in a varying degree by researchers or have been underutilized economically. It is hoped that the information compiled will contribute to: (1) identifying constraints in and possible solutions to the use of the crops, (2) identifying possible untapped genetic diversity for breeding and crop improvement programmes and (3) detecting existing gaps in available conservation and use approaches. This series intends to contribute to improvement of the potential value of these crops through increased use of the available genetic diversity. In addition, it is hoped that the monographs in the series will form a valuable reference source for all those scientists involved in conservation, research, improvement and promotion of these crops.

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Diane Ragone
19 July 1996
Kauai, Hawaii

Introduction

Breadfruit is a multipurpose tree crop that is primarily used for its nutritious, starchy fruit. It is the main staple crop in many areas of the Pacific and supplements other staple foods for home consumption elsewhere. It generally has little commercial use but is becoming an export crop in the Caribbean.

Breadfruit originated in the western Pacific, with New Guinea and associated islands such as the Bismarck Archipelago being the centre of diversity for wild seeded forms of *Artocarpus altilis* (Parkinson) Fosberg. Few-seeded and seedless forms occur throughout the Pacific Islands, with the greatest diversity found in the eastern Pacific in Polynesia. Seedless breadfruit has been widely distributed throughout the tropical world.

A related, seeded species known as breadnut, *Artocarpus camansi* Blanco, naturally occurs in the Philippines, New Guinea and possibly the Moluccas. It is rarely seen elsewhere in the Pacific Islands with the exception of a few recently introduced trees in the south Pacific. Breadnut has been introduced to other tropical areas where it is now widespread, especially in the Caribbean, parts of Central and South America, and coastal West Africa. It remains to be determined whether to consider breadfruit as a single, variable species, *A. altilis* which includes breadnut, or retain *A. camansi* as a distinct species.

Another related species, seeded *Artocarpus mariannensis* Frécul, is endemic to Belau and the Mariana Islands in the western north Pacific. This species has been involved in introgression with *A. altilis* in Micronesia, and numerous seeded and seedless hybrid forms are cultivated throughout these islands.

This publication describes the genetic resources of breadfruit and provides an in-depth look at the current status of breadfruit conservation and the extent of *ex situ* germplasm collections, especially in the Pacific Islands. The extensive technical and ethnobotanical literature on distribution, history and uses are covered in detail.

Most of the studies and utilization of breadfruit have focused on a very limited number of seedless cultivars of *A. altilis*. Yet enormous breadfruit germplasm resources exist in the Pacific Islands that encompass the wide range of variability in *A. altilis* as well as cultivars that are hybrids between *A. altilis* and *A. mariannensis*. Despite its widespread distribution and use, surprisingly little work has been done on characterization, evaluation and description of breadfruit germplasm. This critical work will maximize the potential for breadfruit to become a much more widely grown and utilized crop throughout the tropics.

1 Taxonomy and names of the species

The breadfruit (*Artocarpus altilis*) is a widely grown and nutritious tree fruit. It is a member of the genus *Artocarpus* (Moraceae) which contains about 50 species of trees that grow in the hot, moist regions of the Southeast Asian tropics and the Pacific Islands. Some species are locally valuable as timber trees, while breadfruit, jackfruit (*Artocarpus heterophyllus* Lamour.) and champedak (*Artocarpus integer* (Thunberg) Merrill) are grown for their fruits (Purseglove 1968).

The generally accepted name for breadfruit is *Artocarpus altilis* (Parkinson) Fosberg (Fosberg 1941, 1960) (Figs. 1-2) which has taxonomic priority and replaced *Artocarpus incisus* (Thunb.) L. f. Suppl. 411. 1781 (*A. incisus* variant spelling), and *Artocarpus communis* Forst. Char. Gen. 101. 1776. These names for breadfruit are based solely on specimens or descriptions of seedless Tahitian breadfruit collected during Captain Cook's voyages there in 1768-1771.

While *A. altilis* (and synonyms) has appropriately been applied to the seedless breadfruit typical of Polynesia — a type that is now widely distributed throughout the tropical world — the nomenclature for other forms of breadfruit is not as straightforward. Throughout the Pacific, breadfruit exhibits great morphological variability, ranging from true seedless fruits to fruits with numerous, minute, aborted seeds, to fruits with one to few viable seeds, to fruits with numerous seeds (Fig. 2c-d). Many authors have taken the broad view and encompass all of this variability within one species.

Vernacular names of *A. altilis* are: breadfruit (English), *arbre à pain* (French), *árbol del pan* (Spanish), *Brotfruchtbaum* (German), *rimas* (Philippines), *sukun/timbul* (Indonesia), *kulur/kuro* (Malaysia), *kapiak* (New Guinea), *uto/kulu* (Fiji), *bia/nimbalu* (Solomon Islands), *beta* (Vanuatu), *ulu* (Hawaii, Samoa), *uru* (Tahiti and Society Islands), *kuru* (Cook Islands), *mei/mai* (Micronesia, Tonga, Marquesas), *lemai* (Mariana Islands) and *mos* (Kosrae).

However, there is another valid species of breadfruit in the Pacific Islands (Fosberg 1960). *Artocarpus mariannensis* Trécul (Trécul 1847) (Fig. 3) is a wild, seeded breadfruit, known as *dugdug* and *chebiei* endemic to the high islands of the western north Pacific. It was described from a specimen collected in the Mariana Islands in 1819. This species is morphologically very distinct from *A. altilis* and involved in introgression with this species in Micronesia where numerous cultivars with characters of both species are found (Fosberg 1960; Coenan and Barrau 1961; Ragone 1991a).

The real question to be resolved concerns a spiny, seeded type of breadfruit (breadnut, kamansi, pakok) (Fig. 4) described from the Philippines and naturally found in New Guinea and possibly the Moluccas. Breadnut is rarely seen in the South Pacific with the exception of a few recently introduced trees, and it is not found anywhere in Micronesia (Ragone 1991a). It has been widely distributed throughout the tropical world, especially the Caribbean and Central and South America. It was first described as a distinct species, *Artocarpus camansi* Blanco (Blanco 1837). Subsequent authors reduced this name to synonymy under *A. altilis* (generally as

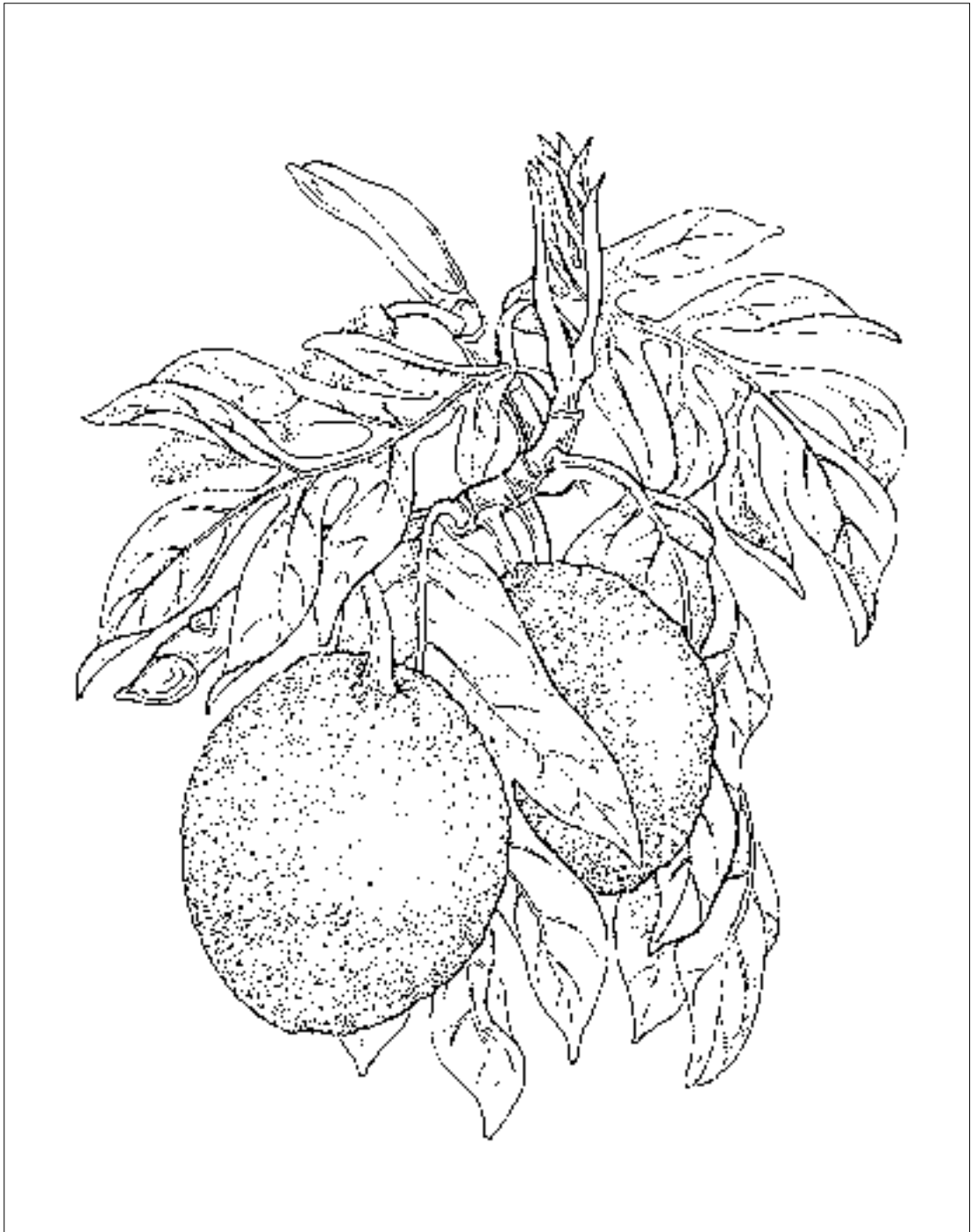


Fig. 1. *Artocarpus altilis* (drawing by Mary Grierson)

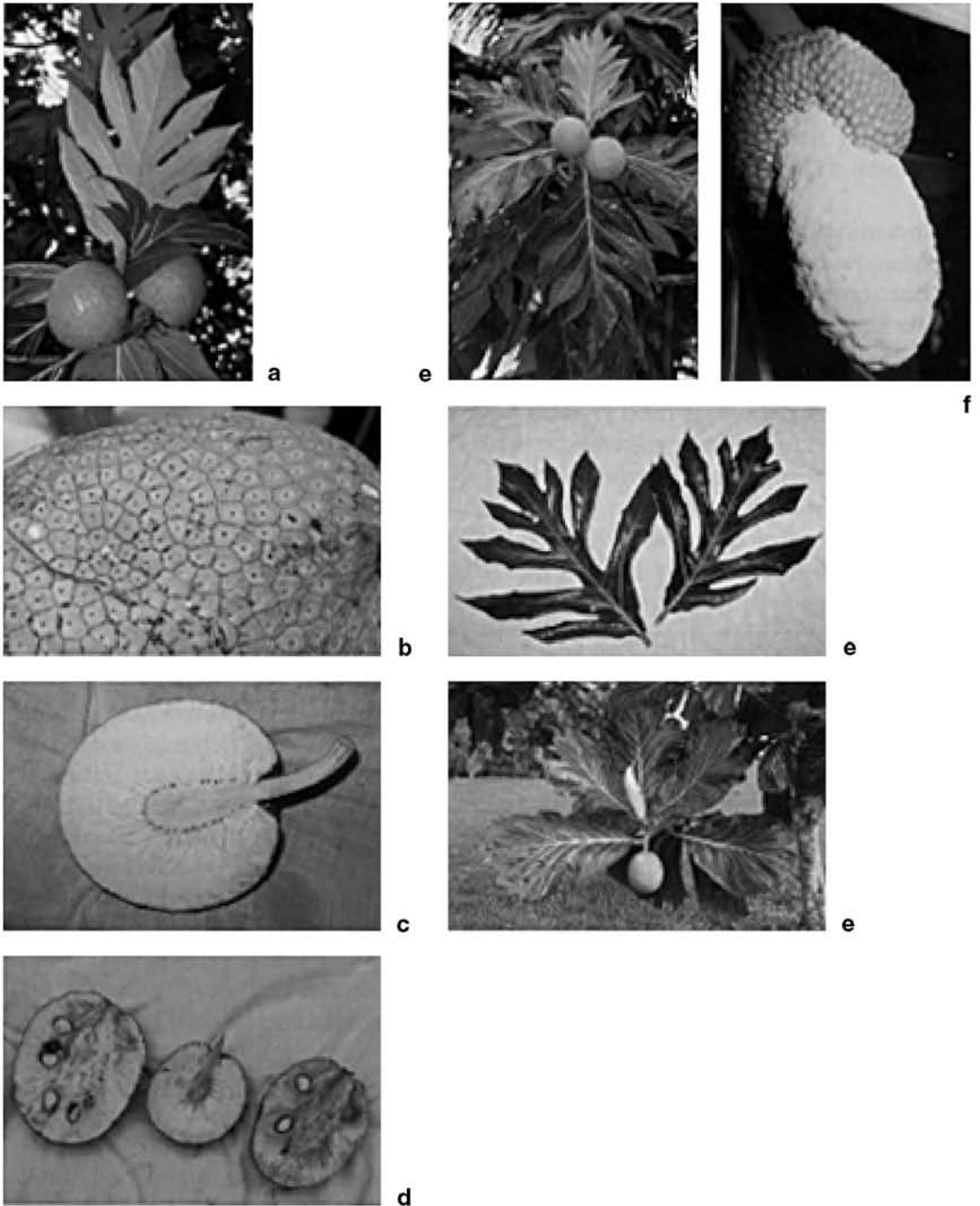


Fig. 2. *Artocarpus altilis*: (a) fruit and leaves of typical seedless Polynesian breadfruit; (b) close-up of typical fruit texture of *A. altilis*; (c) cross-section of seedless *A. altilis*; (d) variation in seed number of *A. altilis*; (e) variation in leaves of *A. altilis*; (f) abnormal inflorescence of breadfruit

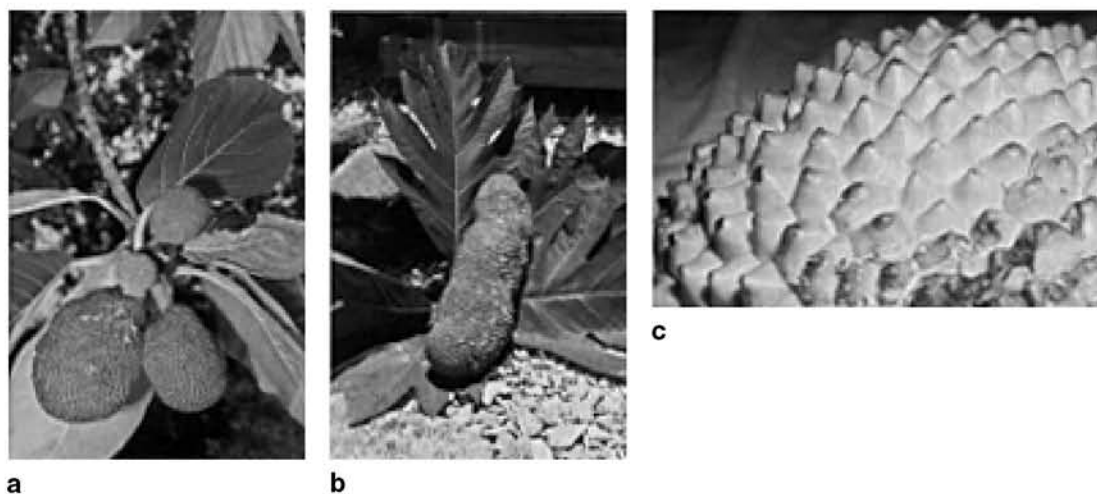


Fig. 3. *Artocarpus* species: (a) *A. mariannensis* — fruit and leaves of dugdug; (b) *A. altilis* x *A. mariannensis* hybrid; (c) close-up of fruit texture of *A. altilis* x *A. mariannensis* hybrid

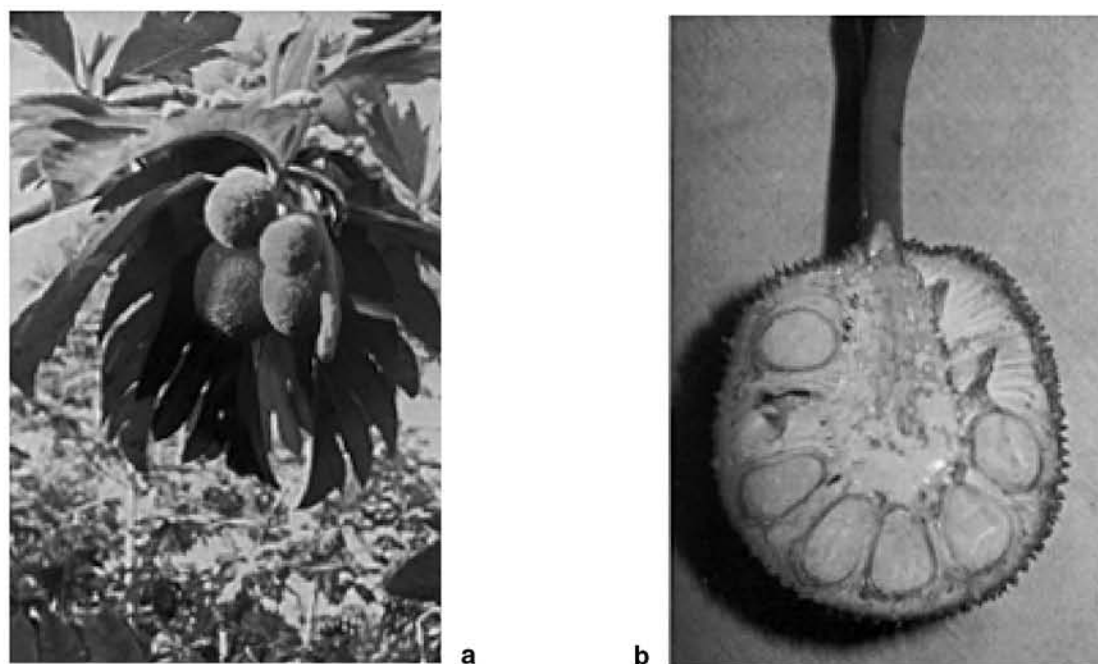


Fig. 4. *Artocarpus camansi*: (a) fruit and leaves of breadnut, (b) cross-section of seeded *A. camansi*

A. communis but it was revived as a valid name by Quisumbing (1940) who recognized it as distinctly different from the introduced seedless breadfruit and considered it an endemic species. Most authors in the Philippines recognize it as distinct from *A. altilis* (Coronel 1983).

Jarrett (1959), in her monograph on breadfruit, thought that *A. camansi* had been introduced to the Philippines from New Guinea or the Moluccas and grouped it under *A. communis*. Fosberg never specifically addressed this question but tended toward considering it as a separate species (F.R. Fosberg, 1993, pers. comm.). Preliminary isozyme data based on a small sample suggest that *A. camansi* is closely related to but distinct from both *A. altilis* and *A. mariannensis* (Ragone 1991a). For the purposes of this monograph, the name breadnut will be used to refer to this spiny seeded breadfruit to distinguish it from the other types of seeded breadfruit.

The resolution of this question will rest on examination of a much greater range of materials than were available to Jarrett or Fosberg. As Jarrett herself noted, most taxonomic work on breadfruit has relied primarily on a limited sample of mostly sterile herbarium specimens with narrow geographic representation. It is important to note that small, newly developing fruits of many breadfruit cultivars, even seedless ones, are often spiny but tend to smooth out as the fruits develop. It is this stage that is most often represented on the relatively few fertile herbarium vouchers.

The author has compiled voucher specimens and photographs of close to 400 accessions from cultivated trees, especially few-seeded or seedless cultivars, representing the great diversity of breadfruit throughout the Pacific Islands. Vouchers were also collected from wild trees in the Mariana Islands. These materials are housed in the herbarium of the National Tropical Botanical Garden (NTBG). A wide range of wild, seeded trees from New Guinea and seeded forms from the western Pacific and Indo-Malaysian islands needs to be collected and examined for morphological characters and molecular markers such as isozymes. These materials, supplemented by meticulous observation of live plants at all stages of growth and development, will help ascertain whether it is warranted to consider breadfruit as a single, variable species, *A. altilis* or to retain *A. camansi* as a distinct species.

2 Botanical description

Tree and leaves

In general, breadfruit trees are large, attractive and evergreen, reaching heights of 15 to 20 meters. The tree has smooth, light-coloured bark, and the trunk may be as large as 1.2 m in diameter, occasionally growing to a height of 4 m before branching. The wood is an attractive golden colour, turning darker upon exposure to air. Latex is present in all parts of the tree. Two large stipules enclose the terminal bud. They are up to 30 cm long at maturity, yellowing and falling with the unfolding of leaves or emergence of inflorescences.

The thick leaves are leathery with a dark-green upper side which is often glossy. The underside is dull with an elevated midrib and main veins. There is striking variation in leaf outline and dissection (Fig. 2e). The leaves are broadly obovate to broadly ovate in outline, varying in size and shape even on the same tree. Juvenile leaves on young trees and new shoots of mature trees are usually larger, more dissected and more hirsute. Leaf dissection in breadfruit ranges from almost entire with only slight lobing to deeply pinnately lobed with sinuses from $2/3$ to $4/5$ of the distance from margin to midrib, or deeper. Leaves are sometimes smooth but are often covered with a few to many pale to reddish hairs, especially on the midrib and veins. The leaves of breadnut are pinnately lobed with sinuses cut half way to the midrib (Fig. 4a). They are densely pubescent on upper and lower surfaces, midribs and veins. The leaves of *dugdug* are generally smaller, broadly obovate to broadly elliptic in outline (Fig. 3a). The leaves are entire or have a few lobes with sinuses cut less than half way to the midrib. Lobing occurs mostly in the distal third or half of the leaf. The upper surface of the leaf is glossy and smooth. The midrib and veins on the underside are covered with dense reddish-coloured hairs that lie flat against the veins and give them a velvety appearance.

Fruit and seeds

The fruit is a highly specialized structure, a syncarp, composed of 1500-2000 flowers attached to the fruit axis or core (Jarrett 1976). The core contains numerous latex tubes and large vascular bundles which discolour rapidly upon cutting, due to oxidative enzyme activity. The bulk of the fruit is formed from the persistent perianth of each flower. The perianths are fused together except at the base (Reeve 1974). As the fruit develops, this area grows vigorously and becomes fleshy at maturity, forming the edible portion of the fruit. The tough rind of the fruit is composed of five- to seven-sided disks, each the surface of an individual flower. Two to three strap-shaped, reflexed stigmas protrude from the centre of the disk and often leave a small distinctive scar when they blacken and wither. The rind is usually stained with latex exudations at maturity.

The fruits of breadfruit are globose to oblong, ranging from 12 to 20cm wide and 12 cm long. The rind is light green, yellowish-green or yellow when mature and the flesh is creamy white or pale yellow. The fruit surface varies from smooth to slightly

Box 1. Brief descriptions of breadfruit species*Artocarpus altilis*

- Leaves broadly obovate to broadly ovate, almost entire with only slight lobing to deeply pinnately lobed with sinuses from 2/3 to 4/5 of the distance from margin to midrib, or deeper; blade generally smooth with few to many pale to reddish hairs, especially on the midrib and veins.
- Fruits globose to oblong, skin light green, yellowish-green or yellow, flesh creamy white or pale yellow; surface smooth to slightly bumpy or spiny with individual disks ranging from areolate, to slightly raised and flattened, to widely conical up to 3 mm high and 5 mm across at the base, to narrowly conical up to 5 mm long. Seedless, with some forms seeded.

Artocarpus camansi

- Leaves pinnately lobed with sinuses cut halfway to the midrib; densely pubescent on upper and lower surfaces, midribs and veins.
- Fruits oblong, light green with white flesh; spiny with flexible, elongated sections 5-12 mm long. Seeded.

Artocarpus mariannensis

- Leaves broadly obovate to broadly elliptic; entire or a few lobes mostly in the distal third or half of the leaf; sinuses cut less than half way to the midrib; blade smooth; midrib and veins on the underside covered with dense, appressed reddish hairs.
- Fruits cylindrical or asymmetrical, skin dark green, flesh dark yellow; perianth disks conical when immature, flattened on top when mature. Seeded.

bumpy or spiny with individual disks ranging from areolate (Fig. 2b), to slightly raised and flattened, to widely conical up to 3mm high and 5mm across at the base, to narrowly conical up 5 mm long. The fruits of breadnut (*A. camansi*) are oblong and spiny with flexible, elongated sections 5-12 mm long that narrow to a point (Fig. 4a).

Fruits of *dugdug* (*A. mariannensis*) are cylindrical or asymmetrically shaped with a deep-yellow flesh (Fig. 3a). They are generally smaller than breadfruit, averaging 8-10cm wide and 10-14cm long. The perianth disks of the dark green rind are conical when immature, becoming flattened on top when mature. The degree of fusion of the perianths of *A. mariannensis* appears to be more similar to that of *A. heterophyllus* (jackfruit) than *A. altilis*. Adjacent flowers fuse at the middle region of the perianths, leaving the lower and upper parts free from each other. The fruits of this species, unlike any other breadfruit, can be eaten raw. Hybrids between *A. altilis* and

A. mariannensis exhibit characteristics of both species. *Artocarpus altilis* characters include deeply dissected and numerous leaf lobes, white hairs on the upper veins and denser fruits with a greater degree of fusion between the perianths of adjacent flowers (Fig. 3b). *Artocarpus mariannensis* often contributes conical, pyramidal or flattened perianth disks (Fig. 3c) to the fruit, yellow flesh and reddish hairs on the lower veins. Hybrid cultivars show the full range of variability from seedless to having only a few seeds or numerous seeds.

Breadfruit/breadnut seeds are thin-walled, subglobose or obovoid, irregularly compressed, 1-2cm thick, embedded in the pulp. Seeds have little or no endosperm, no period of dormancy and germinate immediately. They are not able to withstand desiccation. Important features of the three species are summarized in Box 1.

Reproductive biology

Inflorescences are axillary and monoecious, with the male inflorescence originating first. Male inflorescences are club-shaped, up to 5 cm in diameter and 45 cm long. The thick, spongy axis is covered by numerous minute flowers. Each flower consists of a reduced tubular perianth enclosing a single stamen with a two-lobed anther on a thick filament. In young flowers, the perianth has a narrow opening, but at anthesis its lobes are widely separated and the anther is exerted above the perianth (Sharma 1965). Abnormal inflorescences with both male and female flowers have been observed (Fig. 2f).

The pollination mechanisms of breadfruit are not fully understood, with questions raised as to whether this is mediated by wind or insects. Breadfruit trees are monoecious with male and female flowers occurring separately on the same tree. Male inflorescences originate first, followed by female inflorescences. Pollen is shed 10 to 15 days after the emergence of the male inflorescence for a period of about 4 days (Brantjes 1981). Female flowers are receptive 3 days after the emergence of the female inflorescence from the bracts and open in successive stages with basal flowers opening first. As with other members of this genus, breadfruit is cross-pollinated.

Most authors have claimed that male inflorescences are odourless (Jarrett 1959; Purseglove 1968; Brantjes 1981). Yet, male inflorescences of many accessions, especially fertile forms, in the NTBG germplasm collection have a distinct odour similar to the "sweet scent of honey and burnt sugar" that Corner (1940) reported for *A. heterophyllus*, *Antegerand* and *A. dadah*. Honeybees have been observed actively working male inflorescences and collecting pollen, especially from fertile, seeded accessions. Other insects (such as earwigs) have also been observed on male inflorescences.

Seedless cultivars generally produce little viable pollen compared with fertile, seeded and few-seeded cultivars. In fertile cultivars, the anthers of hundreds of flowers will protrude and dehisce, releasing thousands of pollen grains, so much so that a dusting of pollen can be seen on leaves under the inflorescence. Only a few flowers in male inflorescences of seedless breadfruit produce and release pollen.

Pollen grains from fertile cultivars are uniformly shaped and stain well, while those triploid cultivars have the lowest pollen stainability, averaging from 6 to 16%, and the pollen grains are typically malformed, clumped and poorly stained (Ragone 1991a). These facts were previously noted by Sunarto (1981), who showed that a seeded form had the highest pollen grain stainability (99%), while a few-seeded form had medium stainability (45%) and a seedless form had low stainability (6%). Thus pollen sterility may be one factor contributing to seedlessness in certain forms.

A study of five, presumably seedless, breadfruit trees by Brantjes (1981) documented nectar production in male, but not female, inflorescences. Bees were seen feeding on secreted nectar and collecting pollen but were not seen visiting female inflorescences. He suggested that the lack of nectar secretion and absence of pollinators on female inflorescences meant the bees' feeding merely promoted release of pollen from the protruding anthers with the small, powdery pollen grains being spread by the wind. Honeybees have been observed visiting mature and ripening fruits of cultivars in the NTBG germplasm collection. The bees appear to be collecting latex that has oozed from the fruit surface. It is not known whether bees also visit newly emerging and receptive female inflorescences. Additional observations are necessary to determine the mode of pollination in breadfruit.

Artocarpus altilis diploid ($2n = 56$) and triploid ($2n = 84$) (Barrau 1976; Jarrett 1959; Ragone 1991a). The chromosome number for *A. mariannensis* and for *A. camansi* is $2n = 56$ (Ragone 1991a).

3 Origin of the species and important centres of diversity

Centres of diversity and domestication

Breadfruit is an ancient domesticated cultigen and its origin, domestication and distribution must be considered within a geographic and cultural context. The distribution and proposed centres of origin of species of breadfruit and breadnut in the Pacific Islands are shown in Fig. 5.

Jarrett's (1959) revision of breadfruit placed it with a group of species thought to naturally occur in the Moluccas, New Guinea and the Philippines. Most of the cultivars (seeded and seedless) of breadfruit in Micronesia east of the Mariana Islands exhibit characteristics of both *A. altilis* and *A. mariannensis*. *Artocarpus mariannensis* grows wild on the uplifted rock islands of Belau and on the limestone ridges of Guam and the Northern Mariana Islands (Fosberg 1960; Coenan and Barrau 1961). Native fruit bats have contributed to its dispersal. It is cultivated throughout the islands of Micronesia and south into Kiribati, Tuvalu and Tokelau. *Artocarpus mariannensis* and hybrids are well adapted to atoll conditions and are more tolerant of salinity than *A. altilis* (Catala 1957; Murai *et al.* 1958; McKnight 1964; Coenan and Barrau 1961).

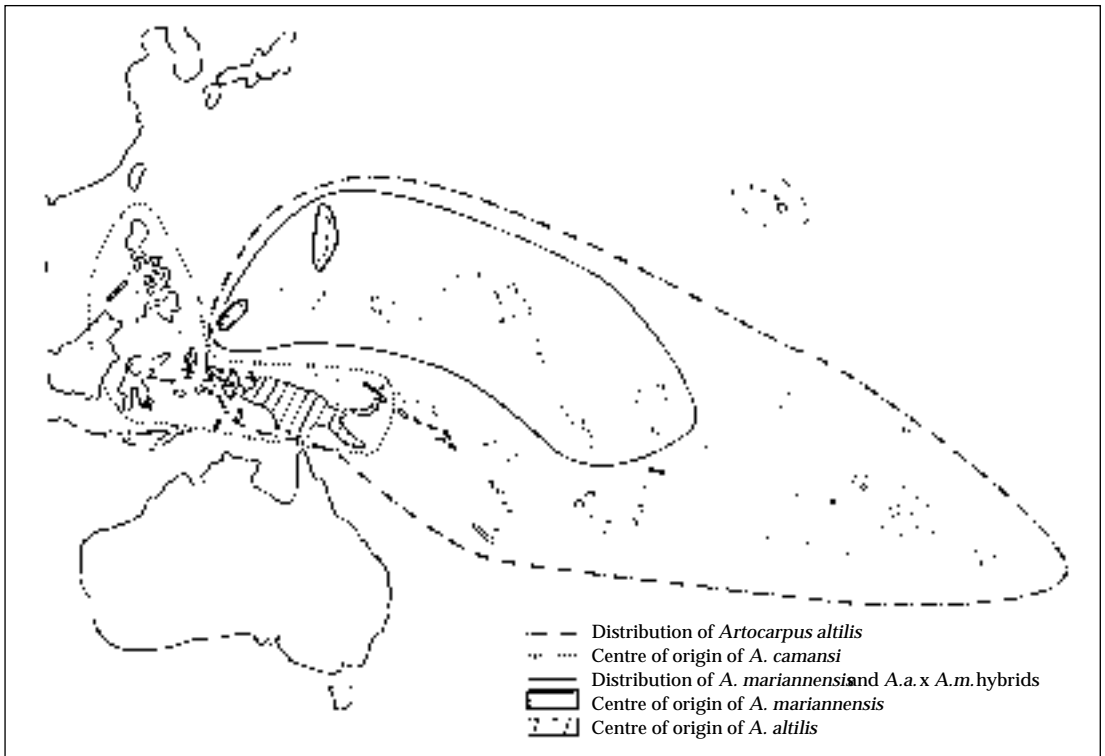


Fig. 5. The distribution and centres of origin of species of breadfruit and breadnut in Oceania

The ability to grow on coral soils may have been a crucial factor in the now-widespread distribution of hybrids throughout the low-lying Micronesian atolls.

Artocarpus mariannensis has not been distributed beyond the northern Pacific Islands with the exception of a possible introduction to the Philippines in the 1600s by the Spanish. Ray's *Historia Plantarum* published in 1704, describes 'dugdug marianorum' a tree introduced from Guam and different from the seedless breadfruit, 'rimas marianorum', introduced at the same time (Wester 1924).

Seeded breadfruit appears to occur wild only in New Guinea where, along with breadnut, it is a dominant member of secondary forests in lowland areas. Seeded breadfruit trees grow widely scattered in primary forest due, in part, to their dispersal by birds, fruit bats and other arboreal mammals which feed on the flesh and drop the large seeds. Wild breadfruit is an important component of the subsistence economy in lowland areas (Conroy and Bridgeland 1950; Pajmans 1976). Both the fruit pulp and the seeds are eaten in some varieties, while in others only the seeds are edible, since the flesh is tough and stringy (Croft 1987). While seedless breadfruit typical of Polynesia is grown in village areas of New Guinea, it did not originate in these islands. In fact, seedless cultivars were introduced from Fiji (Cowley 1898) and Samoa (Barrau 1957) by missionaries in the 19th century.

Wild breadfruit trees do not ordinarily produce root shoots. The first cultivated breadfruits were transplanted seedlings from the forest, or more likely, plants grown from gathered seeds. Breadfruit roots are typically exposed or grow slightly below the surface of the ground; damage to the root often induces a shoot to develop at the site of the wound. It is likely that the vegetative mode of propagation developed from the chance injury to roots of a cultivated tree. Root shoots, which could be removed and planted elsewhere, would have provided an alternative, faster method of propagation than seeds. Also, vegetative propagation would have preserved desirable horticultural qualities of specific genotypes resulting from early selection efforts in a highly variable outcrossing population.

It is most likely that breadfruit was first domesticated in New Guinea and associated islands such as the Bismarck Archipelago (Ragone 1991a). Elsewhere in Melanesia breadfruit occurs only in cultivation, although long-abandoned plantings are often mistaken for wild trees. Many 19th century accounts of breadfruit in the Pacific Islands, such as *Flora Vitiensis* (Seeman 1865-1873) have contributed to the confusion about the natural distribution of breadfruit by mistaking planted trees for wild ones.

Breadfruit seeds quickly lose their viability and seedlings would be difficult to transport and keep alive during longer voyages. The use of vegetative propagative material allowed successful long-distance transfer of this cultigen. The shift to vegetative propagation of breadfruit would have a great impact on its distribution and cultivation, and profound implications for its cultivators. It would allow for transportation over greater distances and ultimately increase the chances of few-seeded or seedless cultivars originating. The development of fruits with reduced fertility and reduced seed number resulted in a shift from utilizing this species as a nut crop in western Melanesia to primarily a starchy fruit crop eastwards.

The greatest diversity of seeded and few-seeded cultivars is found in the eastern Solomon Islands and Vanuatu, and it was probably in the Santa Cruz and possibly the Banks Islands that breadfruit was first extensively cultivated and selected. Samoa in western Polynesia is also an important centre with a range of seeded to seedless cultivars.

The greatest diversity of seedless cultivars occurs in the eastern Polynesian islands (Society Islands and Marquesas) and Pohnpei and Chuuk in Micronesia. Breadfruit cultivars with one to a few seeds are so unusual in eastern Polynesia that the presence of a sporadic seed is denoted in the cultivar name: *huex* in the Society Islands and *mei kakanin* in the Marquesas, both meaning “with a seed”. It is important to note that many of the seedless cultivars in Micronesia are hybrids between *A. altilis* and *A. mariannensis* and are unique to those islands, unlike the ‘Polynesian’ seedless breadfruit which has been distributed all over the globe.

Many early visitors to the Pacific Islands documented names, uses and even provided descriptions of breadfruit cultivars. Extensive survey work over the past 50 years has greatly expanded this body of knowledge and more than 2000 vernacular names have been recorded from 22 island groups (Ragone 1991a, 1995). The number of cultivar names that have been reported or described for centres of breadfruit diversity are listed in Table 1.

Historical distribution

The dissemination of seedless breadfruit beyond Oceania is well documented and involves only a handful of cultivars, primarily Tahitian. Breadfruit has been an evocative symbol of Oceania since Europeans first ventured into the region in the late 1600s. After the long, often arduous, sailing voyage from Europe to the islands, ship-worn sailors were amazed and delighted by a tree that produced prolific fruits that, when roasted, resembled fresh bread. They were especially impressed by the ease with which this abundant food was produced. Numerous accounts were published about this wonder fruit, beginning with Quiros who sailed with Mendana on voyages during 1595-1606. He described seedless breadfruit in the Marquesas and seeded breadfruit in the Solomon Islands (Markham 1904). The Spanish may have introduced seedless breadfruit to Guam from elsewhere in the Pacific in the 1600s to help provision their new colony. They did introduce seedless breadfruit to the Philippines in the 17th century (Wester 1924).

Dampier (1729) was the first to document the use of breadfruit in the Mariana Islands. He was particularly enthusiastic about breadfruit’s use and potential, crediting it for saving the lives of his starving, scurvy-ridden crew in 1686. Various accounts by participants of Captain James Cook’s first voyage to Tahiti in 1768 had a major impact and focused much attention on breadfruit. The botanist John Ellis (1775) summarized the accounts of early voyagers and was one of the first to suggest in writing that the breadfruit should be introduced to the West Indies where it would be most useful to all the inhabitants, especially the slaves.

Table 1. Published vernacular names for breadfruit cultivars in the Pacific Islands

| Island | Author | Year | No. of names |
|-----------------|----------------------|-----------|--------------|
| Marquesas | Jardin | 1862 | 31 |
| | Christian | 1910 | 34 |
| | Wester | 1924 | 25 |
| | Ragone | 1991a | 30 |
| Samoa | Wilkes | 1845 | 20 |
| | Christophersen | 1935 | 30 |
| | Parham | 1966 | 25 |
| | Ragone | 1991a | 27 |
| Society Islands | Bligh | 1792 | 8 |
| | Ellis | 1829 | 50 |
| | Bennett | 1860 | 24 |
| | Wester | 1924 | 52 |
| | Henry | 1928 | 40 |
| | Wilder | 1928 | 58 |
| | Petard | 1986 | 26 |
| | Ragone | 1991a | 66 |
| Fiji | Seeman | 1865-1873 | 13 |
| | Koroveibau | 1967 | 55 |
| | Ragone | 1991a | 38 |
| Solomon Islands | Jackson | 1982 | 20 |
| | Ragone | 1991a | 147 |
| Vanuatu | Murray | 1894 | 65 |
| | Nalo | 1967 | 24 |
| | Walter | 1989 | 132 |
| Kosrae | Safert | 1919 | 18 |
| | Lee | 1976 | 20 |
| | Ragone | 1991a | 13 |
| | Merlin <i>et al.</i> | 1992 | 21 |
| Pohnpei | Christian | 1897 | 45 |
| | Kanehira | 1931 | 50 |
| | Bascom | 1946 | 32 |
| | Sasuke | 1953 | 47 |

Table 1 (continued).

| Island | Author | Year | No. of names |
|--------------|----------|-------|--------------|
| | Lawrence | 1964 | 65 |
| | Soucie | 1978 | 80 |
| | Raynor | 1989 | 131 |
| | Ragone | 1991a | 42 |
| Chuuk (Truk) | Bascom | 1946 | 31 |
| | Elbert | 1947 | 56 |
| | Raynor | 1989 | 20 |
| | Ragone | 1991a | 35 |

These and other accounts helped set the stage for Captain Bligh's well-documented mission to introduce Tahitian breadfruit to the Caribbean. The story of Bligh's ill-fated first trip on the **Bounty** has been extensively chronicled (Howard 1953; Enloe 1975; Powell 1977) and will not be related here. A later voyage on the **Providence** was much more successful, and in 1792 Bligh introduced more than 600 plants to the islands of St. Vincent and Jamaica. These introductions consisted of only a few Tahitian cultivars, whose names he did not specify, and a seedless breadfruit from Timor (Bligh 1976). The latter one was considered inferior to the Tahitian types. Hooker (1828) gave brief descriptions for five seedless types (four from Tahiti and one from Timor) that Bligh had introduced. The majority of breadfruit in the Caribbean today originate from these few introductions (Leakey 1977).

The Tahitian types were disseminated throughout the Caribbean, due in large part to the efforts of the St. Vincent Botanic Garden. Anderson, the garden director, was a great advocate for this new crop and wrote in 1796 (Frost 1993) that "the breadfruit thrives (if possible) better than in its native soil, all the trees in the garden are full of fruit in all stages; they have been bearing constantly for 18 months past." He distributed plants as widely as possible to the Leeward and other Windward Islands and Bahamas.

The French were also avidly trying to procure breadfruit and introduce it to their colonies in the West Indies and elsewhere. These activities centered on the Pamplemousse Botanical Garden in Mauritius. The French introduced a Tongan variety of seedless breadfruit known as *kele kelāto* their Caribbean colonies of Martinique and Guadeloupe, and to Cayenne, French Guyana in the 1790s (Leakey 1977). Rouillard and Gueho (1985) elaborated upon the fascinating background of this introduction. It was collected on the island of Tongatapu (Tonga) during the expedition of La Pérouse. When the ship arrived in Java in 1793 it was detained by the Dutch who controlled the island. Some members of the crew, including the botanist, Labillardière, escaped and managed to reach France. Another member of

the crew, La Haye, the gardener, remained in captivity for 2 years, during which time he continued to care for the breadfruit plants.

In 1796 a French ship arrived in Java to find the captured crew members. The plants (and gardener) were rescued and taken to Mauritius. Two trees were still living 100 years later and this single introduction was the ancestor of all the seedless breadfruit planted in Mauritius, and subsequently was the source material for all the seedless breadfruit distributed by the French to other tropical areas.

Breadfruit was also widely distributed to Central and South America, including Colombia, Guatemala, Costa Rica and elsewhere (Popenoe 1920). Seedless breadfruit was introduced to Brazil from Cayenne in 1811 (Jarrett 1959), although the Portuguese may have made a direct introduction of seedless cultivars to Brazil from other sources, possibly the Maldives (Leakey 1977).

Breadfruit was introduced and established in Sri Lanka before 1796, possibly from the Bligh collections (MacMillan 1908; Parsons 1933). Only one seedless type is found in the extensive Malay Archipelago and its origin is unknown (Burkill 1935). It is interesting to speculate that the Tongan cultivar *kele kel* may be the original source of seedless breadfruit in Java and from there was dispersed to other islands in that archipelago. One visitor there surmised in 1820 that the Javanese had only recently obtained breadfruit, possibly from the Moluccas while trading for spices (Burkill 1935).

Another wave of breadfruit introductions occurred at the end of the 19th century. Seedless breadfruit from Fiji and elsewhere was brought to Queensland, Northern Australia, in the late 1800s (Cowley 1898). It reached Madagascar in 1901 (Moreuil 1971). Breadfruit entered Africa in 1899 by way of the Camayenne Botanic Garden in Guinea and all the breadfruit trees in West Africa apparently stem from that single introduction (Smith *et al.* 1992). Breadfruit has also been introduced to India and throughout Southeast Asia.

Europeans also introduced breadnut to other tropical areas where it is now widespread, especially in the Caribbean, parts of Central and South America and coastal West Africa. The breadnuts now common in the Caribbean, and possibly elsewhere in the tropics, are all derived from a limited introduction of plants originally from the Philippines. There are conflicting accounts as to when the breadnut was first introduced to the Caribbean. Leakey (1977) addresses this in detail. The source materials were plants collected in 1772 in Luzon and taken to Mauritius (Sonnerat 1776). From there they were sent on to the Caribbean, Africa and other French territories. Anderson (Frost 1993) wrote that "The seed-bearing, or that kind I had in the garden before the arrival of the Providence, turns out a valuable acquisition. The fruit is...prickly like a hedgehog, the number of seeds in one is from 40-100, similar to chestnuts, are exceedingly good roasted or boiled. The French first introduced it..."

Breadnut was spread throughout the Caribbean and from there to Central and South America (Leakey 1977). The suggestion has been made that the Spanish may have brought breadnut from the Philippines to the Pacific coast of Central America and Mexico one to two centuries earlier than the Caribbean introductions (Leakey 1977; Morton 1987).

4 Properties of the species

Breadfruit is a nutritious and valuable staple food for the tropics. Extensive studies have been made of nutritional composition and the ethnobotanical literature is rich with information on other parts of the tree that are used, such as leaves, latex, bast and timber.

Nutritional value of seeds

Breadfruit and breadnut seeds have a thin, dark-brown outer skin about 0.5 mm thick and an inner, fragile paper-like membrane which surrounds the fleshy white edible portion of the seed. Seeds are firm, close-textured and have a sweet pleasant taste that is most often compared to chestnuts. The chemical composition of breadnut seeds from trees growing in Colombia and Puerto Rico has been analyzed (Quijano and Arango 1979; Negron de Bravo *et al.* 1983). The nutritional composition of breadnut seeds compared with breadfruit seeds is shown in Table 2. Breadnut seeds compared favourably to other tree nuts: they have a higher protein content than chestnut, macadamia, brazil nut and pecan, and are lower in fat but much richer in carbohydrates than other tree nuts except chestnut. The seeds are a good source of protein and are low in fat, compared with tree nuts such as almonds, brazil nut and macadamia nut, which contain 50-70% fat (Negron de Bravo *et al.* 1983).

Table 2. Nutritional composition (per 100-g edible portion) of seeds from breadfruit and breadnut

| | Breadnut seeds [†] | | | Breadfruit seeds [‡] | |
|------------------|-----------------------------|------|------|-------------------------------|-------|
| | 1 | 2 | 3 | Cooked | Fresh |
| Water (%) | 64.7-66.2 | 56.3 | 56.0 | 47.7 | 61.9 |
| Protein (g) | 13.3 | 19.9 | 15.0 | 8.1 | 7.9 |
| Carbohydrate (g) | 76.2 | — | — | 38.2 | 26.6 |
| Fat (g) | 6.2 | 12.8 | 29.0 | 4.9 | 2.5 |
| Calcium (mg) | 70 | — | 66 | 46.6 | 48.3 |
| Potassium (mg) | 1620 | — | 380 | — | — |
| Phosphorus (mg) | 360 | — | 320 | 186 | 189 |
| Iron (mg) | 8.7 | — | 6.7 | 2.3 | 2.3 |
| Magnesium (mg) | 10.0 | — | — | — | — |
| Niacin (mg) | 8.3 | — | — | 2.1 | 1.8 |
| Sodium (mg) | 1.6 | — | — | — | — |
| Thiamine | — | — | — | 0.33 | .13 |
| Riboflavin | — | — | — | 0.10 | 0.08 |
| Vitamin C | — | — | — | 1.9 | 22.6 |

[†] 1 = Negron de Bravo *et al.* (1983); 2 = Quijano and Arango (1981); 3 = McIntoch and Manchew (1993).

[‡] 4 = Murai *et al.* (1958).

Crude fat was 6.2% and 12.8%, respectively for Colombian and Puerto Rican samples. The fat extracted from the seed is a light yellow, viscous liquid at room temperature with a characteristic odour similar to that of peanuts. It has a chemical number and physical properties similar to olive oil. Seeds are a good source of minerals and contain more niacin than cashews, almonds, macadamia nuts, brazil nuts, pecans, black walnut and chestnuts (Negron de Bravo *et al.* 1983).

The protein content was 13.3% for Puerto Rican breadnut compared with 19.96% for the Colombian sample. Four protein amino acids (methionine, leucine, isoleucine and serine) comprised 50% of the 14 amino acids analyzed (Table 3). The essential amino acid content is high in relation to that of other vegetable proteins, but data were not available for tryptophane and lysine (Quijano and Arango 1981).

One study of the nutritional composition of breadfruit seeds has been published (Murai *et al.* 1958). The seeds are cooked with the raw breadfruit or removed and roasted or boiled. Those from at least one cultivar (not specified) of breadfruit are somewhat astringent and are not usually eaten. Seeds of the mijiwan cultivar from the Marshall Islands were analyzed (Table 2). Both fresh and cooked seeds have about 8% protein. Nutrient levels of minerals and vitamins were very similar for fresh and cooked seeds except that field assays of ascorbic acid were markedly higher for fresh seeds than for cooked seeds tested in the laboratory.

Table 3. Nutritional composition (g/100-g sample) of amino acids found in breadnut seeds

| Amino acid | Composition |
|----------------------------|-------------|
| Methionine [†] | 3.17 |
| Leucine [†] | 2.60 |
| Isoleucine [†] | 2.41 |
| Serine | 2.08 |
| Alanine | 1.53 |
| Tyrosine | 1.45 |
| Phenylalanine [†] | 1.05 |
| Glutamic acid | 0.98 |
| Glycine | 0.95 |
| Histidine [†] | 0.91 |
| Threonine [†] | 0.78 |
| Proline | 0.72 |
| Arginine [†] | 0.66 |
| Cysteine | 0.62 |

[†] Essential amino acid.

Nutritional value of fruit

The composition of fruits from different cultivars from the Pacific Islands and Caribbean has been investigated. Analyses have been made of fresh and cooked breadfruit at various stages of development; products produced by traditional methods such as pit fermentation, dried, roasted breadfruit and sun-dried breadfruit paste; and products such as flour and chips produced by modern processing techniques. Breadfruit's carbohydrate content is as good as or better than other widely used major carbohydrate foods. Compared with other staple starch crops, it is a better source of protein than cassava and is comparable to sweet potato and banana (Graham and Negron de Bravo 1981). It is a relatively good source of iron, calcium, potassium, riboflavin and niacin. A comparison of nutrient composition of mature breadfruit prepared by various methods (boiling, baking/roasting, and preserved by pit fermentation or paste) is shown in Table 4.

Table 4. Nutritional composition of breadfruit (per 100-g edible portion) prepared by various methods†

| | Fresh | | | | | Baked/ roasted | Boiled | Fermented | Paste |
|--------------------|------------------|-----------------------|-----------|------|------|-------------------|-----------|-----------|-------|
| | 1 | 2 | 3 | 4 | 5 | 3 | 3 | 4 | 3 |
| Water (%) | 2.5 [‡] | 2.8-19.0 [‡] | 63.8-74.3 | 66.3 | 71.8 | 59.0-70.3 | 67.5-73.6 | 67.3-71.2 | 20.8 |
| Protein (g) | 4.1 | 2.9-5.0 | 0.7-1.8 | 0.9 | 3.8 | 0.8-2.2 | 0.95-1.2 | 0.7 | 6.3 |
| Carbohydrate (g) | 84.2 | 61.5-73.1 | 22.8-33.4 | 31.2 | 77.3 | 25.7-37.6 | 24.5-30.3 | 27.9 | 67.7 |
| Fat (g) | 1.1 | 0.8-1.93 | 0.26-0.65 | 0.71 | 2.36 | 0.11-0.39 | 0.24 | 1.13 | 2.2 |
| Calcium (mg) | 50 | — | 15.2-31.1 | 24.0 | — | 18.0-26.3 | 12.1-21.1 | 42.0 | 134 |
| Potassium (mg) | 1630 | — | — | 352 | — | — | — | 20-399 | — |
| Phosphorus (mg) | 90 | — | 34.4-79.0 | — | — | 42.7-91.7 | 27.3-37.9 | — | 164 |
| Iron (mg) | 1.9 | — | 0.29-1.4 | 0.96 | — | 0.68-1.56 | 0.27-0.49 | 0.73-1.18 | 0.83 |
| Sodium (mg) | 2.8 | — | — | 7.1 | — | 2.4-5.3 | — | — | — |
| Thiamin (mg) | — | — | 0.07-0.12 | — | — | 0.07-0.09 | 0.08 | — | 0.14 |
| Riboflavin (mg) | 0.2 | — | 0.03-0.1 | — | — | 0.06-0.1 | 0.05-0.07 | — | 0.12 |
| Niacin (mg) | 2.4 | — | 0.81-1.96 | — | — | 1.13-1.54 | 0.62-0.74 | — | 7.42 |
| Ascorbic acid (mg) | 22.7 | — | 19.0-34.4 | 19 | — | 1.0-2.6 | 2.9-3.2 | 4-20 | — |
| β-carotene | — | — | — | 0.01 | — | — | — | 0.04-0.29 | — |

† 1 = Graham and Negron de Bravo (1981); 2 = Wootton and Tumalii (1984); 3 = Murai *et al.* (1958);

4 = Aalbersberg *et al.* (1988); 5 = Dalessandri and Boor (1994).

‡ Dry weight basis.

A detailed study of the nutritional composition of breadfruit determined nutrient levels for the pulp, skin, and stem and core of very immature, immature, mature and

very mature fruits from Puerto Rico (Graham and Negron de Bravo 1981). Fruits were categorized as follows:

- A very immature fruit exudes a copious quantity of milky, gluey latex from the detached stem and when it is cut or pierced. The flesh rapidly discolours and darkens when cut and this stage is not ready (fit) for eating.
- An immature fruit is larger, exudes less latex and does not discolour as severely.
- A mature fruit is comparatively larger. The skin, depending on the type, may show some yellowing and the pulp shows little or no discolouring when cut. Very little sap exudes from the detached stem.
- A very mature fruit may have a yellow skin which has 'cracks' or crevices. The pulp is usually quite yellow and soft. When roasted, it has a strong flavourful aroma and the pulp has a gummy, sweet, pleasant taste.

The nutritional composition of seven Samoan cultivars (*ulu maopo*, *ulu puou*, *ulu ma'afala*, *ulu talatala*, *ulu gutufagu*, *ulu ma'a*, *ulu avelofo*) breadfruit at various stages of maturity was determined (Wootton and Tumalii 1984). There were obvious differences between cultivars in terms of protein and carbohydrate levels for mature breadfruit, the stage most preferred for consumption. 'Ulu talatala' had a higher protein content than all other cultivars but had the lowest levels of carbohydrates. Crude fat and fiber also varied among cultivars at the mature stage.

Amylose levels of starch for each cultivar were determined and all but *ulu puou* (16.4%) had levels comparable to that observed for Puerto Rican breadfruit (18.2%). Four cultivars were sampled at the very mature or ripe stage, and there was no clear pattern of compositional change within cultivars save for a decrease in starch and increase in sugars between the mature and very mature stages. Changes in individual sugars during maturation were studied and fructose, glucose and sucrose were the major sugars, with only trace amounts of ribose and maltose. Fructose was the predominant sugar in less mature fruits, decreasing in comparison to glucose and sucrose as maturation progressed.

Even though crude fat levels were low (0.8-1.9%), fatty acid composition was determined for each cultivar because of the possibility of fat rancidity and poor storage life and/or acceptability of the product. Rancidity was not apparent in any of the flours after storage for 6 months at 5°C. Levels of iron, sodium and calcium were similar to those observed for Puerto Rican breadfruit although potassium was approximately half and phosphorus four times as great. These studies show that the nutritional composition of breadfruit varies among cultivars and should aid in selection of cultivars for different uses for fresh consumption and processed products.

The nutritional composition of 11 traditional cultivars from three island groups (Marshall Islands: *batak dak*, *bukdrol*, *mijiwan*; Chuuk: *atchapar*, *meichon*, *meikoch*, *napar neisoso*, *sawan*; Samoa: *ma'afala*, *puou*) was studied (Murai *et al.* 1958). All were seedless cultivars except for *mijiwan* from the Marshall Islands. The fruits were sampled fresh, roasted, baked or boiled. The amount of waste and edible pulp varied with the cultivar and size of fruit; edible portion was greater than 70% for seedless

cultivars. The total edible portion for the seeded cultivar varied from 46 to 60% including seeds with the pulp comprising less than half the weight of the fruit (43%).

The nutrient levels reported (Table 4) were substantially lower than those reported by later authors and this is probably due not to cultivar differences but to different sampling techniques and advances in laboratory equipment and procedures. For example, Wootton and Tumalii (1984) also analyzed the two Samoan cultivars *puou* and *ma'afala* and reported much higher levels of protein, fat and carbohydrates.

Traditional breadfruit products

The nutritional composition of fermented breadfruit *madrai* prepared in the traditional way has been reported for Fiji (Aalbersberg *et al.* 1988). Peeled, seedless, whole mature breadfruit were placed in a pit, and samples were removed and analyzed after 5 days, weekly for 7 weeks, then at weeks 15 and 21. The pH in the pit decreased from 6.7 (close to neutral) for fresh fruit to a quite acidic value of 4.3 in 2 weeks. Protein and carbohydrate levels remained relatively unchanged for the entire time (Table 4). Fat content increased slightly from 0.71 g for fresh fruit to a high of 1.13 g after 3 weeks. Iron and calcium levels were slightly higher for fermented breadfruit, reaching their maximum at 15 or 21 weeks.

The starch is broken down first to maltose, then glucose, and eventually to lactic acid and carbon dioxide. Lactic acid in fresh breadfruit is only 0.09 g but rises to 0.88 g after only 5 days in the pit, increasing to a maximum of 1.29 g after 4 weeks, and declining to 0.56 g after 21 weeks. The strong characteristic smell emanating from the newly opened pit is due primarily to lactic acid and butyric acid that may be produced by secondary aerobic fermentation of the lactic acid. Analysis by gas chromatography of volatiles from breadfruit after extended fermentation showed the presence of a range of alcohols and organic acids, with ethanol the largest component at 34% (Whitney 1988). No ethanol was detected in samples of fresh breadfruit, while breadfruit boiled for 10 minutes contained 16% (Iwaoka *et al.* 1994).

Another type of preserved breadfruit, a breadfruit paste (*paka kuru*) from the Micronesian island of Kapingamarangi, was analyzed (Murai *et al.* 1958). The resulting paste is a concentrated, nutrient-rich food containing only 21% water, compared with the 60-70% water content of fresh or cooked fruits. It contained 68 g of carbohydrates, double the amount that the authors reported for fresh or cooked breadfruit (Table 4). Protein and fat levels were substantially higher in the paste, with almost five times the average amount of protein and fat found in fresh or cooked breadfruit. Calcium and phosphorus levels were notably higher than that of fresh or cooked breadfruit. Iron, thiamin and riboflavin were the only nutrients with lower levels in the paste.

Modern processed products

Processing breadfruit into a snack such as chips may be a useful value-adding preservation method of breadfruit. Breadfruit chips were made from firm, mature

breadfruit of both the 'Yellow heart' and 'White heart' types of breadfruit from Puerto Rico (Bates *et al.* 1991). Each fruit averaged 2kg fresh weight and was peeled and cored and blemished portions removed before slicing. Each fruit yielded 67% pulp after slicing and frying. Chips were sliced to an optimum thickness and frying each side for 30-40 seconds in partially hydrogenated soy oil at 165°C consistently produced a light-coloured, crisp chip. The amount of oil absorbed by the chip was reduced from 42 to 26% by first air-drying slices at 57°C for up to 40 minutes.

The chips were packed into metallized, commercial 75-gauge polypropylene/polyethylene bags and hermetically sealed in air. Packaged samples were stored at 2, 27 and 55°C and analyzed at 3-day intervals. Storage temperature clearly influenced the keeping quality of chips. Rancidity was detected in chips after 21 days at 27°C, and was comparable to plantain and banana chips at 24 days, after which rancidity in breadfruit chips accelerated. Chips became rancid sooner at the higher storage temperature while those stored at 2°C showed little change in quality for the duration of the study. The chips were prepared under noncommercial conditions and packed in air, conditions representative of industrial capacities of most breadfruit-producing areas. Using a nitrogen gas flush and antioxidants should extend shelf-life considerably.

Flour is another potential commercial product that can be made from breadfruit. Imports of wheat flour can be decreased by substituting a locally grown foodstuff, such as breadfruit, for a portion of wheat flour used in making bread and other baked goods. Breadfruit flour was made from firm, mature breadfruit from Puerto Rico that was peeled, cored, cut into pieces and dried at 80°C for 24 hours (Nochera and Caldwell 1992). The flour contained 4.4% protein, 1.1% fat and 6.4% fiber and ash. It contained higher levels of two essential amino acids, lysine and threonine, than wheat flour. A composite flour was made by substituting 5, 10, 15 or 20% of enriched white flour with breadfruit flour and 5 or 10% of white flour by soy protein, peanut meal or whey. The latter products were added to increase the protein content of the composite flour since enriched white flour has a higher protein content (10-12%) than breadfruit flour. Standard recipes were used to make breads and biscuits with the composite flour. Baked goods were evaluated for acceptability of colour, texture and flavour with breads made from 10% breadfruit and 5% whey preferred.

Breadfruit starch has been isolated and characterized. Starch was extracted from firm, mature breadfruit from Puerto Rico that were peeled, cored, cut into pieces and dried at 80°C for 24 hours and ground into flour (Loos *et al.* 1981). The starch was then freeze-dried for 24 hours and pulverized into a fine powder. The resulting starch was 90% pure and contained 18.2% amylose. Granules were spherical and segmented and appeared to be compound. The intrinsic viscosity of starch was higher than the reported values for wheat, cassava and arrowroot starches. At concentrations of 4-5% the viscosity held stable throughout a heating-cooling cycle. At higher starch concentrations (7-8%), the cooled gels exhibited a breakdown in viscosity during prolonged heating and stirring comparable to potato starch.

Reeve (1974) studied the commercial dehydration potential of breadfruit. Firm,

mature breadfruit from Puerto Rico were peeled, cored and the edible pulp cut into small cubes or slices and tunnel-dried for 4 hours at 60°C or freeze-dried overnight. These were reconstituted and their textural qualities compared with that of freshly boiled, steamed and whole-baked breadfruit. No significant difference could be observed microscopically between freshly baked or boiled and the tunnel-dried breadfruit. There was little difference in colour slices that had been blanched for 3 minutes or treated with 3% sodium sulfite before tunnel-drying, indicating that there is no need for sulfite treatment. Both forms reconstituted readily in cold or hot water and textural qualities were the same. Culinary qualities were very similar to those of freshly boiled or steamed samples.

Freeze-dried breadfruit was slightly greyish-white and chalky in appearance. It reconstituted quickly in cold water but raw texture was not fully restored. When reconstituted in hot or boiling water, the texture and flavour were very similar to the blanched or freshly cooked product. Keeping quality of both forms of dried breadfruit were good. No off-odour was detected in freeze-dried sections kept for 6 months at room temperature. When reconstituted in hot water, these made an excellent substitute for sliced potato in a scalloped-potato and cheese recipe. Both forms are suitable for grinding or crushing into flour. The practicality of producing dehydrated breadfruit flakes or granules, such as instant mashed potatoes, is limited because the textural characteristics of freshly cooked breadfruit are very different from white potato.

Cooked breadfruit can be frozen, and this storage method deserves greater attention as it may provide a simple, effective means to better utilize this crop, at least in areas where electricity and refrigeration facilities are available and affordable. Fruits of 'Yellow heart' cultivar were peeled, quartered and cored and the edible pulp cut into small, wedge-shaped sections weighing approximately 15 g each (Passam *et al.* 1981). These segments were boiled for differing lengths of time (ranging from 1 to 10 minutes), then air-cooled, wrapped in aluminium foil and frozen at -15°C. Segments which had been boiled for 2-5 minutes compared most favourably in flavour, colour and texture of fresh-cooked breadfruit. Segments that were frozen without pre-boiling discoloured on cooking after storage and had poor flavour. After 10 weeks in the freezer, there was no deterioration in quality and the storage life of this product may be much longer. It may be possible to use this method to process and store larger segments, or even slices, which are preferable for boiling or roasting.

Animal feed

Breadfruit and breadnut are nutritious sources of food for animals. Since only the pulp of mature breadfruit is consumed as a human food, at least 25% of the fruit is wasted. The non-edible portions are as high in carbohydrates, contain more protein than the pulp and are excellent sources of nutrients. The non-edible portion comprises approximately 26% of a mature fruit and contains 75.7% carbohydrate, 6.0% protein and 2.8% fat (Graham and Negron de Bravo 1981). The core and stem contained the highest levels of protein and this was attributed to the presence of

several 'aborted' seeds attached to the core. The skin also contained higher levels of protein than the pulp which was attributed to the accumulation of latex on the surface of the skin which may trap minute amounts of nitrogen-containing materials from the air.

Similar results have been obtained for the fruits of breadnut (Negrón de Bravo *et al.* 1983). Seeds are the portion that is consumed and represent only 30-47% of the total fruit. The pulp, skin and the core are as good sources of minerals and carbohydrates as the seeds. The non-edible portion of breadnut fruits contains 74.4% carbohydrate, 6.1% protein and 6.6% fat.

5 Uses

Uses of the fresh fruits

Breadfruit is a versatile food and can be cooked and eaten at all stages of maturity, although it is most commonly harvested and consumed when mature, but still firm, and used as a starchy staple. The relatively bland fruit can form the basis for an array of dishes, and it takes on the flavour of other ingredients in the dish. Very small fruits, 2-6 cm or larger in diameter, can be boiled and have a flavour similar to that of artichoke hearts. These can be pickled or marinated. Mature and almost mature breadfruit can be boiled and substituted for potatoes in many recipes. Ripe fruits are very sweet and used to make pies, cakes and other desserts.

Breadfruit is prepared boiled, steamed or roasted in the Caribbean and has lent itself to the creation of regional dishes such as 'oil down' which is popular in Trinidad and Tobago and Grenada (Leakey 1977; McIntoch and Manchew 1993). It is made with salt-cured meats, breadfruit, coconut milk and dasheen leaves. In the Philippines, breadfruit is eaten boiled and sliced with coconut and sugar as a sweet, and candied breadfruit made from mature breadfruit will keep for about 3 months (Coronel 1983).

The small, immature fruits of breadnut are sliced and cooked as vegetables, seeds and all (Brown 1943). Seeds are harvested from ripe fruits and boiled or roasted with salt. They are sometimes made into a puree in West Africa (Morton 1987). Breadfruit seeds are usually cooked with the raw breadfruit or are boiled or roasted. Seeded forms of breadfruit predominate on many atolls in Micronesia and seeds contribute to the daily diet. In the Marshall Islands, seeds are sometimes not cooked and eaten until they sprout (Murai *et al.* 1958).

Beginning with accounts by the first European voyagers to the Pacific, much has been written about traditional preparation and storage of breadfruit. Pollock (1992) provides an in-depth look at the persistence of traditional food practices in the Pacific Islands. Breadfruit are cooked by roasting whole in hot coals, boiling or baking. Throughout the Pacific the earth oven was and remains the major way of cooking breadfruit and other starchy foods. The oven consists of a pit that is lined with stones upon which a fire is built. A bed of green leaves, usually banana or breadfruit, is placed over the hot stones. The foods to be cooked are placed on the leaves and covered with hot stones and a thick top layer of leaves, pandanus mats or burlap bags and the whole is covered with earth and left for approximately 2 hours. The leaves add special flavours to the food and foods can be steamed instead of baked if water is sprinkled on the leaves. Earth ovens permit a fairly economical use of firewood for cooking.

Whole or cut fruits and 'puddings' are cooked in the oven. Puddings (leaf-wrapped foods) are made from cooked breadfruit that is grated or pounded, mixed with coconut cream, wrapped in leaves and baked. Puddings are made from ripe or mature fruits, and fermented breadfruit is often mixed with fresh breadfruit. In many islands, these starchy puddings are the main form in which breadfruit is

consumed. Puddings make a portable, tasty travel food that keeps for several days. Steamed or boiled breadfruit is also pounded until it becomes paste-like or doughy (Fig. 6). It is preferred when at least 1 day old and can be kept for several days when it begins to ferment and sour.

Traditional methods of preserving fruits

Since breadfruit is a seasonal crop that produces much more than can be consumed fresh, Pacific islanders have developed many techniques to utilize large harvests and extend its availability (Murai *et al.* 1958; Barrau 1961; Yen 1975; Cox 1980; Atchley and Cox 1985; Aalbersberg *et al.* 1988; Ragone 1991b; Pollock 1984, 1992). Preserved breadfruit also adds diversity to the daily diet. The most common method of preservation is the preparation of fermented, pit-preserved breadfruit called *ma*, *masi*, *mahr*, *furo* or *bwiru*. Pit storage is a semi-anaerobic fermentation process involving intense acidification which reduces fruit to a sour paste. Fermented breadfruit is still made every season throughout Micronesia and to a limited extent elsewhere in the Pacific.

Depending on the island, mature or ripe fruits are used. Fruits are peeled, cored, and in the atolls, soaked in seawater for 12-24 hours (Fig. 7). They are then placed



Fig. 6. Pounding cooked breadfruit in Micronesia

in a leaf-lined pit (Fig. 8) and covered with leaves and a thick layer of soil or rocks. The fruits begin fermenting within 5-7 days depending upon how long fruits were left above ground to begin softening. Fermented breadfruit can last for a year or more, and it is removed and eaten at various stages of fermentation depending upon need and taste preference. There have been anecdotal reports of edible paste removed from pits that was 50-100 years old. Fermented breadfruit is sometimes washed, then pounded or kneaded and cooked before being eaten. It can be prepared in various ways and is the mainstay of the diet in many islands. The taste of fermented breadfruit is a favourite and it is used to supplement and enhance the daily diet of fresh breadfruit.

In many areas of the Pacific, urbanization and the availability and ease of using introduced foods have diminished the importance of staple

traditional foods in the daily diet. However, there is a growing interest in reducing imports of foods and more fully utilizing locally grown crops. Traditional storage practices are being revived and modernized to fit contemporary lifestyles (Parkinson 1984; Aalbersberg *et al.* 1988). Fermented breadfruit can be made in plastic tubs, coolers or other containers that can be made relatively air-tight. There are several advantages: it yields a cleaner, more uniform product, it is less labour-intensive, and smaller quantities can be made.

Drying is another common method used to preserve breadfruit. The simplest methods involve slicing raw or cooked breadfruit and drying it in the sun or on hot stones. Morton (1987) reported that seedless breadfruit are cut into slices and dried for 4 days at 49°C in the Seychelles. In Sri Lanka, slices are dipped into a salt solution, blanched in boiling water for 5 minutes and dried at 80°C for 4-6 hours. These will keep for 8-10 months.



Fig. 7. Breadfruit soaking in sea before being fermented in a pit



Fig. 8. Leaf-lined breadfruit fermentation pit in Micronesia

Breadfruit is extensively preserved by drying in the eastern Solomon Islands and northern Vanuatu (Tedder 1956; Yen 1974; Kalotapau 1992). Roasted fruits are cut into bite-size pieces and dried over a hot fire to make 'nabo' in the Solomon Islands (Fig. 9). Whole fruits are dried in a similar manner in Vanuatu but take 7-8 days to completely dry. The dried pieces are placed in leaf-lined woven baskets, hung over the fireplace and can be stored for up to 3 years. Dried breadfruit is usually eaten without additional preparation but it can be made into soup, or ground into meal and mixed with water or coconut cream to make a porridge.

Jankwin is made from seeded breadfruit in the Marshall Islands (Murai *et al.* 1958). Ripe fruits are cooked overnight in the oven; then the pulp is spread on leaves and dried in the sun. After drying it is rolled and pressed to make a compact mass, wrapped in pandanus leaves and tightly tied with sennit. 'Bwiro' biscuits are made in Kiribati (Tusialofa 1992) from small pieces of fruit soaked in seawater for 3-4 days and then rinsed to remove the salt. Round, flattened biscuits are shaped from the doughy mass and dried in the sun for a couple of days until hard and dry. They will keep for more than 2 years if kept in an airtight container.

A novel way to preserve breadfruit was recorded for Kapingamarangi (Coenan and Barrau 1961). The paste or fruit 'leather' is made from peeled, ripe, seeded breadfruit from which the core and seeds are removed. The breadfruit is baked for two or more hours and then pounded into a paste which is thinly spread on coconut-leaf mats and sun-dried to the desired consistency. The thin, flexible sheets are rolled into a firm roll, and tightly wrapped and tied in pandanus leaves; they will keep for up to 3 years.

Fermented breadfruit can also be dried (Murai *et al.* 1958) to make 'manakajen' in the Marshall Islands. Bwiro is removed from the pit and compressed into slabs in 'coconut cloth' the fibrous, mesh-like stipule of the coconut tree. It is dried in the sun until very hard, for about 1 week, and will keep almost indefinitely. It is prepared for eating by breaking it into small pieces and soaking overnight in cold water. It is washed in several changes of water, drained, kneaded until soft and cooked in various ways.



Fig. 9. Drying breadfruit in the Solomon Islands

Commercial processing

Commercial processing of breadfruit is still in its initial stages. Slices canned in brine are produced in Jamaica for local and export markets (Thompson *et al* 1974). Breadfruit flour and chips have been made on a limited basis, and the flour has been evaluated as a substitute for enriched wheat flour and as a base for instant baby food. A preparation made with 25% breadfruit flour and 75% banana flour was comparable to the flavour and appearance of baby food made from commercial flour (Esparagoza and Tangonan 1993). In Brazil, Puerto Rico and Cameroon, the starch has been extracted and may find use in industrial applications such as textile manufacture (Roberts-Nkrumah 1993).

Ethnobotanical uses

Breadfruit is a multipurpose tree species providing food, medicine, clothing material, construction materials and animal feed (Table 5). It is an important component of traditional agroforestry systems in the Pacific Islands, particularly the eastern Solomon Islands, Pohnpei and Kosrae (Yen 1974; Merlin *et. al* 1992, 1993; Raynor and Fownes 1991). The trees are integrated into mixed cropping systems with yams and other root crops, *Piper methysticum* bananas and some cash crops, especially black pepper and coffee.

Table 5. Uses of the breadfruit tree

| Part of tree used | Uses |
|---------------------|--|
| Tree | Agroforestry, shade |
| Timber | Construction of buildings, canoes, furniture and other objects, carvings, firewood |
| Latex | Adhesive, caulking for canoes, birdlime, medicine |
| Bark | Medicine |
| Bast (inner bark) | Cordage, clothing (bark cloth) |
| Leaves | Wrap food for cooking or serving, livestock feed, medicine, dried leaves and stipules used as a sanding cloth, fishing kites |
| Male inflorescences | Candied and eaten, dried and used as mosquito repellent, medicine |
| Fruit and seeds | Cooked fruits and seeds used for human consumption; uncooked for livestock feed. |

Pacific islanders rely heavily on the breadfruit tree for raw materials, but over the past 100 years manufactured materials have supplanted the use of traditional materials. Breadfruit wood is light and durable with a golden-yellow colour that darkens with age. It was widely used for the construction of houses and canoes

because of its resistance to termites and marine worms (MacCaughey 1917). In Samoa, two cultivars, *avelo* and *puou*, were preferred for building purposes (Buck 1930). The hulls of outrigger canoes are often fashioned from a single log and are still made in the atolls and parts of Melanesia. The wood is used to make bowls, carvings, furniture and other items. The trees are an important source of firewood on the atolls.

Use of the inner bark or bast

The inner layer of bark, or bast, was used to make bark cloth known as tapa. Traditionally tapa had ceremonial and ritual uses, and was also used for bedding and items of clothing such as cloaks, loincloths and robes (Kamen-Kaye 1984; Ragone 1991b; Krauss 1993). Breadfruit tapa is still made in some areas of Melanesia and the Marquesas. Breadfruit bast also makes a strong cordage (Buck 1930; Morton 1987; Ragone 1991b) with uses as diverse as harnesses for water buffalo and nets to catch sharks.

Use of the leaves and flowers

The leaves are widely used to wrap foods for cooking or serving. The dried stipules or senescent leaves are slightly rough and in Hawaii were used to polish and smooth bowls and nuts strung for decorative purposes (Handy *et al.* 1972; Krauss 1993). Leaves are even used to make fishing kites on the atolls of Yap to catch reef fish. The leaves are eaten by domestic livestock, and can be fed to cattle, goats, pigs and horses. Horses will also eat the bark, young branches and shoots of young trees and must be excluded from new plantings (Morton 1987). Leaves have even been reported to be good food for elephants (Bennett 1928)! Excess ripe breadfruit, seeds, cores and other breadfruit waste are fed to pigs and other animals.

Male inflorescences are pickled or candied in many areas (Massal and Barrau 1954; Morton 1987). Toasted flowers are rubbed on the gums around an aching tooth to ease the pain (Morton 1987). In Vanuatu (Olsson 1991) and Hawaii, the dried, hard flowers are burned as mosquito repellent. The inflorescences were used to make a yellow, tan to brown dye in Hawaii (Krauss 1993).

Use of the latex

The sticky latex has many uses (Henry 1928; Buck 1930; Handy *et al.* 1972; Croft 1987; Ragone 1991b; Petard 1986; Krauss 1993; Merlin *et al.* 1993). It is used as chewing gum in the Caribbean and elsewhere (Roberts-Nkrumah 1993). The trunk produces a profuse sap, collected by cutting the bark in the early morning and scraping off the dried exudate later in the day. Breadfruit gum is used to caulk canoes to make them watertight and can be used to seal and prepare wooden surfaces for painting. The sap was widely used throughout the Pacific and other areas as birdlime to catch birds for food or their feathers. The latex is mixed with coconut oil for trapping houseflies in Kosrae.

Medicinal uses

The latex and bark are part of the native pharmacopoeia and have several traditional medicinal uses (Handy *et al.* 1972; Croft 1987; Olsson 1991; Petard 1986; Whistler 1992; Krauss 1993). The latex is massaged into the skin to treat broken bones and sprains and is bandaged on the spine to relieve sciatica. It is commonly used to treat skin ailments and fungus diseases such as thrush. The latter is also treated with crushed leaves. Diluted latex is taken internally to treat diarrhea, stomach aches and dysentery. The latex and the juice from crushed leaves are both traditionally used to treat ear infections in the Pacific Islands. The root is astringent and used as a purgative; when macerated it was used as a poultice for skin ailments. The bark is used to treat headaches in several Pacific Islands.

The medicinal uses of breadfruit are being actively researched. In the West Indies the yellowing leaf is brewed into tea and taken to reduce high blood pressure (McIntoch and Manchew 1993). The tea is also thought to control diabetes. A complex organic acid in the leaf extract (γ -aminobutyric acid) is the active ingredient, but it is not clear whether the extract is effective in lowering blood sugar or whether the test for sugar is masked in the presence of the extract.

Research on the efficacy of breadfruit extracts from various parts of the plants has shown promising results. The leaves are used to treat liver disease and fevers in Taiwan (Lin *et al.* 1992), and an extract from the flowers was effective in treating ear edema (Koshihara *et al.* 1988). Bark extracts exhibited strong cytotoxic activities against leukemia cells in tissue culture (Fujimoto *et al.* 1990). Extracts from roots and stem barks showed some antimicrobial activity against Gram-positive bacteria and may have potential use in treating tumors (Sundarrao *et al.* 1993).

6 Genetic resources

The genetic diversity of breadfruit throughout the world — with the exception of some of the Pacific Islands — rests on a very narrow base. Globally, this now widespread, important crop has derived from only a few Polynesian cultivars. These in turn represent a narrowing of the genetic diversity of breadfruit in the Pacific Islands from west to east with little genetic variation in eastern Polynesia. Even though numerous cultivars exist in eastern Polynesia, they are primarily clones selected from a few original introductions many centuries ago. In addition, the few cultivars that Captain Bligh collected may not have been the best cultivars, but merely those that were readily available.

Genetic erosion

Genetic erosion of many clonally propagated traditional crops, including breadfruit, is a serious problem in the Pacific Islands (Ragone 1990, 1991a; Lebot 1992). Although an important staple crop, the cultivation and use of breadfruit has decreased in the past 50 years, and replanting has not kept pace with the losses incurred throughout the Pacific by drought, storm damage, natural attrition and other factors. This has resulted in a decrease in numbers of trees, and a number of cultivars have already disappeared or are becoming rare. The genetic erosion of breadfruit can be attributed to environmental factors, changes in traditional lifestyles and the nature of the crop itself.

Breadfruit trees are prone to damage or destruction from high winds and the accompanying salt spray and intrusion of salt water into the water table during severe storms. The low-lying atolls, such as the Marshall Islands, Tokelau and parts of the Federated States of Micronesia, have been repeatedly inundated by storm-generated tides, resulting in uprooting or destruction of numerous breadfruit trees. In the past decade, many atolls and high islands have experienced destructive storms of hurricane strength. The same applies to the Caribbean where many islands were hard hit by hurricanes during the 1990s.

The impact of storms on islands that rely heavily on breadfruit for a staple food is devastating. For example, in 1990, Hurricane Ofa destroyed as much as 100% of the breadfruit crop in Samoa, and between 50 and 90% of big, mature trees were blown over, depending on location (Clarke 1992). A continuing global trend of warmer ocean temperatures which increases the likelihood of hurricane-force storms has serious implications for island nations throughout the Pacific and Caribbean.

Droughts also contribute to erosion of breadfruit germplasm, and prolonged droughts have resulted in the destruction of trees in the Micronesian atolls. Droughts have also caused damage to trees in Guam, Pohnpei, Samoa, the Marquesas and other high islands.

Changing Pacific subsistence economies have had a major impact, one that is rapidly accelerating with population growth. As Pacific islanders become more westernized and shift from a traditional subsistence economy to a cash economy, more people migrate from the outer islands to population centres. There is increasing

reliance on imported foods, and traditional, locally produced foods are being supplanted by introduced foods such as white rice and enriched-flour products. Breadfruit trees are still numerous on the islands, but cultivation and use of breadfruit and other traditional crops is decreasing in the population centres. Urban households may have one or two breadfruit trees, but these are generally limited to the most common cultivars. Population pressures on limited island ecosystems and resources are causing rapid and damaging shifts in land-use patterns with increasing areas being planted in perennial cash crops (Lebot 1992; Falanruw 1993).

Ex situ conservation and germplasm collections

Numerous collections of breadfruit have been assembled for conservation and study. The FAO — World Information and Early Warning System on Plant Genetic Resources lists 14 institutions holding 112 germplasm accessions of breadfruit (*Artocarpus altilis*). Following are the countries reported in this database as holding breadfruit accessions and the number and type of holdings (if stated): Brazil (10 landraces or primitive cultivars), Colombia (2), Costa Rica (3), Fiji (70 old cultivars), France (2 local cultivars), Honduras (2), Indonesia (3 old cultivars), Jamaica (5 advanced cultivars), Papua New Guinea (6 old cultivars), Philippines (1 advanced cultivar), Taiwan (1), Tanzania (1) and Vietnam (4 landraces). This information is inaccurate for holdings in the Pacific Islands and out of date. For example, the Koronivia Research Station in Fiji does not maintain a collection of 70 old cultivars. An updated list of institutions with collections of breadfruit germplasm is given in Table 6.

The greatest focus on the conservation of breadfruit has occurred in the region where it originated. The need to preserve and study this valuable crop was first recognized on a regional basis in the 1950s when the South Pacific Commission (SPC) began widespread collecting of cultivars. Over 160 trees were described and collected from Samoa, New Guinea, Niue, Rotuma, Tonga and Vanuatu (Parham 1966). Additional collecting was done in the Cook and Society Islands and Micronesia. Propagating materials from this regional survey were sent to Fiji, Tahiti and Western Samoa for comparative trials (Coenan and Barrau 1961).

A small arboretum was planted with breadfruit and other economic trees at a plant introduction station at Naduruloulou, Viti Levu. The Fiji Department of Agriculture Plant Introduction records from 1956 to 1961 show that 69 *Artocarpus* accessions were received from six Pacific Island groups. Nevertheless, only a few breadfruit trees were still growing at the station in 1985 when visited by the author. The Fiji Department of Agriculture also surveyed and described 70 local cultivars, but none were collected or planted (Koroveibau 1967). Many of these cultivars can no longer be found in cultivation in Fiji. The few remaining cultivars planted at Koronivia and Naduruloulou Research Stations need to be identified, labeled and conserved. There is little emphasis on breadfruit as a food crop, and due to financial and staff constraints, no work was carried out on this crop in Fiji (J. Kumar, 1995, pers. comm.). There is interest, however, in establishing a collection of Fijian

germplasm. The status of the materials sent to Tahiti, and whether or not a collection was established, is unknown. Since 1964, the importation of breadfruit and other Moraceae into French Polynesia has been banned.

The Western Samoa Department of Agriculture (WS Dept. Ag.) established a plant introduction station at Nafanua, Upolu, in 1956 (Parham 1959). A collection of 26 Samoan cultivars was planted in the late 1950s and most were still alive when visited in 1987. Regional collections were established at other sites in the country in 1964-65 as part of a project to grow and study local and introduced breadfruit cultivars to determine which cultivars: (1) bear year-round, (2) are high yielding, (3) have overlapping periods of maturity and (4) thrive on coral-atoll soils (WS Dept. Ag. 1964).

Table 6. Institutions with collections of breadfruit germplasm

| Country/Institution [†] | No. of accessions | Passport data |
|---|-------------------|-------------------|
| Brazil | 10 | partial |
| Colombia | 2 | n.a. [§] |
| Costa Rica, CATIE | 1 | n.a. |
| Costa Rica, ANAI | 2 | n.a. |
| Fed. States of Micronesia, Kosrae [‡] | approx. 20 | partial |
| Fed. States of Micronesia, Pohnpei [‡] | approx. 20 | none |
| Fiji [‡] | (70) | none |
| France | 2 | yes |
| Honduras | 2 | n.a. |
| Indonesia | 3 | yes |
| Jamaica | 5 | yes |
| Kiribati [‡] | <20 | partial |
| Papua New Guinea | 6 | partial |
| Philippines | 1 | yes |
| Solomon Islands [‡] | 25 | yes |
| Taiwan | 1 | yes |
| Tanzania | 1 | n.a. |
| Trinidad and Tobago [‡] | approx. 40 | yes |
| USA - Nat. Trop. Bot. Garden [‡] | 173 | yes |
| USA- USDA/ARS [‡] | approx. 40 | yes |
| Vietnam | 4 | n.a. |
| Western Samoa, Upolu [‡] | <30 | partial |

[†] See Appendix 2 for full addresses.

[‡] Information updated by the author.

[§] n.a. = no information available.

Source: FAO — World Information and Early Warning System on PGR (1995).

Introduction records for 1956-64 show that 251 accessions from 13 island groups were received. The main collection was established at Vailima, Upolu, when 109 trees from 11 island groups were planted. This collection slowly declined, and only 26 trees remained in 1987 when visited by the author. It is not labeled, although original planting maps exist, and has not been evaluated. The widespread destruction to breadfruit trees in 1990 by Hurricane Ofa may have wiped out the collection.

Three collections have been established in Micronesia and were all visited by the author in 1987. The Pohnpei Agriculture Station at Kolonia has a Demonstration Collection Plot of breadfruit that was planted in the late 1950s to early 1960s. It consists of local cultivars, cultivars from Chuuk and a few from Tahiti. These trees are healthy and bearing, but there is no documentation available. Kosrae Agriculture Station at Fote has a collection of local and introduced South Pacific cultivars, many of which are identified and most are thriving. Local and introduced cultivars have been planted in Tarawa, Kiribati. Little documentation or evaluation of these collections is being done.

Agriculture departments in other areas of the Pacific have also established collections. In the Solomon Islands, more than 40 cultivars from the Temotu Province (Reef and Santa Cruz Islands) were planted at the Tenaru Research Sub-station on Guadalcanal in the early 1980s (Jackson 1982). Many of the accessions subsequently died from poor soil conditions and hurricane damage in 1986. Some of the accessions were salvaged and transferred to Fote Field Experiment Station on the island of Malaita. The germplasm collection now contains 25 accessions. They are mapped, identified by cultivar name and origin information is known. Precocity and yield are being recorded (M. Max, 1995, pers. comm.).

The National Tropical Botanical Garden (NTBG), formerly Pacific Tropical Botanical Garden, a privately funded, non-profit institution, established a small collection of breadfruit in Hawaii in the 1970s. The Kahanu Garden in Hana, Maui — where numerous mature trees of the Hawaiian cultivar of breadfruit were already growing — was designated as the main site of the NTBG collection, although a few trees were also planted at the Lawai Garden on Kauai (Ragone 1989). Kahanu Garden encompasses 123 acres at sea level with fertile, well-drained, volcanic soils in a area that averages close to 2000 mm of rain annually.

In the 1980s, nearly 400 accessions of breadfruit from 17 Pacific Island groups were photographed, vouchered and documented, and propagating material was collected by the author. Collecting trips to Western Samoa, Tonga, Tokelau, Cook Islands and Fiji in 1985 were made with support from the South Pacific Regional Agricultural Development Project, Institute for Research, Education, Training at the University of the South Pacific in Alafua, Western Samoa and the NTBG. The International Board for Plant Genetic Resources and the US Department of Agriculture funded more widespread collections in 1987.

The NTBG breadfruit collection now consists of 173 accessions (50 of which are duplicated) from 17 Pacific Island groups (Belau, Chuuk, Cook Islands, Fiji, Hawaii, Kiribati, Mariana Islands, Marquesas, Pohnpei, Rotuma, Samoa, Society Islands,

Solomon Islands, Tokelau, Tonga, Vanuatu and Yap) and Indonesia, Philippines and Seychelles. The geographical origin and number of accessions in the NTBG collection are shown in Table 7. This collection is the largest and also the most geographically and genetically diverse. It contains accessions that represent the full range of seeded to seedless cultivated *A. altilis* wild *A. mariannensis* from the Mariana Islands, cultivated plants from the Micronesian atolls, and hybrid accessions from both atolls and high islands. It also contains a few accessions of breadnut from the Philippines, Indonesia or in cultivation in Hawaii.

Most of the accessions have reached reproductive maturity and are bearing fruit. The collection is being actively maintained and studied. It has been completely mapped and labeled, and an extensive computerized database containing location,

Table 7. Status of the breadfruit germplasm collection at the Kahanu Garden of the National Tropical Botanical Garden, Hawaii

| Area of origin | Number of accessions |
|------------------------------|----------------------|
| Belau | 5 |
| Cook Islands [†] | 7 |
| Chuuk | 7 |
| Fiji [†] | 8 |
| Indonesia | 1 |
| Kiribati | 2 |
| Mariana Islands | 3 |
| Marquesas | 8 |
| Hawaii | 1 |
| Philippines | 1 |
| Pohnpei | 17 |
| Rotuma [†] | 5 |
| Western Samoa | 13 |
| Seychelles | 2 |
| Society Islands | 47 |
| Solomon Islands [†] | 5 |
| Tokelau | 19 |
| Tonga | 2 |
| Vanuatu [†] | 7 |
| Yap | 2 |
| Unknown | 11 |
| Total | 173 |

[†] Some accessions from these areas were collected from the South Pacific Commission breadfruit collection at Vailima in Western Samoa.

accession numbers, provenance information, general descriptions and ethnobotanical information has been developed. The database is being expanded into a visual database containing photographs and other images. Ethnobotanical and cultural uses (such as food preparation, storage, seasonality and specialized uses) and local names have been recorded.

Preliminary work on evaluating the germplasm collection at the NTBG using isozyme and cytological analyses has been done (Ragone 1991a). More extensive molecular work to describe genetic diversity is planned. Isozyme data, combined with morphological descriptors and passport information, will provide the basis for identifying a core collection. The core collection will be the focus of more in-depth research, such as cytological studies, and evaluated for yield, fruit quality and nutritional value, and important horticultural and agronomic characters. It will ultimately provide germplasm for utilization and distribution. An ongoing study to document seasonality of all the accessions was started in October 1994 and data have been collected monthly since January 1996.

The United States Department of Agriculture (USDA) National Clonal Germplasm Repository in Waiakea, Hawaii, was established in 1986 and maintains breadfruit as one of its mandated crops. Approximately 36 accessions are represented in its holdings, the majority of which are duplicates of accessions from the germplasm collection at the National Tropical Botanical Garden. The collection is documented with computerized provenance information available on the GRIN database of the USDA (<http://www.ars-grin.gov/gopher/availability>).

There are three small germplasm collections in the English-speaking Caribbean (L.B. Roberts-Nkrumah, 1995, pers. comm.). A collection of one plant each of 24 cultivars originating from the NTBG germplasm collection in 1990 was established at the University of the West Indies, St. Augustine Campus in 1992. Nine plants of the local 'Yellow' and 'White' cultivars were also planted. Local breadfruits and an additional cultivar from NTBG were planted in 1994 and materials from Jamaica and St. Vincent are currently being added. The collection is used for teaching, research and dissemination of planting material.

A collection of cultivars from NTBG and local materials was planted at the University of the West Indies, Mona Campus in 1993. The range of germplasm is not as great as that at St. Augustine. A smaller collection is being established for comparison at the College of Agriculture, Jamaica from materials already growing in the Mona site. The Jamaican collections will be used for comparative evaluation with that in St. Augustine and all collections, when fully established, will supply planting material to the public.

Existing genetic variation

The use of isozymes as genetic markers for cultivar and hybrid identification is a useful tool for evaluating germplasm collections. A preliminary isozyme analysis of breadfruit germplasm assembled for the NTBG collection (Ragone 1991a) showed that it was possible to differentiate between breadfruit accessions and to characterize

genetic variation based on phenotypic banding patterns of six enzyme systems (ACO, ADH, IDH, LAP, MDH, PGM). Ninety zymotypes were observed for approximately 200 accessions. While these systems produced sharp and well-resolved polymorphic banding patterns that could be used to distinguish among accessions, a genetic interpretation of the banding patterns was not made in this study.

The greatest isozyme variation in the Pacific Islands occurred in Melanesia, with 71% of the accessions uniquely characterized (Table 8). A relatively high level of zymotypic variation occurred in Micronesia, with 59% of the accessions uniquely characterized. There were many Micronesian accessions which, based on isozyme phenotypes and morphological characters (fruit surface and presence of red hairs), appear to be interspecific hybrids between *A. altilis* and *A. mariannensis*. The large number of unique zymotypes found in Micronesia is to be expected from the hybrid nature of many of these accessions. While 26% of the Polynesian accessions were unique, the variation predominantly occurred in western Polynesia. In eastern Polynesia, only two zymotypes were observed, one of which was also found in other island groups.

The genetic diversity of breadfruit germplasm in the South Pacific decreases from west to east, reflecting the shift from seeded to few-seeded or seedless cultivars. In Melanesia, breadfruit is primarily a seeded, outcrossing crop. Seeded forms predominate in the western islands of Melanesia, with few-seeded (cultivars usually have from one to several normal or aborted seeds) and seedless forms beginning to occur in eastern Melanesia. Seeded and few-seeded types outnumber seedless cultivars in Samoa, but seedless, triploid cultivars predominate in eastern Polynesia. The decreasing, but still relatively high level of genetic diversity seen in western Polynesia reflects the genetic base inherent in the initial cultigens transported from Melanesia and that arising from subsequent sexual recombination between seeded cultivars.

Table 8. Distribution of zymotypes by island groups

| Island group | No. of accessions | No. of zymotypes | % unique zymotypes |
|-------------------------|-------------------|------------------|--------------------|
| Indonesia/Philippines | 5 | 5 | 100 |
| Melanesia [†] | 28 | 20 | 71.0 |
| Micronesia [‡] | 79 | 47 | 59.5 |
| Polynesia | 92 | 24 | 26.0 |
| West [§] | 35 | 23 | 51.0 |
| East [¶] | 57 | 2 | 3.5 |

[†] Fiji, Rotuma, Solomon Islands, Vanuatu.

[‡] Belau, Chuuk, Kiribati, Kosrae, Mariana Islands, Pohnpei, Yap.

[§] Samoa, Tokelau.

[¶] Cook Islands, Hawaii, Marquesas Islands, Society Islands.

There were limitations to the usefulness of isozyme analysis for characterizing breadfruit. While isozyme analysis readily distinguished breadfruit cultivars of basically different genetic background, it was not sufficient to resolve somatic mutants selected within clones on the basis of morphological and horticultural traits. More than 70 seedless accessions were observed to have the same zymotype. These accessions exhibit a diverse range of fruit and leaf characters, more than would be expected from a single zymotype in natural populations. Leaf indentation ranges from almost entire to very deeply lobed, and fruit shape, flesh and skin texture show great variation. The range of morphological variation is as great as, or exceeds, that of seeded and few-seeded breadfruit found in Melanesia and western Polynesia where 44 zymotypes were observed for 65 accessions. It is likely that accessions with this zymotype all derived from an original seedless, triploid cultivar by human selection of somatic mutations occurring in the vegetatively propagated clone.

A more detailed study using additional enzyme systems needs to be conducted to thoroughly characterize and describe breadfruit germplasm, in particular, those accessions that showed the same zymotype. As with many clonally propagated crops, while many breadfruit clones may not be genetically diverse they have been selected and perpetuated for horticultural and agronomic traits, and other important attributes such as texture, taste, cooking and storage quality, and seasonality. Isozyme data, while very useful, must be supported with morphological data, especially if isozymes do not differentiate between clones.

No systematic evaluation of breadfruit has been previously attempted, with the exception of grouping by gross morphological characters, in particular, vegetative characters. Vernacular names are typically based on morphological traits such as shape of the leaves, fruits and, to a lesser extent, the texture of the fruit epidermis and the presence or absence of seeds (Table 9).

Since the trees in the NTBG collection are of known ages and are growing under the same environmental conditions, detailed measurements and description of morphological characters can be readily made and compared with descriptions, herbarium specimens, photographs and other reference materials documenting the original, source tree from which each accession derived.

The genetic diversity and geographic representation of accessions of breadfruit in germplasm collections, especially those located outside of the Pacific Islands, is extremely limited. As detailed in the section on historical distribution of breadfruit, most of the breadfruit accessions held in collections are derived from a very narrow stock of seedless Polynesian cultivars. Consequently, they are of limited value. One important exception is the six old Papua New Guinea (PNG) cultivars reported to be held at the Lowlands Agriculture Experimental Station on the island of Rabaul (IBPGR 1992). The Caribbean collections appear to represent most of the traditional seedless Caribbean cultivars, but not breadnuts. Representatives of seedless cultivars and breadnuts from more islands in that region should be added. The materials duplicated from the NTBG collection are primarily Tahitian and Samoan cultivars.

Table 9. General characters used to distinguish breadfruit cultivars

| Part of plant | Character |
|---------------|---|
| Fruit | Shape |
| | Size |
| | Texture of skin: length and shape of disks |
| | Colour of skin |
| | Colour of pulp |
| | Size and shape of core |
| | Length of peduncle and insertion into fruit |
| | Presence or absence of seeds |
| | Size of seeds |
| | |
| Leaves | Size |
| | Margin |
| | Number of lobes |
| | Degree of dissection of lobes |
| | Colour and texture of blade |
| | Colour of veins |
| Leaf hairs | Colour |
| | Length |
| | Location |

The germplasm collection in the Solomon Islands is very important, even though it is limited to materials from one island group (Santa Cruz Islands). Breadfruit was probably first extensively cultivated and selected in the eastern islands of Santa Cruz and the Banks Islands. Numerous seeded and few-seeded cultivars are found there, and farmers continue to actively select new landraces from seedling populations.

The collections held by agriculture departments in Pohnpei and Kosrae in Micronesia are also important in terms of genetic diversity, since the genepool represents a wild ancestor, *Artocarpus mariannensis*. The collection in Pohnpei, however, is of limited use since there is no provenance information for the accessions. The collection held at the Nafanua Experiment Station in Western Samoa, while primarily restricted to Samoan cultivars, is also important in terms of genetic diversity. In Samoa, Fiji and Tonga, few-seeded and seedless cultivars occur with seeded types, and the seedless, triploid, Polynesian breadfruit may have originated in these islands. This will be addressed in more detail in the section on breeding.

Conservation and evaluation

There are several constraints on *ex situ* conservation of breadfruit that should be addressed to support existing collections as well as strengthening and expanding germplasm resources. *Ex situ* germplasm collections assembled by agriculture

departments in the Pacific Islands are in a precarious state owing to lack of financial resources and staff to adequately conserve, evaluate and document the collections that have been established (Hazelman 1981). In most cases, the collections are being minimally maintained, but are not being studied or utilized. Neglect of these collections has resulted in loss of accessions since they were first established.

The majority of accessions held in these collections are not duplicated elsewhere and are prone to destruction by catastrophic events such as hurricanes. This is also the case for germplasm collections in Hawaii and the Caribbean. For this reason, the National Tropical Botanical Garden plans to continue developing its breadfruit collection at Kahanu Garden, as well as duplicating selected cultivars at garden sites on Kauai. An additional 200-300 trees can be planted at Kahanu Garden on Maui, up to 50 at the Lawai Garden and 20-25 at Limahuli Garden on Kauai.

Governmental policies also constrain the conservation of *ex situ* germplasm resources and must be addressed if collections in critical areas are to be expanded. As noted above, the Santa Cruz Islands in the eastern Solomon Islands are a critical centre of diversity for breadfruit. However, the local government of the Temotu Province has banned the removal of any planting material from the group and prevented the collecting of germplasm in 1987 (Ragone 1989). This ban apparently went into effect in the early 1980s as a direct result of the Ministry of Agriculture and Fisheries collecting germplasm of breadfruit, *Canarium* and other species for field trials in Honiara, Guadalcanal. These restrictions reflect the desire of Santa Cruz islanders to retain control over precious indigenous arboricultural resources, especially *Canarium* (Yen 1993).

A regional, collaborative approach to breadfruit germplasm conservation in the Pacific Islands is needed to help maximize resources and support local subsistence economies. It is important that cultivars unique to each Pacific island are maintained and available for future use as well as shared with other island nations. Since the number of accessions held in breadfruit germplasm collections is relatively small compared with crop species held in seed banks, all the accessions currently held in Pacific Island collections could be viewed as one, far-flung regional collection.

The accessions in many of the Pacific Island germplasm collections are of limited use because of lack of good provenance information. Detailed passport information needs to be assembled for these collections, where possible. Collectors' notes, herbarium vouchers and other source materials and provenance records, maps and other information in agriculture department records need to be researched. Passport information for these collections can then be entered into a comprehensive database.

The genetic diversity of accessions in collections in Solomon Islands, Pohnpei, Kosrae, Samoa and Kiribati needs to be assessed. This will help determine which accessions are duplicated in more than one collection. More importantly, it will help identify where there are gaps in collections. Examples of the materials needed to develop a definitive collection include: a greater diversity of seeded cultivars of *A. altilis* from New Guinea, Fiji, Solomon Islands and Vanuatu; additional seedless cultivars from Samoa and Tonga; *A. mariannensis* and interspecific hybrids from

throughout Micronesia; and diverse cultivars from island groups currently under-represented in the collection. Some of these materials may already be held in existing collections.

The importance, abundance and use of breadfruit in the Caribbean Islands is second only to the Pacific region. Since Caribbean germplasm is all derived from Pacific stock, breadfruit and breadnut should be widely sampled and compared with Pacific Islands germplasm, for both morphological and molecular characters. This would identify the extent of germplasm resources in the Caribbean and provide the basis for selecting and introducing additional cultivars from the Pacific to expand and diversify the existing germplasm base.

An integrated approach to breadfruit conservation encompassing both *in situ* and *ex situ* conservation is needed. Since breadfruit is a primarily a cultivated crop throughout the Pacific Islands, *in situ* conservation has an on-farm focus. On-farm conservation of breadfruit germplasm continues the perpetuation of clones that have been maintained and grown for centuries, if not millennia. The extent of on-farm germplasm resources needs to be surveyed and documented, especially in the Pacific Islands. This will help identify which cultivars are common and widely grown and in little need of protection. Cultivars which are unusual, have desired qualities, or have a very limited distribution should be targeted for *ex situ* conservation.

Conservation of germplasm must also include wild populations of seeded breadfruit (*A. altilis*), including *A. camansi*— breadnut — and *A. mariannensis*. The centre of diversity, in fact, the only area where wild populations of breadfruit exist, is New Guinea. The primary and secondary forests of New Guinea are under serious threat from logging, mining and other exploitative practices. Wild breadfruit trees will be lost along with other valuable forest biodiversity as these activities increase. The extent and range of wild or cultivated breadfruit has never been determined for Papua New Guinea or Irian Jaya.

A related wild species, *A. mariannensis* in Belau, Guam and the Northern Mariana Islands is also seriously threatened. It was a major component of the native forest on Guam prior to World War II, but deforestation due to fires during and after the war has drastically decreased its numbers. A few isolated trees can still be found on the southern half of the island. The only extensive stands of extant native forest on Guam are found on the northern part of the island on US military lands and other areas where restricted access protected them from damage and destruction. Severe and frequent typhoons have also caused the destruction of trees on Guam and the northern Mariana Islands. Few trees remain on the islands of Saipan and Tinian, with more trees surviving in native forest on Rota. In Belau this species grows wild on Peleliu and the uplifted limestone islands known as the Rock Islands. The latter have limited access and most are not under threat of development or exploitation. The extent and number of wild *A. mariannensis* trees in these islands needs to be determined.

Existing *ex situ* collections are all field genebanks since seedless cultivars of breadfruit must be propagated and perpetuated clonally. Seeded cultivars of

breadfruit are also maintained vegetatively. Field genebanks must involve a long-term commitment of land and labour, and evaluation of this crop requires that trees be grown to maturity. Breadfruit seeds are recalcitrant and cannot be dried or frozen for storage, but little, if any, work has been conducted on storage methods. This is probably because breadfruit is readily propagated vegetatively and only seedless breadfruit are grown in most areas of the world. Studies on methods of *ex situ* conservation of jackfruit, such as seed storage and *in vitro* techniques, may have application to *ex situ* conservation of breadfruit.

Establishment of seedling populations can be a valuable supplement to clonal collections of breadfruit germplasm. If land and funds for long-term management are available, seedlings can be grown to maturity, described and evaluated. Provenance trials can include seeds from a wide range of wild breadfruit trees as well as cultivated trees. Countless seeds are produced by cultivated breadfruit throughout the Pacific Islands, especially in Melanesia and western Polynesia where seeded forms are common. Viable seeds can even be obtained from trees that only occasionally produce seeds, such as *hue* in the Society Islands. Existing germplasm collections already serve as provenance trials since they have brought together a wide range of germplasm and are growing them in a common location. Since breadfruit is cross-pollinated, new, unique seedling progenies will result which can be evaluated and selected for desired characters. In this way, the genetic variation of the crop can be maximized and exploited.

7 Breeding

There has been little deliberate breeding of breadfruit. Indigenous farmers have selected seedling populations or somatic variants for desirable and observable traits over millennia. Beginning 3000-4000 years ago, islanders began venturing eastwards into the vast expanse of the Pacific Ocean. Breadfruit and other crops were carried in colonizing canoes to ensure a supply of food in new lands. Repeated vegetative propagation of breadfruit trees that survived would have multiplied the limited resource. In addition, seeds from seeded cultivars probably were planted to further increase the number of trees. Selected seedlings then would have been vegetatively propagated along with seedless types.

Somatic mutations in existing clones and creation of new clones from selected seedlings resulted in some new cultivars unique to each island. If enough trees became established to provide an ample supply of food, trees with undesired fruit qualities could be removed, and only those trees with desired fruit characters or other useful traits would be preserved and perpetuated. The need to carefully conserve scarce and precious resources would have restricted selection against less-desirable cultivars. Even today, there exist certain Polynesian cultivars with poor fruit quality that are used only if nothing else is available. Hundreds of cultivars of breadfruit are now grown in the Pacific Islands.

Since many cultivars of breadfruit are seedless it has been inferred that fruit development is due to parthenocarpy (Barrau 1976; Hasan and Razak 1992). Seedlessness in breadfruit generally has been attributed to sterility due to triploidy, but failure of breadfruit to set seed can also be due to other genetic factors. A preliminary cytological study of breadfruit by the author (Ragone 1991a) suggests that triploidy is the cause of sterility for those cultivars with a somatic number of $2n = 84$. In areas such as eastern Polynesia, where the majority of cultivars are seedless triploids, little viable pollen is produced, and breadfruit cultivars with seeds are very unusual.

The origin of seedless breadfruit was particularly significant for utilization of this crop. Triploid seedless breadfruit probably arose in western Polynesia (Fiji, Tonga, Samoa) where seeded, few-seeded and seedless cultivars are all found (Ragone 1991a). The isozyme homogeneity of cultivars in eastern Polynesia suggests that the existence of a seedless, triploid cultivar had an overriding significance in determining future selection in this crop. The chance occurrence of a truly seedless breadfruit would have important ramifications for islanders dependent on breadfruit. Each fruit would yield a greater edible portion and the production of pit-fermented breadfruit for long-term storage would be enhanced. The importance of this seedless, triploid breadfruit is signified by the numerous and morphologically distinct cultivars derived from it in the Marquesas and Society Islands, and its widespread prehistoric distribution beyond Polynesia to Micronesia. A few of these triploid cultivars have been widely distributed throughout the tropical world.

Triploidy obviously cannot account for reduced fertility among diploid cultivars. Reduced seed number in some diploid cultivars is probably a by-product of the

practice of clonally propagating these plants using root shoots or sections of roots. Repeated vegetative propagation allows harmful mutations to accumulate, disrupting normal meiosis and resulting in reduced fertility and decreased number of seeds. While this reduction in reproductive fertility may be deleterious in nature, the resulting clones have been selected and perpetuated as useful variants. This mechanism best explains the partial sterility of *A. altidis* diploids in the South Pacific region. Chromosome counts of a wide range of few-seeded cultivars need to be made to determine if these are diploid or triploid.

Micronesian breadfruit cultivars are diverse for zymotypic, morphological and cytological characters. Seeded or seedless diploids, as well as seedless triploid cultivars, which are all interspecific hybrids between *A. altilis* and *A. mariannensis* are found in Micronesia. There are also seedless Polynesian triploid cultivars. Cluster analysis of isozyme zymotypes shows that hybridization and introgression between the two species occurred in more than one island group, and that the Polynesian triploid was involved in some islands (Ragone 1991a). Additional cytological studies combined with isozyme analyses of breadfruit are needed to understand the origin of interspecific hybrids in Micronesia.

Selection of new cultivars is static in most areas where breadfruit is cultivated. It is still an active and ongoing process in only a limited area, primarily Melanesia. Many of the Pacific Island cultivars have been present for generations and, in general, few new cultivars are being recognized and selected. This is the case particularly in areas where seedless and few-seeded cultivars predominate, and islanders typically recognize and rely on a group of standard cultivars. Since survival no longer depends entirely on traditional subsistence crops, there is less interest and need to expand the cultivar base. Slight somatic variants that arise from standard cultivars may be recognized as dissimilar, but are considered merely a different form of the same cultivar, not a new, distinct one. Seedling trees are retained on occasion but are rarely multiplied and distributed since known, recognized cultivars are preferred.

In marked contrast are the Santa Cruz Islands, where breadfruit is a major component of traditional arboriculture systems. Most cultivars have seeds and selection of seedlings is a common practice. Seedlings are allowed to grow until they bear fruit. The fruit is then sampled and the tree cut down if not of desired quality. If the seedling has qualities which are wanted, it is given an appropriate name and perpetuated as a clone by vegetative propagation. This may also be the case for Vanuatu, especially the Banks Islands, where breadfruit is an important crop and names and descriptions have been documented for more than 130 cultivars (Walter 1989).

Improvement of breadfruit will depend on systematic evaluation and characterization of traditional Pacific Island cultivars, selection of superior clones, and their introduction to other areas to expand the existing cultivar base. This is particularly relevant for the Caribbean and other areas where breadfruit is an important staple but limited to only one or a few cultivars. Caribbean cultivars should also be systematically evaluated and compared with their Polynesian

progenitors. Improvement and selection of breadfruit should focus on identification of:

- a suite of cultivars that when grown together will supply a consistent supply of fruit year-round
- high-yielding cultivars
- cultivars with good texture and flavour
- cultivars with improved keeping qualities
- cultivars suitable for processing into flour, chips and other products.

Breadnut, unlike breadfruit which is clonally propagated, is grown from seeds. Improvement of breadnut can be achieved by evaluation and selection of seedling trees for important traits such as high seed number, high yield and trees that produce fruits at a younger age. Selection of early and late-bearing trees will help extend the season and provide a more consistent supply of fruits. There are also varietal differences in the nutritional composition of breadnut seeds, and there is potential for selecting trees that produce more nutritious seeds in terms of protein content and nutrients such as calcium and niacin.

8 Production areas

Breadfruit is more a subsistence crop than a commercial crop in most areas of the world, and the major production areas are the Pacific and Caribbean Islands. In season, breadfruit and/or breadnuts supplement other staple foods for home consumption in Indonesia, the Philippines and parts of West Africa, Central and South America, southeast Asia, India and Sri Lanka. Some fruits may be available at local markets in these areas, especially Indonesia. Breadfruit has never been adopted as a major foodstuff in Africa, possibly because of failure to introduce ways of making the fruit into a food acceptable to local tastes.

Home consumption and local markets in the Pacific Islands

Breadfruit is one of the main staple crops in the Pacific Islands but its significance as a food crop varies with location. In Melanesia, wild breadfruit is still an important component of the subsistence economy in lowland areas of New Guinea. Breadfruit seeds are a valued food in New Guinea and are widely collected. Gathered seeds are sold in village markets, providing an important source of income for women in some areas. The fruits, and to a lesser extent, seeds, are a major subsistence food in the eastern Solomon Islands and Vanuatu. Breadfruit is still widely grown and used in certain areas of Fiji. In western Polynesia, breadfruit is an important staple food crop, especially in Samoa.

In eastern Polynesia, breadfruit was an important staple crop in the Society Islands and Marquesas and Cook Islands, but it has been replaced by introduced foods in the past 50-100 years. Breadfruit remains the main staple food on atoll islands of Chuuk, Yap, Marshall Islands, Tokelau, Kiribati and Tuvalu. On the high volcanic islands of Chuuk, Pohnpei and Kosrae, it is the most important crop in season.

In many Pacific Islands, small quantities of fresh breadfruit are available for sale in village and town markets, especially in population centres where urban households must purchase traditional foods and rely heavily on imported foods. For example, fresh and cooked breadfruit is regularly sold in the markets of Apia, Western Samoa and Papeete, Tahiti. Prepared breadfruit is also sold in village and town markets: *nabo* from the outer islands is sold in the market of Honiara in Guadalcanal and *konis* available in markets in Moen, Chuuk. Breadfruit chips are commercially made and marketed for local consumption on a small scale in Western Samoa, Saipan and Hawaii. Recent efforts in the Marshall Islands to develop a local industry to produce breadfruit chips for export have proved unsuccessful.

There is an increasing demand for fresh breadfruit in Hawaii by Hawaiians returning to traditional diets for health reasons and other Pacific islanders such as Samoans, Tongans and Marshall islanders who reside in Hawaii. Development and increasing urbanization, especially on the island of Oahu, have greatly decreased the numbers of trees growing throughout the state. Fresh breadfruit is occasionally available in ethnic grocery stores and local farmers markets but demand far exceeds supply. There is interest in establishing commercial breadfruit plantings to provide fresh fruit and chips for the local market.

Little, if any, breadfruit is being exported from the Pacific Islands, although a vast potential market for fresh breadfruit exists in the large communities of Pacific islanders living in urban areas such as Auckland, New Zealand, Honolulu, Hawaii and the west coast of the United States, if the constraints of perishability and short shelf-life can be overcome.

Home consumption and local markets in the Caribbean Islands

In the Caribbean breadnut and breadfruit are both grown, with seedless breadfruit more commonly cultivated and used. Its importance and use as a staple food varies from island to island. The importance and use of breadfruit in the Caribbean has waxed and waned since its introduction by Captain Bligh and others in the 1790s. Breadfruit was originally introduced as a source of cheap, easily produced food for slaves labouring on sugar plantations, with high expectations that it would become a major staple food. By 1850 breadfruit was being fed almost exclusively to pigs and poultry (Howard 1953).

Over the years, breadfruit gradually became an accepted food and an important component of the daily diet, especially in rural areas. Breadfruit was very popular by the 1950s (Howard 1953) and had become an important staple food, especially on Jamaica where more than 2.2 million trees were growing (Leakey 1977). The estimated per capita consumption during the 1960s in some territories was as high as 34.5 kg/year (Roberts-Nkrumah 1993). In most cases, breadfruit is used to supplement other staple starchy foods in season and is the main source only in certain rural areas.

Leakey (1977) assessed the status of breadfruit as an economic crop in the 1970s and noted the relative importance of breadfruit for different islands. It was very esteemed and a major source of food in Jamaica but only used as a side dish in Trinidad. In Guyana and Trinidad the breadfruit and breadnut were both much valued and have been incorporated into the diet mainly as vegetables rather than staple starch. Breadfruit production was also high in Barbados. Breadnut is popular mainly in Trinidad and Tobago and Guyana where immature or mature seeds are boiled and eaten as a snack. In the Windward Islands breadfruit is very popular for backyard planting in urban areas, and scattered trees are found island-wide (Marte 1986). In season, fresh breadfruit can be found in any local market, and a small quantity of processed breadfruit products such as frozen, dehydrated and canned slices, flour, chips and candied male flowers are also locally available on the market (Roberts-Nkrumah 1993; Worrell 1994).

Export markets

The 1980s saw the emergence of breadfruit as an export crop and today the Caribbean is the major supplier of breadfruit to Europe, the USA and Canada (Marte 1988). In 1985, 1025 tonnes were imported by the UK from St. Lucia and St. Vincent and the demand by 1987 was up almost 10-fold. Export figures for the six Windward Islands compiled for 1985-89 (Andrews 1990) are shown in Table 10.

Table 10. Export of breadfruit (in tonnes) from the Caribbean Islands

| Island | 1985 | 1986 | 1987 | 1988 | 1989 |
|-------------|------|-------------------|------|------|------|
| Barbados | 25 | n.a. [†] | 65 | 66 | 123 |
| Dominica | 0 | 23 | 24 | 38 | 24 |
| Grenada | n.a. | 1415 | 1429 | 1400 | n.a. |
| Saint Lucia | 911 | 833 | 809 | 867 | 1137 |
| St. Vincent | 94 | n.a. | n.a. | n.a. | n.a. |
| Trinidad | n.a. | n.a. | n.a. | n.a. | 26 |

[†] n.a. = no information available.

In 1990, total exports of non-traditional crops from the Windward Islands totaled 10 058 tonnes, of which breadfruit accounted for 10% (Roberts-Nkrumah 1993). The Caribbean currently provides more than 90% of the breadfruit for the United Kingdom market with the rest coming from Mauritius (Worrell 1994). Mauritius is the only other production area that produces and exports breadfruit for international trade.

Jamaica is one of the largest exporters of breadfruit, especially to the USA (Roberts-Nkrumah 1993). Haiti, Puerto Rico and the Dominican Republic also export to the USA. In 1985, approximately 15 tonnes were exported to the USA and in 1988 a single importer was looking for reliable sources that could guarantee at least this amount weekly (Marte 1988). The USA imported 438.3 tonnes of fresh breadfruit from the Caribbean and 13.0 tonnes of frozen breadfruit from Asia in 1986 (Crane and Campbell 1990). Recent interest in propagation and the establishment of breadfruit orchards has arisen to support and expand the export market in the Caribbean (Roberts-Nkrumah 1993).

9 Ecology

Breadfruit has a wide range of adaptability to ecological conditions, much greater than that usually cited in standard books on crop production in the tropics. These works generally do not take into consideration the genetic variability of breadfruit and knowledge of conditions under which it thrives in its native habitats (Leakey 1977). In general, breadfruit (including breadnuts) is a crop for the hot, humid tropical lowlands and does best at temperatures of 21-32°C (Purseglove 1968). Other authors have expanded the temperature range from as low as 15°C to as high as 40°C (Singh *et al.* 1967; Rajendran 1992). It will not grow where the temperature goes down to 5°C (Coronel 1983; Crane and Campbell 1990).

Rajendran (1992) gave annual rainfall requirements of 2000-3000 mm. The latitudinal limits are approximately 17°N and S; the maritime climates of islands such as Hawaii allow growth to 20-23°N. Rain apparently stimulates extension growth, flowering and rate of growth of the fruit. Annual rainfall of 1525-2540 mm was considered optimum (Purseglove 1968), yet breadfruit will yield regularly on atolls which receive more than 1000 mm of rain annually (Barrau 1961). Breadfruit prefers rainfall of fairly equal distribution but is quite tolerant of short dry periods (Coronel 1983).

Breadfruit grows best in equatorial lowlands below 600-650 m; it is occasionally found in the highlands, but yield and fruit quality suffer in cooler conditions. (Chandler 1958; Coronel 1983; Rajendran 1992). It grows only in the lowlands of Central America and is not found above 600 m elevation (Popenoe 1920). It grows from sea level to 900 m in southern India (Singh *et al.* 1967). In Sri Lanka the tree is cultivated anywhere in the moist zone from sea level up to 900 m but is not suited to the dry zone (Parsons 1933). Breadfruit may be cultivated at elevations up to 1550 m in New Guinea (Powell 1976).

Hawaii is the northernmost limit of breadfruit in the Pacific and because of this trees were not thought to reach the reach the stature or productivity of South Pacific cultivars (MacCaughy 1917). Breadfruit generally grows in the coastal lowlands but flourished in extensive plantations planted at 300-600 m on the island of Hawaii (Handy *et al.* 1972).

Breadfruit can be grown on a variety of soils and thrives on alluvial and coastal soils (Massal and Barrau 1954). They do best in deep, fertile, well-drained sandy loam or clay loam soils (Coronel 1983). Good drainage is essential whatever the soil type, and trees may shed their fruits when the soil is excessively wet. Some cultivars, especially interspecific hybrids, have adapted to shallow calcareous soils and appear to tolerate higher saline conditions (Catala 1957; Coenan and Barrau 1961; McKnight 1964).

Breadfruit is a long-lived perennial tree crop that provides beneficial shade and a cooler microclimate beneath its canopy for humans, as well as plants and animals. When grown with other crops in agroforestry systems it provides support, shade and mulch.

10 Agronomy

Breadfruit is grown mainly as a subsistence crop, especially in the Pacific Islands, where it is a primary staple food. It is typically grown as a backyard crop or in small holdings. There are few, if any, commercial plantations anywhere in the world. It is an important component in arboriculture in the western Pacific and has great potential in agroforestry systems in the Pacific and elsewhere.

Propagation

Breadfruit trees are generally propagated vegetatively (MacCaughey 1917; Pope 1926; Otones and Ruiz 1956; Chandler 1958; Purseglove 1968; Handy *et al.* 1972; Rowe-Dutton 1976; Ragone 1991a). They are traditionally propagated from root cuttings or shoots. The roots grow on or slightly below the surface of the ground and will often produce a shoot, especially if it is cut or damaged. Pacific islanders and others will intentionally wound roots to induce shoot production. When the shoot is 0.5-0.75 m high and has developed its own root system, it is removed by cutting the root 10-15 cm on either side of the shoot.

Care is taken to avoid damaging the new root system, and the top of the shoot is usually removed before planting, cutting it at an angle. The shoot is planted in a hole, into which organic material, such as compost, seaweed or dried manure, is placed. After planting, it is carefully tended, shaded from the hot sun and protected from pigs, chickens and other animals. Once established, breadfruit requires little care. Root cuttings can also be propagated, and this is a useful method for trees that have no root shoots. The time of collecting the roots is the most important factor for successful propagation. It is best to collect roots during the dormant season immediately preceding, or at the beginning of, the renewal of growth when carbohydrate stores in roots are highest. The dormant period begins immediately after the ripening of the crop and lasts for 2-3 months.

Roots of 1.5-6 cm in diameter are cut into sections from 12 to 30 cm long. These are placed in clean, washed sand or potting media and kept moist. The roots can be placed horizontally below the surface of the medium or diagonally with the upper few centimeters exposed to the air. The percentage of rooting ranges from 80 to 85%, and cuttings are large enough to transplant from the propagating bed in 3-5 months. Mass production of breadfruit by root sections is possible (Gunarto 1992). Roots 2.5-3 cm in diameter were cut into pieces 10-15 cm long, planted at an angle in light, sandy soil and covered to a depth of 1 cm and frequently watered. Between 1985 and 1992, more than 150 000 trees were produced this way in the Cilicap district in central Java, Indonesia.

These traditional methods of propagation, while effective and easily done, are relatively slow. Many experiments have been conducted using vegetative material instead of roots to provide faster results (Moti and Chaturveill 1976; Rowe-Dutton 1976; Hamilton *et al.* 1982). Breadfruit and breadnut have been successfully propagated by inarching and budding using other *Artocarpus* species, such as jackfruit, as root stocks. Non-petioled and brownish budwoods are used in budding (Coronel 1983).

Air-layering or marcottage is one method which has shown good results (Rowe-Dutton 1976) and is widely practised in Tokelau (Ragone 1988). Branches (5-15 cm, and occasionally up to 30cm, in diameter) are prepared for air-layering by removing a strip of bark 2.5-5 cm wide around the circumference of the branch. Compost, mulch or other organic material is wrapped around this area and held in place with a tightly tied copra bag. After 2-6 months, roots develop and grow through the bag, and new shoots may grow from above the wounded area. The branch is then cut just below the new roots and planted in a hole containing organic materials. Depending on the size of the air-layered branch, the tree will fruit in 3 to 4 years. Airlayers are most frequently made on branches that have previously borne fruit as the airlayer will bear fruit as soon as 1-2 years after planting.

Root suckers can be successfully air-layered (Coronel 1983). Shoots are airlayered when 2cm or more in diameter. If two or more nodes are left below the surface, new shoots will arise from these nodes after the airlayers are removed. Several airlayers can thus be made over a period of time from one original root sucker. They root quickly and can be separated in 2-3 months.

Another method which promised to facilitate propagation of breadfruit is the use of stem cuttings under intermittent mist (Lopez 1975; Hamilton *et al.*1982). With this method, leafless stem cuttings were treated with rooting hormone and placed under intermittent mist. After 10weeks, 95% of the cuttings had produced sufficient root and shoot growth to be transplanted into larger containers. They were ready for planting in the field after 4 months (Hamilton *et al.*1982).

Lopez (1975) removed newly developed shoots from root cuttings grown in sand. These shoots were treated with rooting hormone and placed under intermittent mist. After 4weeks they were transplanted into larger containers and were ready for field planting in 6months. In Trinidad and Barbados, a similar method is used to multiply the number of suckers from an individual piece of root and reduce the time to obtain suckers (Marte 1986). Sections of root 20-30 cm long and 2-3 cm in diameter are set horizontally in open humidity beds with perlite:peat or vermiculite:peat media. When shoots start to appear, they are covered with the media to etiolate at least 1-2 cm of their base. The shoots are removed in 4-6 weeks, treated with 100 ppm of indole butyric acid (IBA) and placed in mist. They root within 4-8 weeks. This method allows for production of up to 15 suckers/root, while traditional methods produced only one sucker/root. There have been many studies on *in vitro* propagation of jackfruit, but little attention has been given to breadfruit until recently (Ross 1995).

Seeds are extracted from ripe fruits and immediately planted since they lose viability within a few weeks (Rowe-Dutton 1976; Rajendran 1992). Coronel (1983) outlined the germination and care of seedlings. Seeds are planted about 5 cm apart and 1 cm deep and germinate about 2 weeks after sowing. The germinating bed should be kept moist; seedlings can be transplanted into individual containers as soon as they sprout. They grow quickly and are ready for planting in the field when they are about 1 year old. Breadnut trees tend to grow slowly and may start fruiting

in 6-10 years. Asexually propagated breadfruit trees start fruiting in 3-6 years. Regardless of the method used to propagate trees, young plants do best under shade, but trees require full sun once established.

Crop husbandry

Breadfruit are grown mainly as backyard trees and, as yet, are not cultivated on a large scale. Once established they require little attention and input of labour or materials. As a backyard tree, elaborate land preparation is not necessary (Coronel 1983). Generally a hole just wide and deep enough to accommodate the root ball is sufficient. The soil is usually amended with mulch or other organic material, or less frequently, fertilizer is added. Plants should be set out at the onset of the rainy season and supplementary irrigation may be required to help the trees become established. Mulching around the trees is beneficial and widely practised in the Pacific Islands and other areas. Breadfruit are known to grow and fruit well without irrigation, even in areas with a distinct dry season.

An orchard would require thorough land preparation consisting of ploughing the land as deeply as possible followed by harrowing to attain the desired soil tilth (Coronel 1983). He recommended a spacing of 12-14 m, although distances as close as 10 m or less have been suggested. Approximately 100 trees can be planted per hectare if spaced 12 x 8 m or 10 x 10 m apart (Coronel 1983; Narasimhan 1990). The open space between the trees can be used to grow smaller fruits such as papaya, banana or pineapple or field and vegetable crops until the trees become established. Since breadfruit roots grow near the surface, care must be taken not to damage them when cultivating other crops. A cover crop can also be grown and should replace the intercrops as soon as they interfere with orchard operations. Breadfruit trees are an important component of agroforestry systems, and in the Pacific, yam vines are often grown up into their branches and canopy.

There has been no systematic work on the use of fertilizers of breadfruit and research is needed in this area. In the absence of information about the fertilizer requirements, Coronel (1983) recommended the application of 100-200g ammonium sulphate per tree 1 month after planting and again at 6 months. The amount should be gradually increased until the trees start to produce fruits; then 500-1000g complete fertilizer may be applied to each tree twice a year. A full bearing tree may require at least 2 kg complete fertilizer per application.

Trees generally do not require any training or pruning except to remove dead branches. Trees which have grown too tall to readily harvest are easily trimmed back to keep the tree at a more convenient height.

Diseases and pests

Breadfruit is a hardy tree and relatively free of diseases and pests although scale insects, mealybugs and *Cercospora* leafspot can be seen on many trees (Marte 1986; Rajendran 1992). Problems seem to be regional in nature: the two-spotted leaf hopper has been observed damaging trees in Hawaii; *Rastrococcus invaderis* becoming a

pest in certain parts of West Africa (Agounke *et al.* 1988) and *Rosellinia* sp. has been reported as a potential threat in Trinidad and Grenada (Marte 1986). Since it could kill the tree and spreads relatively rapidly, attention must be paid to an effective control method. Liming the soil has been shown to be effective in reducing the damage caused by this fungus. Root-knot nematode (*Meloidogyne* sp.) has been reported as a serious problem in Malaysia and affected plants show retarded growth, sparse branching, yellowing of the leaves and very poor root systems devoid of feeder roots (Razak 1978).

In the 1960s, there was concern that breadfruit trees in Micronesia were being decimated by a problem known as 'Pingelap disease'. Die-back on many islands, in particular Guam and the Caroline atolls, was extensive (Zaiger and Zentmeyer 1966). A subsequent survey by Trujillo (1971) determined that there was no single pathological cause of this die-back. Rather, it was considered to be the result of a combination of typhoon damage, drought, aging of the trees, salinity and other environmental factors. This problem has recently been observed in several Caribbean Islands (L.B. Roberts-Nkrumah, 1990, pers. comm.). Recent work in the Mariana Islands has identified *Phellinus noxius* as the causal organism of crown rot and dieback in breadfruit (Hodges and Tenorio 1984).

Several causal organisms are responsible for fruit rot of breadfruit. Fruits can be affected by *Phytophthora*, *Colletotrichum* (anthracnose) and *Rhizopus* (soft rot), but these can be controlled by prompt harvest of mature fruits and removal of diseased fruits (Trujillo 1971; Gerlach and Salevao 1984). *Phytophthora* was controlled in India by two sprays of 1% Bordeaux mixture on the entire tree at intervals of 2 weeks at the ripening stage (Suharban and Philip 1987). The oriental fruit fly attacks fruits that are allowed to ripen on the tree as well as those that have fallen to the ground. Losses of 30% were estimated for the Philippines during certain seasons (Coronel 1983).

Harvest and handling

Breadfruits are harvested as needed and generally picked when mature but not yet ripe. Breadnut seeds are harvested from ripe fruits and the seeds are separated from the soft pulp. Breadfruits are usually harvested with a sharp scythe or curved knife attached to the end of a long, sturdy pole and are allowed to drop to the ground in most areas. Fruits allowed to fall to the ground are damaged and soften sooner than those that were hand-picked or caught before hitting the ground.

In the Pacific Islands, breadfruit are often caught in a net attached to the pole because the quality of the fruit for fresh consumption and traditional storage is affected when fruits are bruised. Tall trees are climbed to harvest fruits that cannot be reached from the ground. Once harvested, fruits are used immediately or, depending upon the cultivar and its preferred use, are left for 1-2 days before cooking. Fruits may be immersed in water to retard softening, a favourite method in Jamaica (Thompson *et al.* 1974; Passam *et al.* 1981), but the outer surface splits and softens, reducing the amount available for consumption.

Studies to extend the shelf-life of breadfruit (Thompson *et al.* 1974; Marriott *et al.* 1979; Passam *et al.* 1981) demonstrated that whole fruits can be stored in sealed polyethylene bags at low temperatures; however, fruits showed symptoms of chilling injury at temperatures below 12°C. Fruits of the 'White heart' cultivar in Trinidad were successfully stored at 14°C for up to 10 days. Unwrapped fruits ripened within 7 days at this temperature.

Studies in the Caribbean have emphasized the need for careful post-harvest handling, since losses may reach as high as 50% (Narasimhan 1990). Careful post-harvest handling will improve the shelf-life and quality of breadfruit (Maharaj and Sankat 1990). Fruits of the 'Yellow heart' cultivar were carefully harvested and pre-cooled in the field and during transport using chipped ice. They were further pre-cooled to an internal temperature of 16°C in an ice-water bath, then air-dried and stored untreated or in sealed polyethylene bags under ambient and refrigerated conditions. At ambient (28°C) temperature untreated fruits lasted only 2-3 days before softening while those stored in water had a maximum shelf-life of 5 days. Fruits sealed in polyethylene bags have a shelf-life of 5-7 days and waxed fruits can last 8 days.

The shelf-life of untreated and packaged fruits was markedly increased by refrigeration. Packaged fruits at all temperatures were still firm at day 25 but quality declined and chilling injury appeared after only 4 days at 8°C when fruits showed considerable browning of the skin. Under refrigeration, satisfactory fruit quality can best be maintained at temperatures of 12-16°C. At these temperatures, a shelf-life of 10 days appears possible for untreated fruits and 14 days for packaged fruits. Waxed fruits at 16°C were able to store for about 18 days in the first trial and about 10 days in the second trial as external browning limited acceptability in storage. Breadfruits kept at 16°C in atmospheric containers of 5% carbon dioxide and 5% oxygen showed significantly less skin browning and remained firm for 25 days. Controlled-atmosphere storage has excellent possibilities for breadfruit preservation. However, it may not be feasible for most breadfruit-producing areas because of the cost. Additional research in this area will help expand the use of fresh breadfruit beyond the local market.

Yields and productivity

Estimates of yield vary widely, and it is difficult to accurately extrapolate yields on a per unit basis from yields of individual trees. Also, estimates of yield may be unreliable because counts may represent only the number of fruits that are actually harvested from a tree, not the total number produced in a given season. Another variable that must be considered is the average weight of the fruit; this can differ significantly depending upon the cultivar.

Most yield estimates are very general and a figure often cited is 700 fruits per tree per year, each averaging 1-4 kg (Purseglove 1968). In the Caribbean a mature tree could bear up to 900 fruits/tree but the average in the region has been estimated at 200 fruits/tree, each weighing 1-2 kg (Marte 1986). A very conservative figure of

only 25 fruits per tree was given for the West Indies (Morton 1987). Yields for the South Pacific are generally given as 50-150 fruits/tree per year (Massal and Barrau 1954). Per hectare yield estimates have ranged from 16 to 30 tonnes for Barbados, 20 tonnes for Western Samoa, to a high of 50 tonnes for Indonesia, based on 100 trees/ha (Wootton and Tumalii 1984; Gunarto 1992; Verheij and Coronel 1992).

Breadfruit yield in an indigenous multistorey agroforestry system on Pohnpei was recorded for 87 trees in 1988 (Fownes and Raynor 1993). Five cultivars ('meiuhp', 'meikalak', 'meiniwe', 'meinpakahk' and 'luhkual') representing early and late-bearing types were studied. The average number of fruits ranged from 93 to 219 fruits per cultivar with maximum fruit number ranging from 212 to 615. The number of fruits actually harvested from each cultivar ranged from 27 to 89%. Substantial losses due to premature fruit drop and disease were reported, and farmers did not harvest all usable fruits, especially during the height of the main season.

Few yield estimates are available for breadnut and the figures reported for breadfruit are most often used. Mature trees in the Philippines produce 600-800 fruits per season (Coronel 1983). The average number of seeds (Fig. 4b) per fruit is variable, ranging from 59 to 80 with a minimum of 32 and a maximum of 94 per fruit, each seed weighing an average of 7.7-10 g (Quijano and Arango 1979; Negron de Bravo *et al* 1983; Bennett and Nozzollilo 1988). By comparing the number and weight of seeds reported for fruits from different regions and based on 100 trees/ha, each averaging 200 fruits/trees, an average yield of 11 tonnes/ha of fresh seeds was calculated (Narasimhan 1990).

11 Limitations of the crop

The major limitation on utilization of breadfruit is the highly perishable nature of the fruit and the seasonal nature of the crop. The keeping quality of breadfruit is limited by a rapid post-harvest rate of respiration with the fruits ripening and softening in just 1-3 days after harvest. Soft, ripe fruits are unacceptable for consumption and substantial losses are incurred during peak production periods. The perishability of breadfruit restricts local marketing and greatly limits its export potential since fruits ripen before they reach their destination. There are Pacific Islands cultivars that remain firm for as long as 10 days at ambient conditions, and the shelf-life of fresh breadfruit can be extended by selection of those cultivars that do not soften quickly.

Breadfruit is a seasonal crop producing fruits over a 4- to 6-month period. Commercial processing is not economical or sustainable without a reliable, consistent supply of fruit. There are a few cultivars which reportedly produce fruits year-round, but the norm is cultivars which produce one, or occasionally two, crops per year. Early and late-bearing cultivars exist in many areas of the Pacific and extend the period of harvest. Identification and selection of early and late-bearing trees will help provide a more consistent supply of fruits.

While numerous traditional methods have been developed to process and store breadfruit, this easy-to-grow, nutritious carbohydrate fruit will never become more than a locally important crop unless economical, reliable methods of extending its shelf-life and commercially processing it are developed.

12 Prospects

Breadfruit produces a highly nutritious, high-carbohydrate fruit that can be consumed at all stages of maturity. A high-quality starch can be easily extracted from the fruit. Breadnut yields low-fat, high-protein, edible seeds. These multipurpose trees are long-lived, producing for more than 50 years and providing nutritious fruits for human consumption, timber and feed for animals. They require little input of labour or materials and can be grown under a range of ecological conditions.

Fruit texture is an important attribute that affects cooking and processing. Seedless and few-seeded breadfruit both exhibit a wide range of textures at the mature stage. The preferred fruits are those that are dense, smooth and creamy when cooked. There are cultivars with mealy flesh, as well as ones with fibrous, stringy flesh, and spongy ones which are full of what appear to be fine threads of latex. Cooking and processing are also affected by the amount of latex present in a mature fruit. There are many cultivars which exude little or no latex when cut, but others produce profuse amounts of sticky latex from the fruit core and even the flesh itself. The latex oxidizes upon exposure to air and rapidly discolours. The latex is viscous and adheres and hardens onto knives, utensils, cooking pots and other surfaces that it touches.

The quality of cooked fruit also depends on the method of preparation: different cultivars provide different results when boiled, roasted or baked. Some cultivars are suitable for roasting but become mushy and fall apart when boiled. The potential for wide-scale processing by freezing, canning or production of flour will be enhanced by selection of suitable cultivars. The presence or absence of seeds will of course affect how fruits are handled and processed. Fruits with seeds are probably inappropriate for large-scale canning or chip-making operations but are excellent for home use because the seeds are a good source of protein and make breadfruit a more complete food.

Since breadfruit is generally preferred while mature and still firm, nutritional studies, development of commercial products and research to extend shelf-life have focused on this stage. Ripe fruits generally go to waste or are used as animal food, and there has been little attention given to expanding the use of ripe fruits. A much greater proportion of the breadfruit crop could be utilized and marketed if food products incorporating ripe breadfruit, such as baby foods, baked goods and desserts, are developed.

Hundreds of traditional cultivars have been selected based on flavour, texture, size and cooking or storage qualities of the fruit, horticultural requirements, bearing season, yield and productivity. They have adapted to local climates and soils, including saline soils of coral atolls. There are traditional cultivars that would accommodate a wide range of horticultural needs: dwarf trees or ones of lower stature making harvesting easier and requiring less space to grow; cultivars suitable for saline or sandy soils; and cultivars which produce numerous root shoots, facilitating propagation and multiplication. A wealth of cultivars already exists which contain the potential for breadfruit to become a much more widely grown and utilized crop throughout the tropics. These traditional cultivars need to be conserved and evaluated to maximize their potential use.

13 Research needs

Research efforts to conserve breadfruit germplasm include developing a framework to first characterize, describe and evaluate existing collections, especially in the Pacific Islands and identifying future collecting priorities. The recommendations for research are as follows.

1. Describe and quantify the genetic diversity of accessions in the National Tropical Botanical Garden's collection using electrophoretic or other molecular techniques.
 2. Develop a morphological descriptor list for key characters.
 3. Characterize and evaluate germplasm in the NTBG collection.
 4. Analyze Pacific region germplasm collections:
 - compile passport data for accessions
 - describe and quantify the genetic diversity of accessions.
 5. Assess genetic variability of wild and cultivated populations in centres of origin and diversity:
 - wild populations of seeded breadfruit and breadnut in New Guinea
 - cultivated, and wild, if any, populations of breadnut in the Philippines and Indonesia
 - cultivated populations of breadfruit in New Guinea, Vanuatu, Solomon Islands and Fiji in Melanesia, Samoa in western Polynesia, and high islands of Kosrae and Pohnpei and atolls throughout Micronesia.
 6. Identify the extent of germplasm resources in the Caribbean and compare with Pacific germplasm.
 7. Clarify the taxonomic status of *A. camansi* and its relationship to *A. altilis*.
 8. Conduct cytological studies to determine ploidy levels of *A. altilis* and interspecific hybrids between *A. mariannensis* and *A. altilis* in Micronesia.
 9. Determine the origin of interspecific hybrids between *A. mariannensis* and *A. altilis* in Micronesia.
 10. Identify early and late-bearing types to provide a more consistent supply of fruits.
 11. Conduct research on pollination biology.
 12. Develop new food products utilizing fresh and processed breadfruit.
 13. Research post-harvest handling practices to extend shelf-life of fresh fruits.
 14. Research on fruit quality.
 15. Effect of fertilizer on yields and productivity.
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Appendix II. Centres of crop research and plant genetic resources of breadfruit

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PO Box 480, Hope Gardens
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Ministry of Environment and
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Division of Agriculture
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Papua New Guinea

Lowlands Agriculture Expt. Station
Dept. of Agric. and Livestock
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Philippines

National Plant Genetic Resources Laboratory
Institute of Plant Breeding
College of Agriculture
University of the Philippines at Los Baños
College, Laguna 4031

Solomon Islands

Fote Field Experiment Station
Malaita

Taiwan

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Vietnam

Phu guy Fruit Research Centre
Nghe an
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Western Samoa

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