Multipurpose Tree Species Network Research Series

Jackfruit Biology, Production, Use, and Philippine Research

Monograph Number 1

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Preface

Few multipurpose tree species (MPTS) are of greater importance to small farmers in tropical Asia than jackfruit (*Artocarpus heterophyllus* Lam.).

In a study of farm and village forestry practices in Asia, researchers asked farmers of 26 villages in 6 countries to name their first and second choices of trees for each of 10 uses. Jackfruit was the second most frequently mentioned tree, right after mango (*Mangifera indica*) and before coconut (*Cocos nucifera*). Food, of course, was jackfruit's most frequently cited use, but timber, fodder, and fuelwood uses were mentioned with surpising frequency (49%, 42%, and 13%, respectively, compared to the level of responses for food use).

The popularity of jackfruit among small farmers in Asia is eminently sensible. What other timber, fodder, and fuelwood tree also yields a staple food? For farmers with limited land who are striving to meet household needs for wood products, animal feed and, above all, family food security, trees like jackfruit are a godsend.

Recognizing the need to know more about such trees, the MPTS Research Network has added a new emphasis on "multipurpose food trees" to its existing emphasis on fast-growing, nitrogen-fixing trees. Recently, the Artocarpus network was formed to give a focus to this new emphasis. Initial network activities will concentrate on jackfruit, but in time it is expected that they will expand to include breadfruit and other members of this most interesting genus.

This monograph by Dr. Antonio L. Acedo, Jr. of the Department of Horticulture, Visayas State College of Agriculture in the Philippines, is the first of a series of publications from the Artocarpus network. In addition to providing a review of the status of jackfruit research in the Philippines, it answers the need for a general introduction to the tree. Other country-specific monographs will follow, along with a wide range of studies on both biophysical and socioeconomic aspects of jackfruit production, utilization, and marketing.

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I. Introduction

Artocarpus heterophyllus Lam. (jackfruit) is one of the most widely distributed and cultivated fruit tree species in the Philippines. Major jackfruit-growing areas are the three regions that comprise the Visayas (Western, Central and Eastern Visayas) and the Southern Tagalog and Bicol regions on the island of Luzon (Figure 1). In 1987, these areas accounted for 40.6% and 32.2% of the country's total jackfruit production, respectively (CRC 1990). The remaining 27.2% is scattered throughout the other eight regions of the country in Luzon and Mindanao.

In the Philippines, jackfruit is a backyard crop cultivated under subsistence farming conditions (Gatchalian 1978; Espino 1987). In fruit production, it leads all other "minor" fruit crops in the Philippines, ranking sixth overall after the country's five major fruit crops: *Musa* spp. (banana), *Mangifera indica* (mango), *Carica papaya* (papaya), *Ananas comosus* (pineapple), and *Citrus spp.* (citrus)(CRC 1990). Total jackfruit production in 1987 from an area of 12,970 ha reached 67,527 metric tons, valued at 343.2 million pesos (about US$13.73 million). Jackfruit has great potential for export expansion. Philippine Central Bank records show that in 1986, the total export of 184,975 kg fruits in syrup and 3,441 kg fresh fruits amounted to 8.1 million pesos (US$324,000).

Although primarily grown for its fruits, jackfruit has many other uses (see Section 9). In this, it typifies a multipurpose tree species with considerable potential as a horticultural, forestry, and industrial crop.

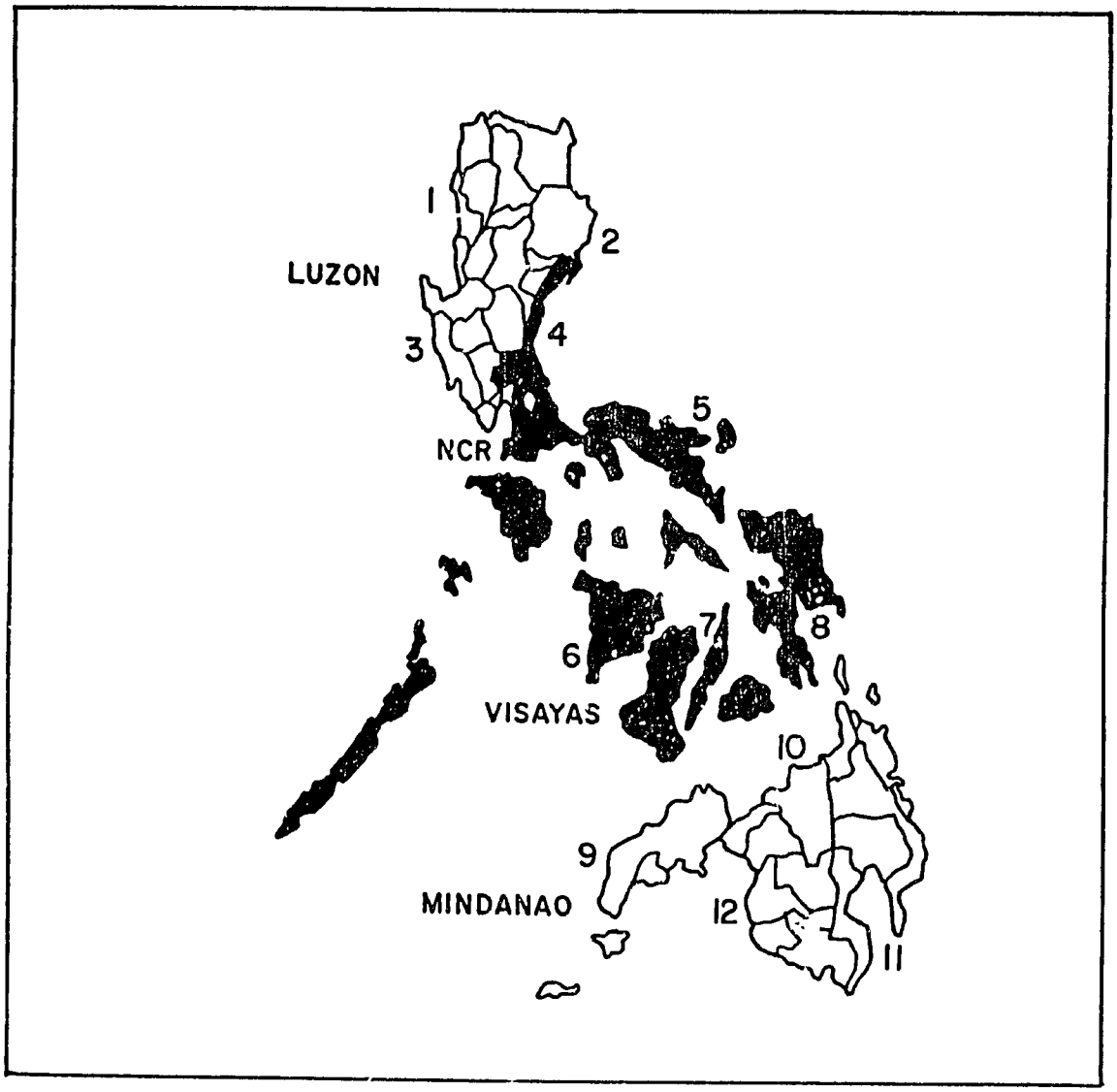

Figure 1. Map of the Philippines showing major jackfruit-growing regions (shaded): Southern Tagalog (4), Bicol (5); Western Visayas (6); Central Visayas (7); and Eastern Visayas (8).

2. Overview and State of Jackfruit Research in the Philippines

2.1. Research Trends

Jackfruit studies conducted in the Philippines are few, mostly intradisciplinary and directed towards improving production and utilization of the fruit. They cover the general areas: crop improvement, developmental physiology, production management, postharvest management, processing and utilization, and socioeconomics (Table 1). One non-investigative research study involving the establishment of seed orchards and seed banks of jackfruit and other plantation and agroforestry tree species (Zabala and Esteban 1986), is classified under extension research. No marketing study has been done. A few of the researches covered more than one area of study.

The area of crop improvement included studies on varietal collection, characterization, evaluation, and maintenance. One early investigation provided evidence for the natural hybridization of jackfruit and *Artocarpus integer* (Mendiola 1940). Research on developmental physiology consists mostly of short-term studies on tree growth and flowering habits, fruit growth and development, and floral and fruit abscission. The area of production management has several components, but so far only propagation, intercropping, and surveys and control studies of diseases and insect pests have been carried out. Research on postharvest management has been limited to the evaluation of fruit maturity indices and ripening behavior. Under processing and utilization, several studies have been undertaken on fruit processing, product development, and the determination of chemical compositions of the fruit and its parts. The two socioeconomic studies identified were surveys determining scale of production and the production and utilization practices of jackfruit.

Many of the studies in Table 1 started in the late 1970s or 1980s. These, particularly studies that received agency or outside-agency funding, are multi-commodity projects or programs rather than more focused, intensive, single-commodity jackfruit studies. They were conducted mainly at the regional level within the country.

2.2. Overview of Research Findings and Gaps

Sections 5-9 incorporate significant results of this research. Based on these findings and the nature of the studies, this section attempts to draw an overview of the research gaps and a possible agenda for future research.

In the area of crop improvement, very limited varietal collection and evaluation works have been done. To develop outstanding cultivars for specific purposes (for example, vegetable, fresh fruit, processing or timber), a more vigorous selection and hybridization program is imperative. Non-conventional breeding systems like tissue culture might be useful to expand the pool of genetic variability. This *in vitro* technique

Table 1. Studies of *Artocarpus heterophyllus* in the Philippines.

Subject	Number of studies	
	1975-1991[1]	Before 1975[2]
Crop Improvement	7	1
Developmental Physiology	5	
Production Management		
Propagation	3	3
Fertilization		
Irrigation and Drainage		
Cropping Schemes	1	
Pruning		
Weed Control		
Diseases and Control	2	
Insects Pests and Control	2	
Postharvest Management	2	
Processing and Utilization	7	2
Marketing		
Socioeconomics	2	
Extension Research	1	

[1]obtained from: the two national research monitoring agencies, the Philippine Council for Agriculture, Forestry and Natural Resources Research and Development (PCARRD) of the Department of Science and Technology, and the Bureau of Agricultural Research (BAR) of the Department of Agriculture; national and regional research centers; University of the Philippines at Los Banos; and the Visayas State College of Agriculture. Information on processing was also received from the College of Home Economics, University of the Philippines at Diliman.

[2]obtained from *Philippine Agricultural Review* and *Philippine Journal of Science*.

can also serve as an alternative germplasm conservation system to complement varietal field maintenance, which has been faced with the problems of limited land area and damage by natural forces of pests and typhoons.

Studies on developmental physiology can serve as a fundamental basis for tree-breeding programs and for designing appropriate production systems. They also offer insights into how the tree functions, and give clues for the elimination of yield-limiting factors (Soepadmo 1991). Results on the morphological characterization of the tree or fruit during development, and on the tree's flowering and fruiting habits, have been so variable and inconclusive that only generalizations can be drawn. This is due to the use of seedling trees of sometimes unknown origin or variety, coupled with the fact that these studies were mostly short-term, one-trial undertakings. For these phenological

studies to be more meaningful and useful, they should be cultivar-specific, locality- or environment-specific, and perhaps specific to particular tree ages. Verification studies are also important for authenticating first-time results.

There is a lack of research and development directed towards improving production management and devising effective plantation development systems. This is essential for the commercialization of jackfruit. Although there have been several studies on propagation (Table 1), the results are variable. A reliable vegetative technique for rapid propagation has not been developed. Among the asexual propagation methods tried, approach grafting or inarching has shown greater success (Angeles 1983), but it is only suitable for small-scale propagation (Coronel 1983). One method with potential is cleft grafting, which has been found to give 30-80% graft take. If it can be perfected to give consistently higher success rates, it is a much better system than inarching for perpetuating and propagating outstanding varieties. *In vitro* propagation is another alternative for rapid propagation, but genetic variabilities that may be imposed by *in vitro* conditions must be considered.

Other production management systems that need to be optimized include: planting systems, fertilizer requirement, irrigation, systems of culture (e.g., monoculture, multiple cropping), and control of insect pests and diseases. Although there have been studies on identification and control of insect pests and diseases of jackfruit, a proven pest management strategy has not been devised. Furthermore, in developing production techniques it is important to consider farmers' existing practices, so that technological innovations will suit users' needs and requirements and be easier to adopt.

Likewise, very little work has been done in the area of postharvest management; none has addressed specific development areas. Improvement of postharvest management first requires a quantitative and qualitative assessment of existing practices and problems, so that real needs and problems are identified and promptly addressed. In addition, studies on postharvest physiology should undertake to understand the behavior of the commodity after harvest. This is indispensable to the design of appropriate postharvest management approaches.

Much of the research conducted on jackfruit is on fruit processing. Several processed products from the fruit and its parts have been developed, but most of these have not been market-tested for possible commercialization. Nor has any study attempted to determine the effect of processing or preservation methods on the nutritional quality of processed products. In other fruit commodities, preservation methods such as canning, drying, freezing, or fermentation have been reported to cause varying degrees of nutrient losses (Bolin 1982). Research on this aspect can be instrumental in developing nutritious jackfruit food products.

At the same time, the various non-food uses of jackfruit also need to be exploited and popularized.

The commercialization of jackfruit hinges not only on the development of suitable varieties, production and postharvest management strategies, and processing and utilization systems, but more importantly on the marketing of its products. The neglect of marketing research is lamentable. A deliberate marketing and market development program must be pursued. Among other things, this program should:

- o determine market channels, outlets, and pricing
- o assess supply and demand, market potentials, and cooperative marketing systems
- o establish workable marketing information systems and quality standards

Socioeconomic studies have so far established the fact that jackfruit is primarily a backyard crop whose fruits are mainly consumed fresh or processed (Espino 1987; Gatchailan 1988). Very little socioeconomic information is available on:

- o economic factors that affect consumers' purchasing capability
- o users' preferences, beliefs, and consumption-related practices

Such information would help to guide policy makers, researchers, and development workers in formulating technological and non-technological interventions to energize the jackfruit industry. A continuing research effort must be undertaken to exploit the considerable potential of the jackfruit and make the jackfruit industry a viable component of the country's economic development program.

3. Origin, Distribution, and Domestication

3.1. Origin and Geographic Distribution

The jackfruit has only one identified center of origin (Harlan 1987): the Indo-Malayan region (Barrau 1976; Zielenski 1955). More specifically, the species reportedly originated in the rainforests of the Western Ghats of India (Chandler 1958; Popenoe 1974; Purseglove 1968) and in Malaysia (Brown 1941; Hensleigh and Holaway 1988; Merill 1912; Wester 1921). It then spread to neighboring Sri Lanka, southern China, Southeast Asia, and farther to tropical Africa, including Kenya, Uganda, Zanzibar, Mauritius, and Madagascar (Figure 2)(Barrau 1976; Hensleigh and Holaway 1988; Morton 1965, 1987; Purseglove 1968; Soepadmo 1991).

From the mid-seventeenth century to the late nineteenth century, the species spread further to tropical and subtropical America (Brazil, Suriname, Jamaica, and Florida) and Australia (Morton 1965, 1987; Popenoe 1974; Purseglove 1968). From these countries, the jackfruit may have dispersed even further, to other tropical and warm subtropical regions where it is now widely cultivated at low and medium elevations (Harlan 1987; Purseglove 1968).

3.2. Introduction and Domestication in the Philippines

Jackfruit's introduction to the Philippines (Brown 1941; Merill 1912; Wester and Barrette 1912) possibly dates back to the twelfth century A.D., when the coastal Filipinos started to trade commodities, including economic plants, with Indians, Malays and Chinese (National Historical Society 1970; Pelzer 1948). Domestication of the crop likely started soon thereafter. In the mid-sixteenth century a Spanish official, Andres de Mirandaola, identified jackfruit as a native Filipino food in a letter to the King of Spain, referring to it as *nancas* (Blair and Robertson 1903). Jackfruit and bananas were the two aromatic fruits consumed by the early Filipinos. Presently, jackfruit is widely distributed throughout the archipelago (Merill 1912; Wester 1921) in both cultivated and wild forms (Brown 1941).

4. Taxonomy and Nomenclature

Artocarpus heterophyllus Lam., belongs to the family Moraceae, along with *Ficus* spp. (fig), *Morus* spp. (mulberry), and *Maclura pomifera* Schneid (osage orange or hedge apple) (Chandler 1958; Popenoe 1974). This family encompasses about 1,000 species in 67 genera, mostly tropical shrubs and trees, but also a few vines and herbs (Bailey 1942; Merill 1912). The Philippines is home to about 150 species representing 13 of these genera (Merill 1912).

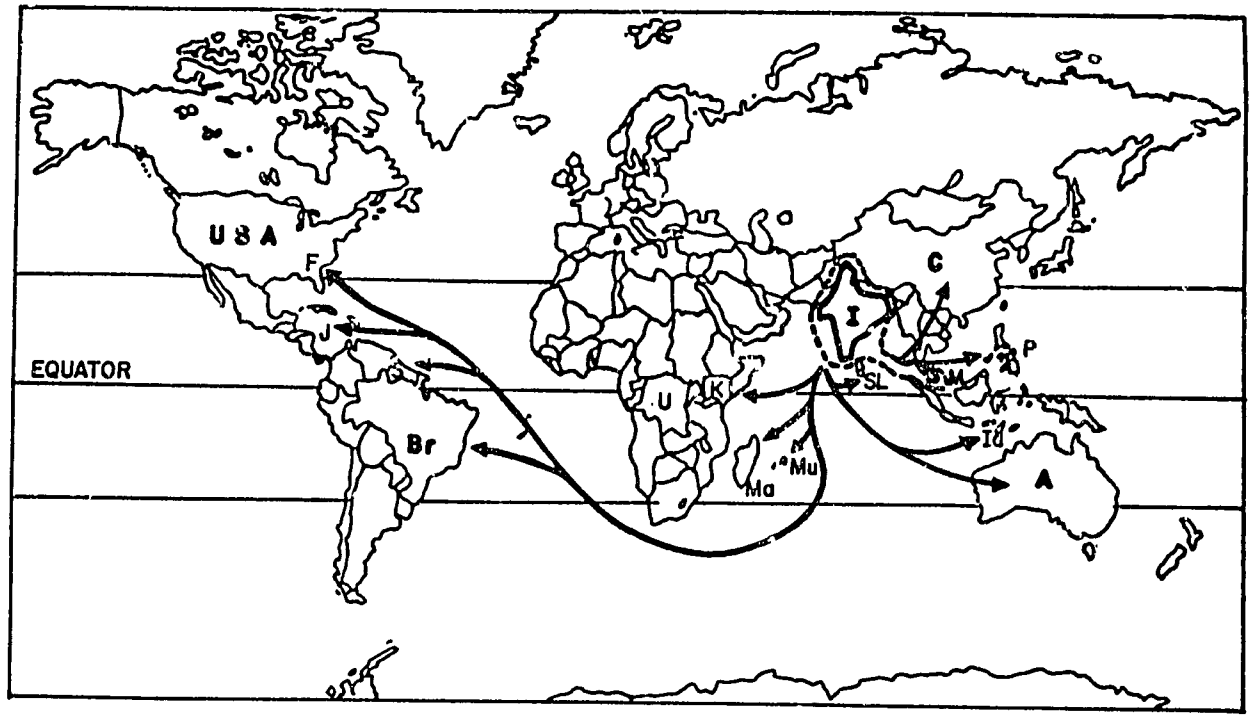

Figure 2. Origin and early introduction of jackfruit. Probable center of origin is enclosed by dotted lines. A = Australia, B = Burma (Myanmar), Br = Brazil, C = China, F = State of Florida, U.S.A., I = India, J = Jamaica, K = Kenya, M = Malaysia, Ma = Madagascar, Mu = Mauritius, P = Philippines, S = Suriname, SL = Sri Lanka, U = Uganda.

The word Artocarpus is derived from the Greek words *artos* (bread) and *carpos* (fruit)(Bailey 1942). The genus includes about 50 species with a milky latex in the Asiatic tropics and Polynesia (Barrau 1976; Campbell 1984; Corner 1938), 18 of these species are found in the Philippines (Merill 1912).

The complete taxonomic classification of *A. heterophyllus* is as follows (Stanton 1970; Zielenski 1955):

Kingdom:	Plantae
Division:	Spermatophyta
Sub-division:	Angeospermae
Class:	Dicotyledonae
Order:	Urticales
Family:	Moraceae
Genus:	Artocarpus
Species:	heterophyllus

The jackfruit also belongs to the series cauliflori (Barrau 1976). Cytotaxonomically, the jackfruit is a tetraploid (Soepadmo 1991). Its basic chromosome number (x) is 14; its somatic number (2n) is 56 (2n=4x=56)(Darlington and Wylie 1956).

The species' botanical or scientific name was coined by the botanist Lammarck (abbreviated usually as Lam. or sometimes Lamk.)(Corner 1938). Its legitimate synonyms are: *A. heterophylla* Lam., *A. philippinensis* Lam., *A. maxima* Blanco; *Soccus arboreus* major Rumph., *Polyphema jaca* Lour., and *A. brasiliensis* Gomez (Corner 1938; Soepadmo 1991).

Erroneously used synonyms include: *A. integrifolius* Auct., *A. integrifolia* L. f., *A. integra* (Thunb.) Merr., *A. jaca*, and *Rademachia integra* Thunb. All of these refer to a related species, *A. integer* (Thunb.) Merr., or chempedak (Corner 1938; Morton 1987).

Other edible fruit-bearing species related to jackfruit are *A. altilis* (Park.) Fosb. (rimas), *A. blancoi* (Elmer) Merr. (antipolo), *A. camansi* Blanco (camansi), *A. odoratissima* Blanco (marang), *A. lancaefolia* Roxb, (kledang), and *A. rigidus* Blume (mandalika)(Coronel 1983; Hensleigh and Holaway 1988).

The jackfruit is also commonly named *jak* or *jack*, English adaptations of the Portuguese *jaca* (Popenoe 1974). This name is in turn taken from the Malayan term *tsjaka* or *chakka*. Table 2 lists the species' common names.

Table 2. Common names for *Artocarpus heterophyllus*.

Country	Name
Cambodia	khnor or khnaor
China	Po-lo-mi
India	kanthal, kathal, penasa or kantaka
Indonesia	nangka or nongko
Laos	mak mi, may mi, miiz or miiz hnang
Malaysia	nangka
Myanmar	peignai
Papua New Guinea	kapiak
Philippines	langka or nangka (Tagalog, Bisaya, Ilocano) nanka or lanka (Tagalog, Bisaya) sagakat (Mountain Province) badak (Cagayan) ananka (Ilocano) yanka (Kapampangan) ubiyen (Ibanag)
Thailand	khanun, makmi or banun
Vietnam	mit
Also	
English	jackfruit, jak, or jack
French	jacque or jacquier
Spanish	jaca

Sources: Liu 1987; Popenoe 1974; Soepadmo 1991.

5. Morphological Characteristics

5.1. Tree

Artocarpus heterophyllus is a large evergreen tree with a height varying from 8-25 meters (Bailey 1942; Barrau 1976; Morton 1987; Popenoe 1974; Soepadmo 1991; Wester 1921). The tree produces a long, delicate tap root (Hensleigh and Holaway 1988). It is straight-stemmed branching near the base at an angle of 32-88° from the trunk (Tarroza 1988). Growth habit varies from moderately or slightly upright to spreading (Angeles 1983; Corner 1938; Tarroza 1988).

Its canopy is dense and mostly dome-shaped or slightly pyramidal, rarely pyramidal or flat-topped (Angeles 1983; Tarroza 1988). Canopy diameter varies with age; in five-year old trees, it ranges from 3.52-6.74 m (Tarroza 1988).

The trunk is rarely or not buttressed (Corner 1938). Its girth may develop to 0.3-0.8 m, with a circumference of 42-96.3 cm (Hensleigh and Holaway 1988; Soepadmo 1991; Tarroza 1988).

The bark is dark grey to greyish brown, rough, uneven, and somewhat scaly (Corner 1938). The inner bark is thick and ochre in color. The wood is yellow (Corner 1938) and has a specific gravity of 0.6-0.7 (Hensleigh and Holaway 1988). All parts are smooth, having either no hairs (glabrous) or minute, white hairs up to 0.5 mm long with tips easily broken, giving the leaves and twigs a slightly rough or scabrid feel. When injured, all living parts of the tree exude a copious, white, gummy latex (Bailey 1942).

5.2. Leaf

The leaves of the jackfruit are deep green, coriaceous (leathery), glossy, and usually glabrous, with 1.2-4.9 cm long petioles (Barrau 1976; Corner 1938; Popenoe 1974; Purseglove 1968; Soepadmo 1991; Tarroza 1988; Wester 1921). The upper side of the leaf is dark green; the underside is pale green. The leaves may be flat, wrinkled, or with upcurled sides. They are pinnate-nerved, with 5-12 pairs of veins (Angeles 1983; Corner 1938; Purseglove 1968). The midrib and main veins are greenish-white to pale greenish-yellow (Corner 1938). The leaves are arranged alternately on horizontal branches and spirally on ascending branches with 2/5 phyllotaxis (Corner 1938; Purseglove 1968). They are entire when mature and may be two- or three-lobed when young or at the sapling stage. Leaf shape can be elliptic, elliptic-obovate, obovate, oblong, or oval (Angeles 1983; Corner 1938; Morton 1987; Popenoe 1974; Purseglove 1968; Tarroza 1988).

In general, the leaves on fertile or flower-bearing branches are obovate (Bailey 1942; Morton 1987). Those on high branches are more obovate or oblong. Those leaves in young shoots are oblong or narrow, in addition to being lobed. They are broadest at

or above the midportion. The rounded or blunt apex has a short, pointed tip. As shown in Figure 3a, the base shape is tapered cuneate (wedge-shaped) or pointed (Corner 1938; Purseglove 1968). Leaf size varies from 4-25 cm in length and 2-12 cm in width (Angeles 1983; Corner 1938; Purseglove 1968; Tarroza 1988).

5.3. Inflorescence

The jackfruit is a monoecious plant species, which means that it bears separate male and female inflorescence on the same tree (Barrau 1976; Corner 1938; Querijero 1988; Thomas 1980). The individual flowers are borne on an elongated axis. They form a racemoid inflorescence, which is also termed *spike* or *head.*

The male spike is produced singly and appears as a solid, elongated structure, as in Figure 3b and 3c. It is light- or whitish-green to dark-green in color with smooth skin, becoming yellowish and rough when mature (Angeles 1983; Corner 1938; Moncur 1985; Querijero 1988). It can be oblong, cylindrical, clavate (club-shaped), ellipsoidal, or barrel-shaped (Angeles 1983; Chandler 1958; Corner 1938; Purseglove 1968; Querijero 1988; Thomas 1980). Figure 3c shows the 1.5 - 2.5 mm wide annular ring at its distal end. The spike is 3-10 cm long and 1-5 cm wide, slightly hairy, and hanging or dropping (Angeles 1983; Chandler 1958; Corner 1938; Moncur 1985; Purseglove 1968). It has a peduncle 1.5-3.5 cm long and 4-5 mm thick (Corner 1938). A male spike has many densely crowded flowers, which may be sterile or fertile. The sterile male flower has a solid perianth: the fertile male flower is tubular and bilobed (Figure 3d)(Corner 1938; Purseglove 1968; Soepadmo 1991; Thomas 1980). The individual flower has a single, 1-2-mm-long stamen and four anthers (Moncur 1985).

Female spikes, on the other hand, are either solitary or paired, as in Figure 3e (Angeles 1983; Corner 1938; Moncur 1985; Querijero 1988). They are oblong or cylindrical in shape with rough, light- to dark-green skin. The female inflorescence is relatively larger (5-15 cm) and has a thicker peduncle (8-9 mm) than the male spike. Its base has a 3-4.5 mm wide, green annulus (Figure 3f). The individual flowers are borne on stout, fleshy receptacles. They are small, tubular and greenish. Each flower has a pair of perianth lobes and a single pistil (Figure 3g and 3h). The ovary is oblong, compressed or coalesced. The style is long and obliquely inserted. The stigma can be clavate, spatulate (spoon- or spatula-shaped), or ligulate (strap-shaped). Stigmatic points are persistently sharp, becoming blunt in mature fruits.

When young, both male and female spikes are enclosed by a pair of spathe-like stipules 1.5-8 cm long and 0.5-3 cm wide (Figure 3c). These stipules can be fugacious or deciduous and ovate-acute or ovate-triangular in shape. They eventually fall off and leave a prominent annular scar on the node.

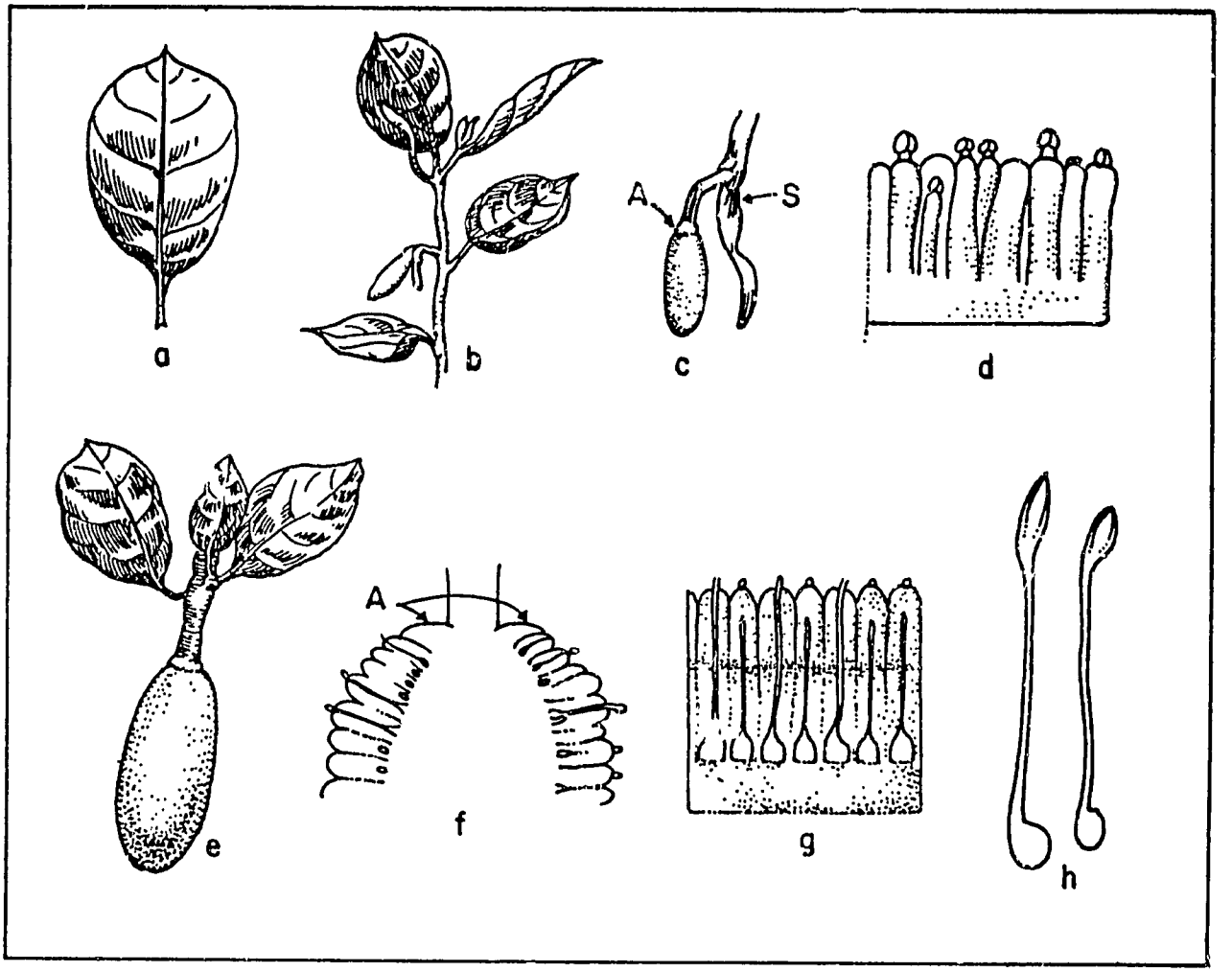

Figure 3. The jackfruit leaf and inflorescence: (a) leaf with tapered cuneate or pointed base; (b) terminal shoot with male inflorescence; (c) male inflorescence with annulus (A) and stipules (S) shown; (d) part of male inflorescence with stamens and anthers; (e) footstalk with female inflorescence; (f) longitudinal section of basal part of female inflorescence showing annulus (A); (g) part of female inflorescence and the individual flowers; (h) spatulate style.

5.4. Fruit

The fruit of *A. heterophyllus* is technically termed 'syncarp,' a type of multiple fruit consisting of several achenes (Corner 1938; Purseglove 1968; Soepadmo 1991). Each achene is indehiscent and has only one seed, which is separable from the ovary walls. The fruits are cauliflorous, that is, borne on the main trunk and old branches, as in Figure 4a.

Depending on the variety or strain, the fruit may measure 20-100 cm in length, 15-50 cm in width and 4.5-50 kg in weight (Angeles 1983; Bailey 1942; Brown 1941; Campbell 1984; Chandler 1958; Corner 1938; Morton 1965, 1987; Popenoe 1974; Purseglove 1968; Tarroza 1988; Wester 1921). Its shape may be oval, oblong, oblong ellipsoid (ellipse longitudinal section and circular cross-section), or pyriform (pear-shaped). The fruit color is pale- or dark-green at the immature stage; at the mature or ripe stage it becomes greenish-yellow, yellow, or brownish The fruit has a green stalk or peduncle 2-10 cm long and 1-3.5 thick. It is covered with a rubbery rind (Figure 4b) and spines that are hard, pyramidal, and either pointed or blunt. The spine is formed from the tipmost part of the perianth, which is the stigmatic protrusion. Spine length varies from 1.5-10 cm, with about 3-12 spines per cm^2 surface area. The rind is formed from the hardening of the distal tip of the tubular perianth.

Inside the fruit are the fruitlets, or true fruit. These are sometimes called bulbs, mericarps, pods, or pips (Angeles 1983; Bailey 1942; Corner 1938; Morton 1965, 1987; Thomas 1980). As shown in Figure 4b, they are massed among narrow ribbons of thin, tough, undeveloped perianths which are also known as perigones, white pulp, or rags. The white pulp is firmly attached to the core. The core or receptacle is pithy and 4.2-10.5 cm thick.

Each fruitlet is 4-11 cm long, 2-4 cm wide, and weighs 6-53 g (Angeles 1983; De Leon 1987; Sampilo 1983; Tarroza 1988). It is composed of the fleshy aril and the seed (Figure 4c). The aril, which is the part that is commonly consumed fresh or processed, is sometimes referred to as pulp, fleshy perianth, pericarp, flesh, or carpel. It can be waxy, firm, or soft. Its color ranges from yellow, golden yellow, to yellow orange. The aril is sweet, very aromatic, about 2-6.5 cm long, 0.1-0.7 mm thick, and 5-42 g in weight (Angeles 1983; Brown 1941; BPI 1991; Campbell 1984; Corner 1938; Liu 1987; Tarroza 1988; Wester 1921).

A fully developed fruit can contain more than 500 seeds (Tarroza 1988). The seed is firm and waxy, and can be oval, oblong, or oblong ellipsoid in shape (Corner 1938; Purseglove 1968; Tarroza 1988). In general, it is flattened in a plane parallel with the sagittal (that is, the longitudinal plane through the hilum)(Corner 1938). Seed size varies from 2-4.5 cm in length, 1-3.7 cm in width, and 2.5-14 g in weight (Angeles 1983; Corner 1938; Purseglove 1968; Sonwalkar 1951; Tarroza 1988). The testa is pallid white (Corner 1938). It is rather thick, tough, parchment-like and crinkly when dry. The inner

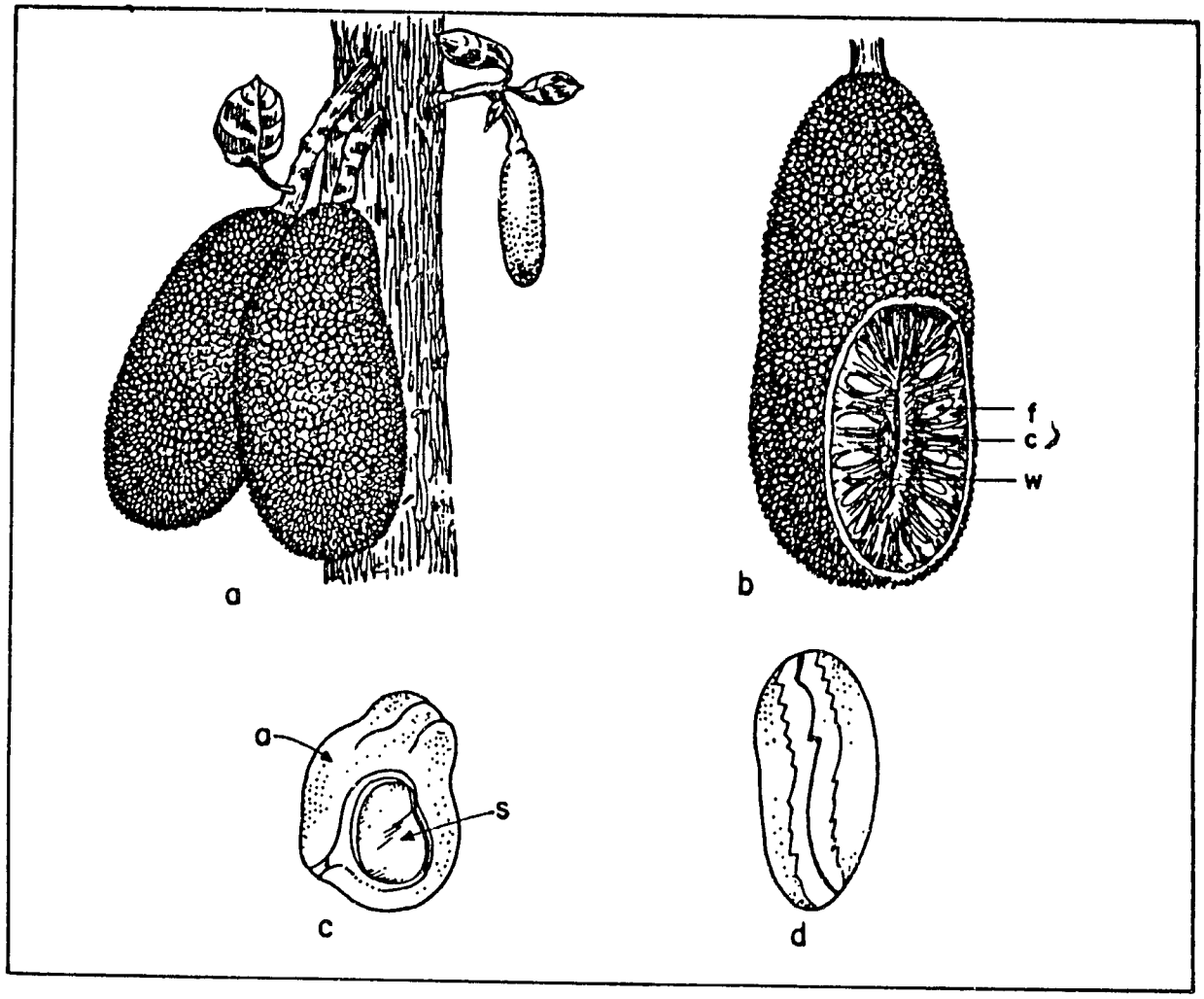

Figure 4. The fruit of *A. heterophyllus*: (a) cauliflorous fruiting habit; (b) fruit showing interior parts (f = fruitlet, w = white pulp and c = core); (c) fruitlet showing aril (a) and seed (s); (d) seed with partially removed seedcoat to show the two unequal cotyledons.

seedcoat is a thin, brownish membrane. The seed is thickened at the hilum, which is situated with the micropyle in the distal third or near the radicular end of the seed. The fleshy cotyledons are very unequal, with one cotyledon only about one-third to one-half the size of the other cotyledon. The endosperm, if present, is very small. The embryo has a superficial radicle (the basal lobe of the smaller cotyledon being undeveloped). The proportion of the different components of the fruit varies with variety or strain, and with growth condition. The edible portion (aril), for instance, may constitute 17-58% of the total fruit weight (Soepadmo 1991; Tarroza 1988). In general, the fruit consists of: 27% aril, 15% seeds, 28% peel, 20% white pulp or rags, and 10% core (De Leon 1987).

5.5. Morphological Differences Between Jackfruit and *Artocarpus integer*

Artocarpus heterophyllus and *A. integer* (Thunb.) Merr., or chempedak, are closely related species. They share common characteristics of tree size, canopy architecture, leaf arrangement and structure, site of inflorescence production, and some flower and fruit structural traits (Corner 1938). In early botanical works, *A. heterophyllus* is often confused with *A. integer*, and in the Philippines, the chempedak (locally known as *lemasa*) is commonly mistaken as a variety or strain of jackfruit (BPI 1991). However, more than a dozen morphological features distinguish the two species from each other (Table 3).

Table 3. Morphological differences between *Artocarpus heterophyllus* and *A. integer* (chempedak).

Morphological Feature	*Artocarpus heterophyllus* Lam.	*Artocarpus integer* (Thunb.) Merr.
Shape of the base of the lamina or leaf blade	tapered cuneate and decurrent (lamina prolonged on the petiole)	cuneate (wedge-shaped) and not decurrent
Leaf color	dark shiny green	dull green or yellowish
Relative number of long, stiff hairs on leaves and young branches	fewer	more
Size of male inflorescence	larger spike with stout peduncle	smaller spike with slender peduncle
Color of male inflorescence	dark green	pale green to yellowish
Annulus at the base of the inflorescence	present	absent but with minute furrow at the base
Shape of the style	spatulate or ligulate, slightly curved at the apex	filiform (thread-shaped) and often coiled apex
Fruit size	generally bigger and elongated	generally smaller and roundish
Relative amount of fruit latex	more	less
Relative rind thickness	thinner	thicker
Adherence of the rind and core or receptacle of the ripe syncarp	rind and core firmly attached to the fruitlets	rind and core easily separable from the fruitlets
Structure of the fruitlet	oblong, cartilaginous thick aril, with subgelatinous pellicle or jacket around the seed, aril thickened at its base to form a stout stalk	short and dumpy, easily squashed thinner aril, no jacket around the seed, aril base not thickened to form a stalk
Aril texture and flavor	less juicy; sweet taste like sugared banana	juicier; sweet taste of durian and mango, more aromatic
Size and attachment of the style of the fruitlet	string-like persistent style attached from the distal third of the aril	thread-like style attached from the proximal third of the aril
Shape and attachment of the seed	mango-shaped, distinctly flattened in a plane parallel to the sagittal; hilum and micropyle in the distal third	plump, scarcely flattened; hilum and micropyle in the proximal third
Structure of the testa	pallid white, thick, tough, parchment-like testa thickened at the hilum; inner seed-coat as thin brownish membrane	very thin, brownish membranous testa; inner seedcoat indistinguishable
Dissimilarity of the cotyledons	very unequal cotyledons; one is 1/3 - 1/2 the length of the other	less unequal cotyledons; one is 2/3 - 3/4 the length of the other
Position of the radicle cotyledons	superficial radicle (basal lobe of the cotyledon undeveloped)	immersed radicle (both having basal lobes)

Sources: Baltazar 1984; Corner 1938; Mendiola 1940.

6. Developmental Patterns

6.1. Tree Growth, Flowering and Fruiting Patterns

Jackfruit exhibits fairly rapid growth, attaining a height of 3 m and a canopy diameter of 2 m two years after planting, under Philippine conditions (Angeles 1983). In five years, tree height and canopy diameter can reach about 7 m and 4 m, respectively, and trunk girth can be 50 cm. As trees mature and age, growth increment decreases, particularly for height, which decreased to about 36-60 cm per year (Soepadmo 1991). A 20-year-old tree may reach 17.5 m height (Morton 1987).

Seedling trees start flowering and fruiting two to eight years after planting (Angeles 1983; Dutta 1956; Purseglove 1968; Richards 1950; Soepadmo 1991). Clonally propagated trees, however, produce flowers and fruits after only two to four years (usually one to two years earlier than seedling trees). Flower and fruit loads are initially low. When a two-year-old tree starts to flower and fruit, it can produce up to about 25 flowers and 3 fruits (Angeles 1983).

Flower and fruit production increases with increasing tree size and age. A five-year old tree can bear as many as 840 inflorescences. This can increase to 1,500 inflorescences in six-year old trees. The number of fruits that may develop, however, remains relatively low: about 15-18 fruits for both five- and six-year old trees. This is largely due to the low production of female spikes, amounting to only about 0.6-5% of the total number of inflorescences produced. Shaker and Singh (1965) found that young trees bear more male than female flowers at a ratio of 4:1. Female flower production increases in older trees. A male:female flower ratio of about 2:1 can be attained, with the number of fruits that set and develop reaching 250 per tree per year (Purseglove 1968). As trees continue to age, fruit productivity declines (Morton 1987).

In suitable environments, jackfruit bears flowers and fruits throughout the year. Usually, however, there is a major harvest season. In Malaysia, this period is from April to August or from September to December; in Thailand, January to May; and in India, the summer months of January to May (Soepadmo 1991).

In the Philippines, flowers and fruits are produced year-round in areas with evenly distributed rainfall (Hensleigh and Holaway 1988). In regions with distinct dry and wet seasons, flower production occurs during the wet or rainy months (Angeles 1983; Querijero 1988). Angeles (1983) found that flower production starts in August and ends in March (Figure 5). Very few flowers are produced in April to July. Flowering peaks in September, two months after the onset of the rainy season, and again in January, the start of the dry season. Fruit production coincides with flowering months (Angeles 1983; Laserna 1988).

In young trees, fruits are usually borne on branches. As trees age, fruit production shifts to the trunk, and on roots in old trees (Morton 1965, 1987). Fruits that develop underground raise small mounds which they eventually burst, thus exposing themselves (Corner 1938; Morton 1987). Fruits produced this way are exceptionally large and flavorful. Morton (1987) reports that jackfruit trees raised from seedlings with a stem bent and coiled beneath the soil produce large and fine-quality fruits on the spiral underground five years after. However, this phenomenon has not yet been scientifically examined.

6.2. Floral Development and Induction

Inflorescence development

The male inflorescence or spike, together with the bud and the leaf primordia, are sheathed with stipules (Figure 3c)(Angeles 1983). As the bud grows larger, the stipules gradually open longitudinally and expose the bud, a new leaf, and the spike. At emergence, the male spike is about 3.5 cm long and 1.5 cm wide. It then increases in size by about 0.5 cm in length and 0.2 in width every week before falling off.

A spike is densely covered with minute flowers. Each flower has perianth segments that are free although tightly fused. These perianth segments are shorter than those of the female spikes and have no interfloral bracts (Moncur 1985). Prior to anthesis, the spike's surface appears armored with spine-like structures and scales that split as the stamen exserts. At anthesis (about two to three weeks after emergence), the stamen, consisting of four anthers, splits to expose the mass of sticky, spherical, yellow pollen grains (Moncur 1985; Soepadmo 1991). The stamen also emits a sweet scent (Purseglove 1968).

Spikes generally fall off two to four weeks after emergence (Angeles 1983; Querijero 1988). Abscission starts with a change in spike color from green to yellow, then to brownish yellow, and finally, to brown or black. Browning or blackening of the spike is due to fungal infection. A few days afterward the spikes fall off. Sometimes they remain on the tree longer before falling to the ground as a black mass.

In early development, the female spike has characteristics similar to those of the male spike. Later, it forms a thicker peduncle and a larger annular disc at the base (Moncur 1985). Soon after emergence from the stipules, the female spike develops apical swellings, which are the primordia of individual flowers. Scattered larger swellings, which are the primordia of interfloral bracts, also appear. Initiation of the primordia increases rapidly and results in crowding. The tubular calyx initially grows from the base, then extends up to enclose the developing flower parts. The interfloral bracts enlarge, develop distal apices, and elongate above the developing flowers. By the time the stigma protrudes through the spiny perianth tip, the number of primordia is considerably reduced. Prior to anthesis, the perianth segments remain free though tightly

packed. Later, they enlarge in the center and fuse but remain free at the lower and upper regions of the perianth segments. At anthesis, the stigmatic surface composed of papillae becomes sticky. This indicates receptivity, and may occur one to two weeks after exsertion and last for two weeks (Laserna 1988, Moncur 1985). A few interfloral bracts are shed soon after anthesis.

Abscission of female flowers is similar in behavior to that of male flowers (Angeles 1983). It starts on the first week after spike emergence and continues up to the eighteenth week. During this time the spikes develop into fruits. Heavy drop occurs during the first four weeks and on the seventh week from spike emergence (Hidalgo 1984; Laserna 1988). The major cause of abscission is a physiological disorder characterized by browning and eventual dry rotting of the spike/fruit without mechanical or insect damage (Laserna 1988). This has been said to be a natural physiological thinning mechanism of the tree, and is evidenced by the findings that greater abscission of the fruits occurs with greater fruit set.

Site of inflorescence production

Spikes develop on leaf axils of terminal shoots or on short, stout specialized laterals, termed *footstalks* (Angeles 1983; Manalo 1986; Moncur 1985). The terminal shoots produce only male spikes. Each shoot measures about 0.4 cm in diameter and has seven to eight leaves clustered at its end (Figure 3b). One male inflorescence appears on one terminal shoot per flowering season (Manalo 1986).

Footstalks are of two types. One type is called the *non-bearing* footstalk, as it produces only male spikes (Manalo 1986). The other type is the *bearing* footstalk, which produces female spikes or both female and male spikes. Non-bearing footstalks emerge early in the season on branches or stems. They appear as yellow-green, bud-like structures but later develop into leafy, twig-like laterals. These footstalks are thicker than the terminal shoots, about 0.72 cm in diameter. They also contain fewer leaves and produce more male spikes (about three per footstalk per flowering season). Male flowers start to emerge in the fourth week after footstalk emergence.

Bearing footstalks, on the other hand, originate from the trunk and main branches. They are larger, with a diameter of about 1.74 cm, but have fewer leaves than the non-bearing type. Each bearing footstalk produces one or two female spikes. At emergence, both bearing and non-bearing footstalks can be confused with watersprouts. As they increase in length to 38-54 cm, they appear thin and twig-like. They initially produce six or seven leaves but later bear inflorescences. Male spikes are produced first, followed by female spikes (Angeles 1983; Moncur 1985; Thomas 1980). During the peak flowering season, bearing footstalks can produce male and female spikes simultaneously (Hidalgo 1984). As the female spike sets into fruit, the footstalk grows thicker. These fruiting branches may terminate its growth in length. Sometimes, they branch to bear two or more inflorescences.

Floral induction

Flowering in jackfruit can be induced by applying potassium nitrate (1%) by trunk injection or spray on a girdled stem (Angeles 1983). In spraying a girdled stem, the footstalks that developed eventually die without producing inflorescences. In trunk-injected trees, all footstalks produce male spikes, with a few bearing female spikes afterward. This high degree of maleness is not reduced by spraying footstalks with the same chemical.

Foliar application of potassium nitrate at 0.5 g/L was found to be an ineffective floral induction method (Angeles 1983), as were foliar spraying of: 0.5-2 g/L calcium nitrate, silver nitrate, sodium nitrate or ammonium nitrate; 1-4 g/L daminozide (Alar 85) or chlormequat (Cycocel); 0.25-1.0 g/L ethylpropylphosphonate or chlorofuranol; 0.125-0.5 ml/L ethephon, 0.125-0.5 g/L ascorbic acid; 0.05-0.2 g/L benzylaminopurine; 2.5-10 g/L maleic hydrazide; 20-80 g/L urea; and 45-180 g/L ammonium sulfate. Although these chemicals have been found to induce flowering in other plants, in *A. heterophyllus* they only promoted vegetative growth, manifested by the emergence of new leaves on terminal shoots.

6.3. Pollination and Fruit Set

Pollination is essential for fruit setting in jackfruit. If female inflorescences are bagged, fruit formation does not take place (Purseglove 1968). Jackfruit pollination is reportedly effected by wind (anemophily) (Morton 1987) and insects (entemophily) (Purseglove 1968; Soepadmo 1991).

Jackfruit's production of more male than female flowers is a characteristic typical of anemophilous species. However, pollens in the male spike are not shed readily by light physical disturbance, as would be expected of a wind-pollinated plant (Moncur 1985). And while several pollinating insects are attracted to the sweet scent of the male inflorescence, very few visit the female flowers. These facts make pollination solely by either wind or insects less likely.

An alternative pollination mechanism may involve the interplay of wind and insect activity (Moncur 1985). Insect activity in the male flowers is supposed to promote the release of pollen grains from the protruding anthers. The pollens may then be eventually transmitted to the female flowers by wind or gravity. This behavior is possibly an evolutionary shift between insect and wind pollination.

After the flowers have been pollinated, fertilization occurs and fruits are set. Wilting and drying stigmas are the best indicators of fruit set (Laserna 1988).

6.4. Fruit Development

Fruit growth

The fertilized female spike develops into fruit. As seen in Figure 6, growth of the fruit exhibits more or less linear increase in length and width and exponential increase in weight (Hidalgo 1984). The fruit gains weight slowly during the first eight weeks of growth, followed by a rapid increase. The sharp increase in fruit weight has been found to coincide with the rapid development of the fruitlets (Angeles 1983; Hidalgo 1984).

The fruitlets are the fertilized flowers in a spike. The unfertilized flowers develop into strap- or string-like structures, earlier called *perigones, white pulp*, or *rags*. These occupy the spaces between fruitlets. Uneven pollination and fertilization of the flowers in a spike causes fruit deformation or indentation (Dutta 1956).

Initially, fruitlets are hardly discernible and appear as tape-like structures (Figure 7a)(Corner 1938). A week later, the ovary enlarges (Figure 7b), and as it grows, the embryo becomes distinct. It is supplied by a stout vascular bundle (Figure 7c). In some jackfruit varieties or strains, the fruitlet becomes highly visible and differentiated only in the eighth week after flower emergence (Hidalgo 1984; Laserna 1988). They fully develop eight weeks later (Figure 7d).

The arils of the fruitlets increase proportionately in thickness and length with fruit age (Hidalgo 1984). Fruits that develop thicker arils have heavier arils, as well as heavier and thicker fruitlets. Initially, spines are closely spaced and distinctly pointed or blunt (Figure 7c). With the development and enlargement of the fruitlets, spines become stretched and appear somewhat flattened and widely spaced (Figure 7d). Spines located at the distal end (tip part) of the fruit are much wider in base diameter and shorter in length than those at other fruit parts. From spike emergence to maturity, rind thickness increases from about 0.4 cm to 1-2 cm (Angeles 1983; Hidalgo 1984).

Similarly, the pithy core or receptacle enlarges from about 1.89 cm to 7.5 cm in width at maturity. However, at maturity the core constitutes only about 16% of the total fruit width, decreasing from as high as 55% at emergence. It also contains a latex composed of a white sticky fluid and a brown watery liquid. The amount of latex increases as the fruit matures but decreases as the fruit ripens. As the fruit grows larger and heavier, it becomes pendulous (Moncur 1985).

Fruit maturation

The fruit can mature in 79-163 days (Angeles 1983; Laserna 1988; Thomas 1980) or as long as 6-8 months (Morton 1965, 1987; Rodrigo 1968) after spike emergence. This great variation in fruit maturity period may be due to the inherent differences in

fruit development among varieties and strains, and to differences in growing conditions. When overmature, the fruit may develop cracks (Hidalgo 1984).

Fruit maturation has various physical manifestations. Reported indices for determining fruit maturity include (Angeles 1983; Hidalgo 1984; Yap 1972):

- o rind changes color from green to yellow or greenish yellow
- o spines become well-developed and well-spread and yield to moderate pressure
- o last leaf on the footstalk turns yellow
- o fruit produces a dull hollow sound when tapped by a finger

Among these indicators of fruit maturity, the last is claimed to be the most reliable (Angeles 1983; Hidalgo 1984). It is exhibited by fruits maturing in 79-163 d (Angeles 1983) as well as by fruits of some strains harvested 18-19 weeks after spike emergence (Hidalgo 1984). These fruits normally ripen after harvest. In Hidalgo's study, fruits harvested 16-17 weeks after emergence appeared mature due to their well-spread and well-developed spines, but did not produce a dull hollow sound when tapped. They also developed immature characteristics when ripe, including reduced aril sweetness and aroma.

The other indicators of fruit maturation, particularly the yellowing of the last leaf of the footstalk, appear to be inadequate as sole indices. Angeles (1983) observed that some footstalks with no remaining leaves still had developing fruit. Likewise, the change in rind color as a basis for determining fruit maturity needs to be re-examined. Some strains or varieties turn light green, greenish-yellow, yellow, yellowish-brown or rusty brown at the mature but unripe stage.

Fruit ripening

The emission of a sweet and strong aroma best indicates that a fruit is ripe (Hidalgo 1984). During ripening, the fruit exhibits a typical climacteric pattern of respiration (Selvaraj and Pal 1989). This is characterized by an initially low rate of carbon dioxide production or oxygen uptake (pre-climacteric), followed by a sudden upsurge (climacteric rise), levelling off (climacteric peak), and finally a decline (post-climacteric). The same pattern may also apply for ethylene production. In fruits from a jackfruit variety belonging to the Varikha group (firm and fleshy pericarp), the pre-climacteric rate of respiration of the fruitlets at harvest maturity (fruits with well-separated spines and brownish yellow skin) is about 160 mg CO_2/kg-h. The respiratory rate increases to 225 mg CO_2/kg-h two days after harvest, when the fruits are at the half-ripe stage. It peaks a day later at about 250 mg CO_2/kg-h, and then declines to about 170 mg CO_2/kg-h in three-quarter ripe fruits (four days after harvest).

The rate further decreases to 80 mg CO_2/kg-h in full, "eating" ripe fruits (eight days after harvest).

Most of the physico-chemical changes associated with ripening occur during the climacteric rise and are recognizable at the three-quarter to fully ripe stages. These include:

- a dramatic increase in **softening** (little softening occurred from harvest maturity to half-ripe stage)
- a twofold increase in **aril color** due to increased carotenoid content
- an increase in **total lipids, total fatty acids, unsaponifiables and total sterols**
- an increase in **sugar contents** (the major sugar is sucrose, followed by fructose and glucose)
- an increase in **citric and malic acids** (the major non-volatile organic acids) at the three-quarter ripe stage, followed by a decrease at the fully ripe stage
- a decrease but with no qualitative changes in **total soluble amino acids** (these amino acids include asparagine, aspartic acid, glutamine, glutamic acid, glycine, alpha-aminobutyric acid, phenylalamine and proline)
- a decrease in **tannin content**
- a decrease in **dry matter, alcohol insoluble solids and starch contents**
- a decrease in **free fatty acids**

The decrease during ripening in free fatty acid content, particularly the unsaturated ones (palmitoleic, oleic, linoleic, and linolenic acids), indicates their role as a potential precursor of other metabolites, including aroma compounds.

The ripe jackfruit aroma has been chemically resolved into 38 components. Fruit aroma is absent at harvest maturity, slight at half-ripe stage, and increases considerably at three-quarter and fully-ripe stages. From harvest up to the ripe stage, fruits may lose 15-20% of their weight (Angeles 1983).

The physiological state of the fruit at harvest has a profound effect on fruit quality at the ripe stage, as demonstrated by Hidalgo's study (1984) of the ripening characteristics of fruits harvested 16-19 weeks after spike emergence. Fruits of different ages between 16 to 19 weeks were all unripe and already had well-spread and well-developed spines. But only the 18- and 19-week old fruits produced a dull hollow sound when tapped. The 16- and 17-week old fruits ripened in 7-9 days after harvest. However, they developed immature characteristics, including pale yellow aril, plenty of latex when cut, low total soluble solid (TSS) content of about 16 degrees Brix (°B), and slight aroma. In contrast, the 18- and 19-week old fruits ripened earlier (about 5-6 days after harvest), possessed yellow to yellow-orange arils, produced practically no latex, contained higher TSS (about 22°B and 25°B, respectively), and emitted the typical sweet aroma. From these findings, we can deduce that the jackfruit trees used in this study

required about 18 weeks for the fruits to reach physiological maturity. We also see that maximum size development (shown by the full development of the spines in 16- and 17-week old fruits) is not a guarantee that the fruit is physiologically mature.

6.5. Seed Development and Germination

As with other seeds of higher plants, jackfruit seed originates from a meristematic tissue of the ovary wall, called *ovule primordia* (Copeland 1976). Its development accompanies the development of the ovary, which begins with the successful pollination of the flower. Approximately one month after pollination, a seed-like structure coated with a white, loose covering starts to fill the ovary (Angeles 1983). Its subsequent growth in weight, length, and thickness follows a linear pattern up to maturity. The seed and testa may become very distinct two months after pollination. At this time, the seed measures about 2.2 cm long, 1.5 cm wide, and 2 g in weight. The testa is still very thin and weighs about 0.25 g. The seed may become fully developed in the fourth month after pollination. It grows to about 3 cm in length, 1.5 cm in width, and 4 g in weight; the testa measures 0.25 mm thick and 1.2 g.

Jackfruit seeds are recalcitrant in character (IPB 1990b). They are remarkably short-lived and lose viability after a few days or weeks in the open air (Purseglove 1968; Richards 1950). Hensleigh and Holaway (1988) report that keeping them at near freezing temperature can preserve viability for 5-12 months. At room temperature, seeds can be stored for one month without much loss in germination capacity (Sonwalkar 1951). Stored seeds, however, have reduced vigor and take longer to germinate than fresh seeds (Familiar 1981; Sonwalkar 1951).

Seeds germinate in 9-60 days depending on the condition of the seeds and the treatment applied (Concepcion 1990; Padolina 1931; Sonwalkar 1951). Large, heavy seeds have a longer viability period, higher germination potential, shorter germination time, and produce more vigorous seedlings than small, light seeds. Seeds of the same weight may still differ in germination period due to variations in the internal development of the embryo. Keeping the aril intact drastically reduces the seed's ability to germinate. In a comparative study, seeds with arils showed only 20% germination, whereas more than 80% of those without arils germinated. Soaking seeds in water or gibberellic acid solution reportedly promotes germination (Shanmugavelu 1970; Sonwalkar 1951).

Germination of *A. heterophyllus* can be either sub-epigeal (Corner 1938) or hypogeal (Soepadmo 1991). In sub-epigeal germination, the cotyledons, with the elongation of the short hypocotyl, are raised from beneath the soil to the soil line. They then separate and spread at the ground level, allowing the long epicotyl (plumule) to emerge. This behavior is a possible variation of the epigeal type of germination wherein the cotyledons are raised above the ground.

On the other hand, jackfruit seeds that germinate hypogeally presumably exhibit underground separation of cotyledons. This permits underground growth and elongation of the epicotyl. Eventually, the epicotyl emerges from the soil and bears several scale-leaves before the first pair of true leaves is formed. In a few cases, polyembryony occurs and is characterized by the emergence of two or more seedlings from different points of a seed. This phenomenon can be induced by presoaking the seeds in gibberellic acid solution at a relatively high concentration, such as 500 ppm (Shanmugavelu 1970). Once emerged, jackfruit seedlings grow by as much as 2.5 cm per month (Sonwalkar 1951).

7. Varieties and Varietal Improvement

As it is open-pollinated (Coronel 1983) and highly cross-pollinated (Purseglove 1968; Soepadmo 1991), *A. heterophyllus* shows great variability in many characteristics, such as tree growth habit, canopy architecture, leaf shape, and fruit quality. The current large number of varieties have apparently evolved through natural crossing. These varieties are selected by professional tree breeders principally based on fruit characteristics. Varieties or hybrids of jackfruit selected for their timber characteristics have not been reported.

When classified based on fruit quality, jackfruit varieties form two broad types: the firm-fleshed type and the soft-fleshed type (Corner 1938; Dutta 1956; Morton 1965, 1987; Popenoe 1974; Purseglove 1968). The firm-fleshed varieties are characterized by thick, firm, crisp, and more flavorful arils. The ripe fruits produce a dull sound when flicked with fingers.

The soft-fleshed varieties are characterized by arils that are thin, fibrous, soft, mushy, and sweet to insipid. The ripe fruits have a soft rind through which fingers may be thrust. The firm-fleshed and soft-fleshed varieties are known by various names in different countries (Table 4). The same two forms are known to exist in Brazil (Popenoe 1974), while in the West Indies, soft-fleshed varieties predominate (Morton 1965, 1987). Moreover, Corner (1938) argues that the *Vela* and *Gerrisal* (Sri Lankan and Indian terms, respectively, for the soft-fleshed type) are a variety of *A. integer*. They

Table 4. Names of firm- and soft-fleshed varieties of *A. heterophyllus*, by country.

Country	Firm-fleshed varieties	Soft-fleshed varieties
India	Karcha, Khujja, Koozha puzham, Varaka, Kapa, Kapiya, Varikha, Barica	Ghula, Ghila, Koozha chakka, Tsjakapa, Barka, Berka, Koolai, Gerrisal
Indonesia	Nangka salak	Nangka bubur
Malaysia	Nangka bilulang	Nangka bubur
Myanmar (Burma)	Kala	Talaing
Philippines	Tinumbaga	Sinaba
Sri Lanka	Waraka, Varaka	Vela
Thailand	Kha-nun nang	Kha-nun lamoud

Sources: Corner 1938; Dutta 1956; Morton 1965, 1987; Popenoe 1974; Soepadmo 1991.

resemble some forms of the wild *A. integer* in Malaysia. There is however no available literature disputing this claim. Nevertheless, it is worth mentioning that the jackfruit and the chempedak can naturally hybridize (Mendiola 1940). A chempedak-jackfruit hybrid, 'Ch/Na,' has been selected and cloned in Malaysia (Soepadmo 1991).

Among both firm- and soft-fleshed types, many cultivars have been identified, mainly as a result of selection. In the Philippines, many varietal collections have been characterized based on traits of the tree or its parts (Angeles 1983; BPI 1990; Estioko 1990; IPB 1990a, 1990b; Sampilo 1983; Tarroza 1988). So far, only four varieties have been identified as having outstanding characteristics and popularized. These are the J-01, J-02, TVC, and Torres varieties (Table 5).

In Malaysia, about 30 cultivars have been registered (Soepadmo 1991). Examples are the 'Na 2,' 'Na 29,' and 'Na 31' varieties.

The Na 2 variety bears large, roundish fruits that always split at maturity. The fruits have yellow-green, sweet to slightly acid, coarse- and hard-textured arils which emit little odor and have poor storage quality.

Table 5. Outstanding Philippine varieties of jackfruit for fruit production.

Variety	Fruit		Arils	Comments
	Length (cm)	Weight (kg)		
J-01	30-40	10-20	Thick, crisp, deep yellow, sweet (23% TSS), excellent eating quality and sweet aroma	Fruits are oblong, fruitlets are ovate; rinds are thin, soft, spineless.
J-02	50-60	40-50	Pale to lemon yellow, crisp, sweet (24% TSS) and of excellent eating quality and strong aroma	Approved for cultivation by the Philippine Seedboard Authority; oblong fruits and fruitlets; thick, spiny rinds.
TVC	50-60	20-30	Golden yellow, of good eating quality, and strong aroma	Fruits and fruitlets are oblong.
Torres	about 38	3.5	Golden yellow, crisp, and very sweet (47% TSS)	The flesh may comprise about 47% of total fruit weight; fruits up to 15 cm wide; responds well to cleft grafting.

Sources: BPI 1990; Concepcion 1990; SAVI 1983.

The **Na 29** variety produces medium to large fruits containing little latex and thick, yellow, sweet arils. This variety is good for fresh consumption.

The **Na 31** variety bears small, elongated and long-stalked fruits that contain much latex. The arils are yellow, sweet, fine- textured and of strong aroma. This variety is suitable for canning.

In Sri Lanka, 'Peniwaraka' and 'Kuruwaraka' varieties have long been identified (Morton 1965, 1987), and clearly belong to the firm-fleshed type.

The **Peniwaraka** or honey jak has a sweet pulp. It is claimed to be the best of all varieties.

The **Kuruwaraka** variety bears small, rounded fruits.

The **Singapore jak** or 'Ceylon jak' is another firm-fleshed variety but seedling trees may produce soft-fleshed fruits since they do not always come true to type (Richards 1950). It is an early bearer, producing fruits after 18 months under favorable lowland conditions, two years or more at higher elevations. The fruits are medium-sized and have small, fibrous, and very sweet arils.

The **Johore jack** is another variety of jackfruit (Popenoe 1974), although Richards (1950) claims it belongs to *A. integer* (Thunb.) Merr. This variety possesses characteristics similar to that of *A. integer*, including the presence of stiff brown hairs in the young shoots and the small size and ovoid shape of the fruits which, when ripe, emit an overpowering odor like *Durio zibethinus* (durian). The tree does not grow large, and its timber has very little commercial value.

In India, several excellent cultivars have been selected including **Safeda, Khaja, Bhusila, Bhadaiyan, Handia, and T Nagar jack** (Morton 1987). Hybridization has also been done using the Singapore jack as the female parent and a local selection bearing large fruits with large, superior quality arils, **Velipala**, as the male parent. In 25 years of testing, one hybrid, unnamed as of 1987, has been rated as outstanding for precocity, fruit size, off-season as well as main-season production, and yield excelling its parents.

It has been contended that since the different jackfruit varieties are propagated by seed, they should instead be called "races" (Popenoe 1974). Presumably this suggestion excludes those varieties selected or purposively developed and perpetuated vegetatively.

8. Production

8.1. Ecological Considerations

A. heterophyllus can thrive under varied climates and on a variety of soil types. It grows in tropical, near-tropical and subtropical regions (Liu 1987; Morton 1987) and from low to medium elevations of up to 1.600 m (Baltazar 1984; BPI 1991; Morton 1987; Purseglove 1968; Wester 1921; Yap 1972). The species' range extends into much drier and cooler climates than that of other *Artocarpus* species (Chandler 1958; Popenoe 1974; Purseglove 1968). It can also withstand lower temperatures and frost. It bears fruits at latitudes of up to 30°N and S, with good crops at 25°N and S of the equator (Soepadmo 1991). Jackfruit grows even in the poorest soils, including gravelly or lateritic soils, shallow limestone, shallow light soils, and sandy or stony soils (Morton 1965, 1987). Growth, however, can be slow and the tree may not be tall, robust, or vigorous. The tree exhibits moderate tolerance to saline soils and wind, but is poorly tolerant of drought and flooding (Soepadmo 1991).

For optimum production, *A. heterophyllus* requires warm, humid climates and an evenly distributed annual rainfall of at least 1,500 mm (Baltazar 1984; Concepcion 1990; Department of Agriculture 1991; Morton 1987; Popenoe 1974; Purseglove 1968; Richards 1950; Yap 1972). It thrives in deep, alluvial, sandy-loam or clay-loam soil of medium fertility, good drainage, and a pH of 5.0-7.5. It grows best at altitudes of up to 1,000 m. Trees at higher elevations bear flowers and fruits late (Hidalgo 1984; Morton 1987; Richards 1950), and produce fruits of inferior quality.

8.2. Propagation and Nursery Management

Sexual propagation

Jackfruit is commonly grown from seed (Baltazar 1984; Hensleigh and Holaway 1988; Popenoe 1974; Purseglove 1968; Soepadmo 1991). This propagation method is considered the cheapest, easiest, and most convenient. Seeds should be obtained from outstanding mother trees. Large seeds possess higher germination potential and can produce more vigorous seedlings (Sonwalkar 1951). After extraction, seeds should be thoroughly washed to remove their slimy coating (Concepcion 1990). Seeds must be planted fresh since they do not retain viability for a long period of time. Stored seeds may take longer to germinate, or may not germinate at all.

If short-term storage is unavoidable, seeds should not be allowed to dry out. This can be achieved by keeping them in coir dust or sand (Richards 1950) or in air-tight polyethylene containers (Soepadmo 1991).

Seeds may be sown directly in the field or in nurseries (Morton 1987; Purseglove 1968). In the latter case, seeds are planted in flats, seedbeds, or containers. To hasten

germination, they should be laid flat with their embryo (hilum part) facing down (Sonwalkar 1951). Seedbed-raised seedlings should be potted at the four-leaf stage, since older, larger seedlings are hard to transplant without injuring the long, fragile tap root.

Asexual propagation

Seedling progenies are quite variable due to the fact that jackfruit is open-pollinated and highly cross-pollinated. To produce true-to-type plants and perpetuate selected or outstanding varieties, asexual or vegetative propagation is essential. Furthermore, vegetatively propagated jackfruit trees bear fruits early. Asexual propagation can be done by "air layering," cutting, grafting, or budding, although the results obtained so far are variable. These methods need to be refined and optimized.

Air Layering

In an early air layering trial in the Philippines, young, three- to four-cm-thick stems (distinguished by their green color) were successfully grafted (Fabello 1934). The young stems showed better response than mature or old stems. Callus formation in 23-26 days was followed by root production. The layers produced roots in 92-98 days when pretreated with 5% potassium permanganate for 24 hours, and in 98-111 days in untreated stems.

More recently, however, Angeles (1983) obtained very low success with air layering. The highest rooting success was 45% when air layering was done in July. Only layered watersprouts formed roots in 58 days. Layered terminal shoots failed to root.

In India, air layering has been shown to be 100% successful, when done in the rainy season using one- to two-year-old shoots with brownish stems 1-1.5 cm thick and 50-55 cm long (Jauhari and Mehra 1960; Singh 1955). Younger shoots with a diameter of under one cm showed poor response. A 4- to 6-cm-long girdle is made and applied with 1% indole butyric acid (IBA)(Singh 1955) or combinations of 0.75% IBA and 0.75% indole acetic acid (IAA), or 0.5-0.75% IBA and 0.5-0.75% naphthalene acetic acid (NAA)(Jauhari and Mehra 1960). With 0.025-0.05% NAA, only 60-70% of the layers formed roots (Singh 1951). Application of these auxins induced profuse rooting in 22 days, and improved the survival rate of rooted layers when planted in the field.

Propagation from Cuttings

Propagation by cuttings is not yet promising. Morton (1987) reported rooting of young jackfruit woody stem cuttings under mist. However, when tried in India, apical, semi-hard, or hard-wood cuttings did not root, even when treated with root-promoting auxins (Singh 1955). Poor rooting (less than 10%) of young and mature stem cuttings has also been noted in the Philippines (Angeles 1983). Root cuttings were likewise unsuccessful (Hensleigh and Holaway 1988). Application of NAA or IBA, use of low- or

high-pressure mist propagators, and use of different media all failed to improve the rooting ability of the cuttings (Angeles 1983).

With some strains, however, rooting of cuttings may reach more than 80%. Callus formation first occurred after one month, followed by root formation.

Grafting and Budding

Grafting and budding are the two most promising methods of propagating jackfruit vegetatively. Among grafting methods, approach grafting (inarching) appears to be the most effective (Angeles 1983; Chong 1987; Galang and Elayda 1924; Purseglove 1968). Approach grafting, however, is suitable only for small-scale propagation (Coronel 1983). In the Philippines, approach grafting can result in about 75% graft take on the average, with 100% take when done in April, May, or November (Angeles 1983). Union of stock and scion and separation of inarched plant can be done 42-99 days after the grafting operation. This method has also been reported to be very successful in India (Coronel 1983), where more than 80% graft take has been obtained.

A form of approach grafting, called "suckle-grafting," is used routinely on a large scale in Thailand (Soepadmo 1991). Young potted seedling rootstocks are decapitated, then inserted in twigs of a selected mother tree. The success rate is high and the method can be applied at any time of the year.

In Australia, wedge grafting has been found to give very good results. Scions are grafted onto young vigorous rootstocks in an enclosed, high-humidity chamber (polyethylene covers).

Other grafting methods attempted in the Philippines yield variable results. Cleft, splice, whip, and side grafting methods have yielded only up to about 20% graft take (Angeles 1983). This was not improved by using waxed scions, grafting at different stem heights of the rootstock, using young or mature scions, or draining the latex in both scion and stock by delaying the grafting operation after excision.

Some sources state that 35% grafting success can be obtained using the common cleft method in the month of February, although this contradicts findings that grafting success is greater when done during the rainy season, which usually starts in June or July (Sumagang et al. 1990). A preliminary study at the Bureau of Plant Industry's Mandaue (Cebu) Experiment Station attained grafting success of 30-80% by the cleft method. Scions used were defoliated one to two weeks before the grafting operation to induce bud germination, and small cuts were made at the base of the rootstock to minimize latex accumulation at the point of contact of the scion and stock.

Coronel (1983) reports the use of bud grafting, or "budding," for commercial propagation of jackfruit in Malaysia. The method used there is patch budding. It has

also been proven very successful in India, where a success rate of greater than 90% can be attained from May to July (Teaotia et al. 1963). The average rainfall during these months is sufficient to keep both scion and stock in active growth. In Sri Lanka, jackfruit is bud-grafted by the modified Forkert method using budwoods of the previous season's growth (Richards 1950). Shield budding has been tried in the Philippines, with extremely low success rates (Angeles 1983).

Jackfruit scions can be bud grafted onto rootstocks of other Artocarpus species, such as *A. integer* (Thunb.) Merr., *A. hirsutus* Lam., *A. rigidus* Blume., or *A. altilis* (Park.) Fosb. (Chong 1987; Purseglove 1968; Soepadmo 1991). Rootstocks should be 8-12 months old. In Indonesia, best results have been obtained by budding onto 8-11-month-old *A. integer* rootstocks (Soepadmo 1991). Sumagang et al. (1990) report, though, that grafting a jackfruit variety or strain onto a rootstock of a different strain or variety drastically reduces graft take. Budded or grafted jackfruit trees are generally low branched and may not be suitable for timber production (Hensleigh and Holaway 1988).

Another promising method is micropropagation, or the tissue culture technique. This could be suitable for rapid, large-scale propagation. This technique has been tried successfully with jackfruit in India (Morton 1987) and Bangladesh (Roy 1991).

Nursery management

Seedlings and vegetative propagules (including rooted layers or cuttings and grafted or budded plants) should be raised in containers. They should be arranged in rows in the nursery to minimize crowding and facilitate management. For more rapid growth, propagules may be grown in compost-clay loam soil mixture (Department of Agriculture 1991). Nitrogen fertilizers may also be applied every two to three months with regular watering. Jackfruit propagules thrive best under partial shade of 50-70% full sunlight (Soepadmo 1991).

Seedlings can be transplanted when still young but when leaves are mature (usually less than one-year old or when they are 20-25 cm tall). Grafted or budded plants can be transplanted three to five months after operation, or when flushes in the scion part have matured. Air-layered plants should be transplanted two to three months after the rooted layer is severed from the parent plant (Angeles 1983; Baltazar 1984; Singh 1951; Soepadmo 1991). In general, these propagules should be transplanted before the roots grow outside the container. Disturbance of the root system during transplanting can adversely affect subsequent growth and development of the plant.

8.3. Field Establishment

Land preparation

The type of site preparation depends on the scale of production and the condition of the land. For backyard or small-scale plantings, land preparation consists merely of digging holes large enough to accommodate the ball of soil that goes with the planting material (BPI 1991; Coronel 1983). For a larger-scale planting (such as a plantation or commercial orchard) on a newly opened site, the area should first be cleared, then plowed and harrowed several times until the desired tilth is attained.[1] On sites previously under cultivation, it could be sufficient to clear tall grasses or bushes from the area and then dig holes. On land covered with second-growth forests, the trees should be cut down, stumps removed or burned, and the whole area cleared before digging holes (Coronel 1983; Yap 1972).

Field lay-out, spacing, and holing

A jackfruit plantation or orchard can be established in a square or triangular (hexagonal) pattern at spacings of 7.5-12 m (Baltazar 1984; BPI 1991; Coronel 1983; Purseglove 1968; Richards 1950; Soepadmo 1991). For asexually propagated planting materials, a closer in-row spacing can be used (BPI 1991), resulting in a rectangular planting pattern.

If the trees are to serve as windbreaks, spacing should be much closer, about 5.5 m apart (Richards 1950), with trees set in double rows in alternating order. A closer spacing may also be used for timber production, as this may minimize branching and promote development of straight and long trunks.

During field layout, locations where holes are to be dug should be staked. Elaborately prepared holes are not necessary. Small holes of 40-cm width and 40-cm depth suffice (Baltazar 1984; Richards 1950) although holes 60-80 cm wide and 40-50 cm deep are ideal (Department of Agriculture 1991).

Planting

The plant should be set in the prepared hole and the roots covered with topsoil mixed with compost or well-decomposed manure if available (Baltazar 1984; Coronel 1983). The soil around the base of the plant is pressed down to remove large air spaces and to make the plant stand erectly and firmly in the ground.

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[1]There is not yet an accepted recommendation for 'desired tilth.' The common land preparation method is to plow and harrow alternately three times.

During the transplanting operation, care must be taken not to disturb the plant's delicate root system (Chandler, 1958; Concepcion 1990; Yap, 1972). It is best to prune the leaves by about half or two-thirds of the foliage. Leafy branches or extra shoots are cut to prevent excessive transpiration of the newly planted crop. Transplanting is best done at the start of the rainy season (Baltazar 1984; BPI 1991; Concepcion 1990; Richards 1950; Soepadmo 1991). In the Philippines, this usually falls in the late May or early June. If irrigation water is available, planting can be done any time of the year. Young plants require protection from grazing animals and sunscald (Morton 1965, 1987). In India, the stems of newly transplanted seedlings are wrapped with banana sheaths to protect them from sunscalding (Dutta 1956).

8.4. Field Management

Irrigation and drainage

As mentioned earlier, jackfruit tolerates drought poorly (Morton 1987; Soepadmo 1991). For this reason, planting should coincide with the beginning of the rainy season. If no rain is expected soon after planting, arrangements for watering must be made (Concepcion 1990; Richards 1950). Additional watering during the first two years of growth is also advisable, particularly during dry months (Coronel 1983), as it can hasten plant establishment. In later years, the water requirement is less critical. Still, if irrigation facilities are available, it is a good practice to water the trees during the dry season.

The species is very intolerant of poor drainage (Hensleigh and Holaway 1988; Soepadmo 1991), and roots fail to grow under flooded conditions. Unless drainage canals are constructed, waterlogged areas cannot be used for growing jackfruit. The soil at the base of the plant should also be raised to prevent water stagnation. Drainage pathways should be made in waterlogged spots in a jackfruit field.

Fertilization

In the Philippines, fertilizer application for improved quantity and quality of jackfruit yields is seldom practiced. One reason for this may be that little is known of the crop's fertilizer requirement from which specific recommendations can be based. In general, it is recommended to fertilize the trees twice yearly: once at the onset of the rainy season and again towards the end of the rainy season (BPI 1991; Concepcion 1990; Coronel 1983) or at the start of the dry season (Baltazar 1984).

In the Philippines, three general fertilizer recommendations are reported for jackfruit and the amount per application, as follows:

- 100-150 g ammonium sulfate (20-0-0) per tree in the first year, increasing as the trees grow bigger; 0.5-1.0 kg complete fertilizer (14-14-14) per tree at the

start of fruiting, increasing as the trees age and fruit production increases, with a full-grown tree (15-20 years old) receiving 2-3 kg complete fertilizer (Concepcion 1990; Coronel 1983)

- 50-60 g ammonium sulfate in the first year, increasing to 200 g, 300 g and 400 g ammonium sulfate on the second, third, and fourth years, respectively; 1 kg complete fertilizer (5-10-5 or 6-12-6) in the fifth year of growth, but if the trees are bearing this increases to 1.5 kg of complete fertilizer; in the sixth year and thereafter, 1.5 kg complete fertilizer (12-24-12) is applied (Baltazar 1984)

- 200-300 g complete fertilizer (14-14-14) per tree at planting time; 300-500 g complete fertilizer (14-14-14) plus 200-300 g urea (45-0-0) per tree for young trees; 1.5-3 kg complete fertilizer and 200-300 g of muriate of potash (0-0-60) for bearing trees (BPI 1991)

Soil and climatic conditions are not considered in these suggested fertilizer rates. Studies are needed to reconcile these differing recommendations and better understand the fertilizer requirement of jackfruit.

Fertilizer can be applied in a 5- to 10-cm deep trench or in holes made along the periphery of the tree canopy (BPI 1991; Concepcion 1990), then covered with soil. If organic fertilizers are available, they should be applied around the tree (Coronel 1983).

Cropping schemes

In a jackfruit plantation or orchard, supplemental cropping systems can be employed to maximize land use, conserve soil fertility and moisture, control pests, and improve farm productivity (Baltazar 1984; Yap 1972).

At the pre-bearing stage before the trees' canopies have closed, the spaces between tree rows can be planted with annual crops such as legumes and vegetables (Baltazar 1984; BPI 1991; Coronel 1983; Magos 1988; Yap 1972). Growing systems of intercrops should be well designed so as not to interfere with plantation operations. When the cultivation of cash crops becomes unviable, a leguminous cover crop can be planted to help control weeds and conserve soil fertility and moisture (Department of Agriculture 1991; Yap 1972). The cover crop should not be allowed to climb the trees. When its growth becomes too thick, it should be pressed down (Coronel 1983).

A well-timed tree relay planting or replanting scheme can maximize productivity of the trees and the farm as a whole. In Thailand, it is recommended that alternate rows be planted every 10 years so that 20-year-old trees may be routinely removed from the plantation and replaced by new generation trees (Morton 1987).

Pruning

Unnecessary twigs and branches, including those in the tree interior, should be pruned to give more room and light to the developing fruits. Diseased and insect-infested branches should also be pruned to minimize spread of the pests (Hensleigh and Holaway 1988). Trees intended primarily for fruit production should be pruned at two years of age by cutting the main stem back to leave a 3-5-m trunk (BPI 1991). The wound is then applied with fungicide and painted. This practice limits tree height and concentrates the fruits at the lower, more accessible parts of the tree.

Control of weeds

Both inter-row and circle weeding are employed to keep down weed population. If cover crops are not grown, inter-row weed control may involve shallow cultivation by hoeing, plowing, or disking. On the other hand, circle weed control consists of hand-weeding or hoeing a ring at the base of the tree with diameter equivalent to that of the lower canopy. The tree base can also be mulched with rice straws or other mulching material. This can check weed growth and at the same time conserve soil moisture, particularly during the dry months (Baltazar 1984; Concepcion 1990; Soepadmo 1991).

Diseases and their control

Diseases affecting the jackfruit in the Philippines have been identified and are listed in Table 6.

In Malaysia, bacterial dieback caused by *Erwinia carotovora* is causing increasing losses in both jackfruit and chempedak (Soepadmo 1991). The disease first affects the growing shoots, spreads downward and eventually kills the tree. In India, a number of diseases has been reported. The major ones are the pink disease, Rhizopus rot (which may also affect the stem), and leaf spot which can be caused by *Phomopsis artocarpina, Colletotrichum lagenarium, Septoria artocarpi* and other fungi (Cook 1975; Morton 1965 1987; Weber 1973). Other diseases known to occur in India include Physalospora fruit rot caused by *Physalospora rhodina*, gray blight caused by *Pestalotia elasticcola*, charcoal rot caused by *Ustilana zonata*, collar rot caused by *Rosellinia arcuata*, and rust caused by *Uredo artocarpi.*

In general, diseases can be controlled by removing and burning infected parts, spraying the trees with fungicide such as copper fungicide at recommended dosages, using disease-resistant varieties, and adopting improved cultural practices to increase tree vigor and resistance to disease (Baltazar 1984; Coronel 1983; Soepadmo 1991). Specific control strategies against specific jackfruit diseases are limited and are essentially at the developmental stage. *In vitro* laboratory and field tests found fungicides such as copper oxychloride and captafol to be effective against the Choanephora fruit rot organism, while chlorothalonil appeared to control the Rhizopus rot pathogen (Quimio 1985). In

Table 6. Diseases affecting *Artocarpus heterophyllus* reported in the Philippines.

Disease	Cause	Affected parts of the tree
Rhizopus rot	*Rhizopus nigricans* (synonym: *R. artocarpi*)	male inflorescences, young fruits and injured mature or ripening fruits
Choanephora fruitlet rot	*Choanephora cucurbitarum*	very young fruits
Pink disease	*Pellicularia salmonicolor* (synonym: *Corticium salmonicolor*)	branches
Rhizoctonia thread blight	*Pellicularia koleroga*	foliage
Brown leaf spot	*Phomopsis artocarpina*	foliage
Nectria canker	*Nectria cinnabarina*	branches, stems, or young plants
Cercospora leaf spot	*Cercospora artocarpi*	foliage
Fusarium wilt	*Fusarium* spp.	roots and stem base of seedlings

Sources: BPI 1991; Hensleigh and Holaway 1988; Quimio 1985; Villegas 1990; Yap 1972; Baltazar 1984; Quimio 1985.

Malaysia, the application of chemicals, including trunk injection with antibiotics, is being tested to control the bacterial dieback disease (Soepadmo 1991).

Insect pests and their control

In the Philippines, at least 20 insect pests are known to infest jackfruit (Baltazar 1984; Quimio 1985). The principal ones are shown in Table 7. So far, only two are considered important and of abundant or widespread occurrence. These are the nangka fruitfly (*Dacus umbrosus*) and the nangka fruitmoth (*Diaphania caesalis*) (Cendena et al. 1984; Quimio 1985).

The nangka fruitfly is the most destructive pest. The female adult lays eggs in the maturing fruit and the maggots (larvae) that hatch penetrate into the fruit tissues, where they feed and develop, causing the fruit to rot (Cendena et al. 1984). Bagging fruits with plastic sacks can totally prevent fruit fly infestations (Quimio 1985). Sacks can be treated with Malathion. Other bagging materials can be used, such as gunny sacks or newspaper wrap (Concepcion 1990; Hensleigh and Holaway 1988). Other potential control strategies are the use of chemical baits and the sterile insect technique, both of which have been found to work against the oriental and melon fruit flies (Manoto et al. 1987).

Table 7. Insect pests affecting *A. heterophyllus* in the Philippines.

Common name	Scientific name	Affected part of tree
Nangka fruitfly	*Dacus umbrosus*	maturing fruit
Nangka fruitmoth	*Diaphania caesalis*	developing fruit, buds, young shoots
Barkborer	*Batocera rubus*	bark, trunk
Slug caterpillar	*Thosea sinensis*	leaves
Mealybug	*Planococcus lilacinus*	leaves, branches
Soft scale	*Pulvinaria psidii*	leaves, branches
Short-horned grasshopper	*Melicodes tenebrosa*	leaves
Citrus green locust	*Melicodes* sp.	leaves
Nangka katydid	*Melicodes* sp.	leaves
White mealy bug	*Nipaecoccus filamentosus*	stem
Grey mealy bug	*Ferrisia virgata*	leaves
Brown beetle	*Phytorus lineolatus*	leaves
Root grub	*Anomala* spp.	roots
Root grub	*Leucopholis irrorata*	roots
Nasute termites	*Nasutitermes luzonicus*	trunk, branches

Sources: Baltazar 1984; Cendena et al. 1984; Quimio 1985.

The nangka fruitmoth caterpillar (larvae), the destructive stage, feeds on the outer tissues of the developing fruit and tunnels into it (Cendena et al. 1984). It is also called shoot borer as it tunnels into buds and young shoots (Soepadmo 1991). It infests other Artocarpus species as a young-stem borer destroying the tips of branches. Removal of affected shoots or branches where the caterpillar pupates can control the pest somewhat, as this breaks its life cycle. The fruits may also be bagged for protection. Spraying with insecticides such as Malathion (0.5% a.i.), Methomyl (0.5% a.i.), or Endosulfan (0.1%) at 15-day intervals can reduce fruit infestation by 80% (Quimio 1985).

In other countries, such as India, principal pests are shoot borers, mealy bugs, the spittle bug (*Cosmoscarta relata*), jack scale (*Ceroplastis rubina*), bark borers (*Indarbela tetraonis* and *Batocera rufomaculata*), stem and fruit borer (*Mangaronia caecalis*), and brown bud weevil (*Ochyromera artocarpi*). Minor pests are leaf webbers, aphids, and thrips (Morton 1965, 1987). In Southern China, longicorn beatles are considered important pests.

In general, these insect pests can be controlled by pruning out infested tree parts, proper sanitation, fruit bagging, and applying insecticides (Baltazar 1984; BPI 1991; Concepcion 1990; Coronel 1983; Morton 1965, 1987; Soepadmo 1991, Yap 1972).

8.5. Fruit Harvesting and Postharvest Systems

Harvest maturity

The stage of maturity at which fruit is harvested depends on the intended use. When used as a vegetable, immature fruits are picked when they are rather dark green with stiff, hard and closely spaced spines (Baltazar 1984; Concepcion 1990). When eaten as a fresh fruit, harvest maturity is determined using the methods described in Section 6.4. Some of these indices are relative and require experience and skill to master; some require much labor if practiced in large commercial farms (Angeles 1983).

The production of a dull, hollow sound when tapped is considered the most reliable indicator that the fruit is mature but not yet ripe. Harvesting at this stage permits the fruit to be handled and distributed to distant markets or held for a longer period before consumption. If fruits are used or consumed soon after harvest, they can be picked at the ripe stage when they emit jackfruit's characteristic aroma.

Time and method of harvesting

Harvesting fruits between mid-morning and late afternoon can reduce latex flow, as latex cells are less turgid at this time of day. This can minimize unsightly latex stains.

During picking, the fruit peduncle is cut by a sharp knife (Baltazar 1984; Soepadmo 1991; Yap 1972). For fruits located on high branches or at the top of the tree, it is advisable to use a sack or similar material to receive the severed fruit, which is then lowered slowly to the ground. It is always best to harvest and handle fruits with care to prevent mechanical injuries that hasten fruit deterioration and disease infection. After harvesting, the footstalks can be cut back to the trunk or branch to induce flowering the following season (Morton 1965, 1987).

Postharvest handling and storage

Right after harvest, the fruit should be laid for some time against a railing with its stalk down to allow the latex to flow and coagulate (Yap 1972). Use of container lining materials, such as dried leaves or newsprint, or cushioning materials between fruit layers, can minimize mechanical damage during transport.

Fruits are sorted based generally on their size and physical appearance. Grading is not practiced in the Philippines, although the Philippine Trade Standard promulgated in 1970 a set of grade standards for jackfruit used as fresh fruits (Coronel 1983). In these standards, the fruit is considered mature when it emits its characteristic aroma and its spines are well developed and set far apart. Three size classifications are specified:

large - fruits weighing 15 kg or more
medium - fruits weighing 8-15 kg
small - fruits weighing less than 8 kg

Two grades based on fruit condition (Grade 1 and Grade 2) were also proposed.

Fruits harvested at the mature but unripe stage may take longer to ripen. In the Philippines, ripening is sometimes hastened by inserting a stick along the core of the fruit. In Jamaica, making an 'X' cut at the fruit apex is employed to speed ripening and improve flavor (Morton 1965, 1987). These methods of enhancing fruit ripening by inflicting wounds induce the production of the ripening hormone ethylene.

Ripe fruits turn brown and deteriorate rapidly after harvest. If stored at temperatures of 11-13°C and relative humidity of 85-95%, shelf life can be prolonged by three to six months (Morton 1965, 1987).

9. Utilization

Artocarpus heterophyllus is truly a multipurpose tree species. Some parts of the tree have uses found only in certain localities, but many tree parts, including the fruits and timber, are utilized intensively and widely. Unless the country is specified, the following descriptions of jackfruit's uses and value are reported or practiced in the Philippines.

9.1. Fruit Utilization

Whole fruit

Jackfruit is mainly grown for its fruits. The relatively nutritious young or immature fruit (Table 8), is used primarily as a vegetable (Bagtas 1989; Concepcion 1990; Vega and Carcallas 1991; Yap 1972). It can be pickled or prepared as a vegetable salad (Bagtas 1989). Industrial processors utilize the young fruit as an ingredient in the manufacture of a food seasoning known locally as *patis* (Vega and Carcallas 1991). In other jackfruit-producing countries, both immature and mature but unripe fruits are eaten as a vegetable (Morton 1965, 1987; Purseglove 1968). Immature, overripe, and fallen fruits from a tree are also fed to hogs and cattle (Morton 1965, 1987; Vega and Carcallas 1991).

Aril

The ripe fruit is mainly used for its sweet and aromatic arils. The fresh ripe aril (nutritional value shown in Table 8) is relished as a dessert or snack food (Concepcion 1990; Morton 1965, 1987; Purseglove 1968; Vega and Carcallas 1991; Yap 1972). It can be used to flavor ice cream and various native delicacies, such as fruit salad (Concepcion 1990; Vega and Carcallas 1991). In India, the ripe arils are dried, fried in oil, and salted for eating like potato chips (Morton 1965, 1987). They are also used to produce jackfruit nectar.

In the Philippines also, the arils are preserved in syrup, dried, and processed as dehydrated products (Bagtas 1989; Concepcion 1990; De Leon 1987; Evangelista 1989; Giron et al. 1971; PCARRD 1988; Villanueva 1985; Yap 1972). Drying or dehydration can be accomplished by the osmotic-solar drying technique (Pablo 1980). This involves partial dehydration by osmosis (using syrup), followed by final drying with a solar drier. To enhance the color, texture, and flavor of the dehydrated jackfruit, sulfite can be added to the syrup used for dehydration (De Leon 1987). Shelf life of dehydrated products can be prolonged by irradiation (Evangelista 1989; Giron et al. 1971).

Several processed products are made from the arils. These include: candy, jam, jelly, marmalade, fruit bar, and pastilles (Bagtas 1989; BPI 1991; De Leon 1987; Evangelista 1989; PCARRD 1988; Villanueva 1985). A powder is also prepared and

Table 8. Chemical composition of the fruit, aril, seed, and white pulp of jackfruit (per 100-g sample).

Chemical Constituent	Whole Fruit (immature)	Aril (ripe)	Seed (fresh, mature)	White Pulp (ripe fruit)
Water (g)	85.2	65.6-73.1	51.6-60.9	83.3
Food energy (cal)	51	94-98	143-151	
Total carbohydrates (g)	11.5	22.4-24.0	32.6-38.4	5.7
Total sugars (%)		15.2	1.9	
Soluble solids (%)		11.7-23.2		4.2
Titratable acidity (%)		0.18-0.27	0.16	0.19
pH		5.2-5.3		5.4
Proteins (g)	2.0	0.4-1.5	4.3-6.6	1.8
Fats (g)	0.6	0.4-0.6	0.2-0.6	0.7
Fiber (g)	2.6	0.8-1.8	1.4-1.8	8.2
Ash (g)	0.7	0.5-1.2	1.2-3.5	0.5
Calcium (mg)	53	19-23	23-35	
Phosphorus (mg)	20	18-68	80-126	
Iron (mg)	0.4	0.7-1.1	0.8-1.2	
Sodium (mg)	3	2	3-22	
Potassium (mg)	323	88-407	673-841	
Vitamin A (I.U.)	30	175	25	
Thiamine (mg)	0.12	0.04-0.09	0.18-0.22	
Riboflavin (mg)	0.05	0.05-0.13	0.05-0.06	
Niacin (mg)	0.5	0.9	0.5	
Ascorbic acid (mg)	12.0	5.0-5.8	10.0-17.0	

Sources: Angeles 1983; Bagtas 1989; Brown 1941; Chandler 1958; Coronel 1983; De Leon 1987; Maranon 1944; Popenoe 1974; Selvaraj and Pal 1989; Vitug 1991.

used as flavoring in recipes for pastilles, gelatins, and baked products (Bagtas 1989). A puree can be produced and used for the preparation of candy, sherbet, or a ready-to-drink beverage. The arils can even be fermented and distilled for an alcoholic beverage (Coronel 1983).

Aside from its food value, the aril has medicinal properties. It has been reported to be demulcent and laxative (Coronel 1920). In China, it is considered a cooling and nutritious tonic (Morton 1965, 1987).

Seed

The seed is more nutritious than the aril, being richer in protein, carbohydrate and mineral contents (Table 8). Seeds can be boiled, roasted, fried or baked and eaten (De Leon 1987; Morton 1965, 1987; Purseglove 1968; Vega and Carcallas 1991; Wickramasinghe 1991). They can be processed into flour which is used to produce snack foods such as pastilles (Vitug 1991). In flour preparation, the seeds are first boiled and then dehydrated. Using mashed, boiled seeds in making snack food has not been successful due to the short shelf life of the products. The seed is an ingredient in several native delicacies. They can be processed into jam (De Leon 1987). Fresh seeds are used as an industrial raw material in the manufacture of a fermented milk drink, known as *yakult* (Vega and Carcallas 1991).

In India, jackfruit seed is an ingredient in many culinary preparations (Purseglove 1968). They can be boiled and preserved in syrup like chestnuts, or canned in brine, curry, or tomato sauce (Morton 1965, 1987). Roasted dried seeds are ground for a flour, which is blended with wheat flour for baking.

Like the arils, the seeds serve as a cooling and nutritious tonic (Morton 1965, 1987). The seed starch is used to treat bilious colic. Roasted seeds are said to be aphrodisiac.

White pulp, rind and core

These parts of the fruit are considered by many as waste or inedible. With the advent of processing technologies, however, they can be made very utile. The white pulp (undeveloped flower) can be used as a major component of jackfruit puree. It constitutes about 75% of the white pulp-aril mixture used for puree preparation (Bagtas 1989). A highly consistent puree can be obtained due to the high fiber content of the white pulp (Table 8). The white pulp can also be processed to produce a flavor extract or wine (De Leon 1987). Similarly, a flavor extract can be prepared from the rind or peel. The rind can be jellied with citric acid (Morton 1965, 1987). It can be used as feed for cattle or other livestock (Morton 1965, 1987; Purseglove 1968). The fruit core or receptacle, rind, and white pulp can be processed to produce a pectin extract (Morton 1965, 1987). They also yield a syrup used for curing tobacco leaves.

9.2. Other Tree Parts

Trunk and branches

The trunk and main branches of the tree are sources of lumber. Jackfruit lumber is prized in making guitars and ukeleles for its resonant qualities and beauty (Hensleigh and Holaway 1988; Vega and Carcallas 1991; Yap 1972). It is used for furniture construction and as building material; for example, purlins, and door jambs (Chandler 1958; Vega and Carcallas 1991). The trunk and branches are also used as fuelwood, and as fertilizer when decomposed. Tool handles can be made from the small branches.

In Sri Lanka and India, jackfruit is an important timber tree (Morton 1965, 1987). The wood is said to be termite-proof and fairly resistant to fungi and bacteria. Its color changes with age from orange or yellow to brown or dark red. The wood seasons without difficulty and polishes beautifully. When boiled with alum, the sawdust of wood or chips of the heartwood produce a rich yellow dye used for dyeing garments. In Indonesia, splinters of the wood are placed into bamboo tubes used for collecting toddy to impart a yellow tone. This yellow colorant from the wood has been identified as the flavonoids morin and artocarpin. The wood also contains a colorless flavonoid known as cyanomaclurin. The wood is claimed to have a sedative property and its pith is said be able to induce abortion.

Bark

The bark of the tree, particularly the inner part, or bast, is occasionally made into cordage or cloth (Morton 1965, 1987; Yap 1972). It gives a dark, water-soluble resinous gum and contains about 3.3% tannin.

The bark can also be made into poultices for medicinal purposes.

Roots

The roots of old trees are highly prized for carving and picture-framing (Morton 1965, 1987). They are also used to make handles for farm implements (Vega and Carcallas 1991). A root decoction can be prepared and used to alleviate fever and diarrhea or remedy skin diseases and asthma (Morton 1965, 1987).

Leaves

Tender, young leaves of jackfruit can be cooked and served as a vegetable (Morton 1965, 1987). When stitched together, they are used as food wrappers in cooking and as plates. The leaves also serve as feeds for cattle and goats (Vega and Carcallas 1991). In India, the leaves are used as fodder for cattle and other livestock (Morton 1965, 1987), and are said to be fattening.

When charred and powdered, the leaves have therapeutic value (Chandler 1958) against diarrhea, boils, and stomach ache (Vega and Carcallas 1991). To heal ulcers, the ash of leaves burned with corn and coconut shells are used alone or mixed with coconut oil (Morton 1965, 1987). Heated fresh leaves are used for wound healing.

Inflorescence

In some parts of the Philippines, particularly Batangas, the male spikes of jackfruit, which elsewhere are commonly left to rot on the tree, are used as a vegetable salad or pickle. The spikes are ground using a grater or mortar and pestle. Salt and vinegar are then added and the dish is served. In other countries, the male spikes are cooked and served as a vegetable (Morton 1965, 1987).

Latex

Jackfruit exudes an abundant white latex. The latex yields 71.8% resin, consisting of 63.3% fluavilles (yellow) and 8.5% albanes (white)(Tanchico and Magpantay 1958). These resins may have value in varnishes.

The latex is commonly used as adhesive for mending broken chinaware or earthenware, caulking boats and holes of buckets, and trapping birds (Morton 1965, 1987; Purseglove 1968; Tanchico and Magpantay 1958; Vega and Carcallas 1991). It can also be used as chewing gum. In India and Brazil, the latex serves as a rubber substitute (Tanchico and Magpantay 1958).

The dried latex yields artotenone, which is convertible to artosterone, a compound with marked androgenic action (Morton 1965, 1987). The latex can be mixed with vinegar and used to promote healing of abscesses, snakebite, and glandular swelling. The bacteriolytic activity of jackfruit latex is equal to that of papaya latex.

9.3. Uses of the Whole Tree

Whole trees of jackfruit are used as windbreak, fence, or shade, and for flood and soil erosion control in rural farms (Vega and Carcallas 1991). They are occasionally used as intercrops, for example in coconut groves (Soepadmo 1991). The tree is an important agroforestry species (Hensleigh and Holaway 1988).

In Malaysia, jackfruit is intercropped in durian (*Durio zibethinus*) orchards to provide shade (Soepadmo 1991). It is similarly used to shade coffee and orange trees, and in India to provide shade and living support for black pepper (Chandler 1958; Purseglove 1968). In Africa, the trees are utilized for yam support. In Australia, they are used as windbreaks at close spacings (Soepadmo 1991). In Bangladesh, jackfruit is an important reforestation species (Hensleigh and Holaway 1988).

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