Jackfruit

Artocarpus heterophyllus

Author:
N. Haq

Editors:
J.T. Williams (Chief editor)
R.W. Smith
Z. Dunsiger

DFID Department for International Development
FRP Forestry Research Programme
World Agroforestry Centre Transforming Lives and Landscapes
IPGRI

First published in 2006 by:

Southampton Centre for Underutilised Crops, University of Southampton, Southampton, SO17 1BJ, UK

© 2006 Southampton Centre for Underutilised Crops

Printed at RPM Print and Design, West Sussex, UK

The text in this document may be reproduced free of charge in any format or media without requiring specific permission. This is subject to the materials not being used in a derogatory manner or in a misleading context. The source of the material must be acknowledged as [SCUC] copyright and the title of the document must be included when being reproduced as part of another publication or service.

Copies of this handbook, as well as an accompanying manual and factsheet, in English, can be obtained by writing to either address below:

International Centre for Underutilised Crops
International Water Management Institute
127 Sunil Mawatha, Pelawatta, Battaramulla, Sri Lanka

or

Southampton Centre for Underutilised Crops, University of Southampton, Southampton, SO17 1BJ, UK

British Library Catalogue in Publication Data

Jackfruit

1. tropical fruit trees

i Williams ii Smith iii Dunsiger

ISBN 0854327851

Citation: Haq, N. (2006) Jackfruit, *Artocarpus heterophyllus*, Southampton Centre for Underutilised Crops, University of Southampton, Southampton, UK.

Cover photographs supplied by A. Latham

DFID/FRP and DISCLAIMERS

This publication is an output from a research project funded by the United Kingdom Department for International Development (DFID) for the benefit of developing countries. The views expressed are not necessarily those of DFID [R7187 Forestry Research Programme].

The opinions expressed in this book are those of the authors alone and do not imply acceptance or obligation whatsoever on the part of SCUC, ICUC, ICRAF or IPGRI.

ICUC

The International Centre for Underutilised Crops (ICUC) is an autonomous, non-profit, scientific research and training centre. It was established in 1992 at the University of Southampton in the UK and has now moved to the International Water Management Institute (IWMI) in Sri Lanka. The Centre was established to address ways to increase the use of underutilised crops for food, nutrition, medicinal and industrial products. The enhancement of currently underutilised crops is a key to food security, to the conservation of biological diversity and to the preservation and restoration of fragile and degraded environments throughout the world.

World Agroforestry Centre

The World Agroforestry Centre (ICRAF), established in Nairobi in 1977, is an autonomous, non-profit research body supported by the Consultative Group on International Agricultural Research (CGIAR). ICRAF aims to improve human welfare by alleviating poverty, improving food and nutrition security and enhancing environmental resistance in the tropics.

IPGRI

The International Plant Genetic Resources Institute (IPGRI) is an international research institute with a mandate to advance the conservation and use of genetic diversity for the well-being of present and future generations. It is also a centre of the CGIAR.

Also available in this series:

Tamarind - *Tamarindus indica*, revised edition by K. El-Siddig, H.P.M. Gunasena, B.A. Prasad, D.K.N.G. Pushpakumara, K.V.R. Ramana, P. Vijayanand and J.T. Williams (ISBN 0854328599)

Ber and other jujubes – *Ziziphus* species, revised edition by S. Azam-Ali, E. Bonkoungou, C. Bowe, C. deKock, A. Godara, and J.T. Williams (ISBN 0854328580

Safou – *Dacryodes edulis* by J. Kengue (ISBN 0854327649)

Baobab – *Adansonia digitata* by M. Sidibe and J. T. Williams (ISBN 0854327762)

Annona spp. by A. C. de Q. Pinto, M. C. R. Cordeiro, S. R. M. de Andrade, F. R. Ferreira, H. A. de C. Filgueiras, R. E. Alves and D. I. Kinpara (ISBN 0854327851)

Mangosteen – *Garcinia mangostana* by M. bin Osman and Abd. Rahman Milan (ISBN 0854328173)

Monkey orange – *Strychnos cocculoides* by C. K. Mwamba (ISBN 0854328416)

Ndjanssang – *Ricinodendron heudelotii* by Z. Tchoundjeu (ISBN 0854328424)

Sapote species – *Pouteria sapota, P. campechiana, P. viridis* by C. Azurdia (ISBN 0854327651)

Contents

Abbreviations i
Preface iii
Acknowledgements v

Chapter 1. Taxonomy, origin and distribution 1
1.1 Introduction 1
1.2 Moraceae 2
1.3 The genus *Artocarpus* 3
1.4. *Artocarpus* species 4
1.4.1 Jackfruit: *Artocarpus heterophyllus* Lam 4
1.4.2 Chempedak: *Artocarpus integer* (Thunb.) Merr. 11
1.4.3 *Artocarpus odoratissimus* Blanco 12
1.4.4 *Artocarpus rigidus* Blume 13
1.5 Other *Artocarpus* species bearing edible fruits 14
1.6 Origin and distribution of jackfruit 15
1.6.1 Climate and ecology 18

Chapter 2. Properties and uses 19
2.1 Fruits 19
2.1.2 Pulp 19
2.1.3 Rind 21
2.2 Seeds 21
2.3 Leaves and flowers 21
2.4 Use of jackfruit in traditional medicine 22
2.5 Jackfruit wood 24
2.6 Latex 26
2.7 Use in agroforestry 26
2.8 Socio-cultural aspects 27
2.9 Environmental value 28

Chapter 3. Agronomy 29
3.1 Field establishment 29
3.2 Direct seeding 29
3.2.1. Seed germination 30
3.3 Transplanting 32
3.4 Propagation 33
3.4.1 Raising seedlings as rootstocks for vegetative propagation 34
3.4.2 Methods of vegetative propagation 34

3.5 Recommended methods 44
3.6 *In vitro* propagation 45
3.6.1 Rooting of regenerated shoots 45
3.6.2 Establishing and using a nursery 48
3.7 Spacing 50
3.8 Time of planting 51
3.9 Management 51
3.9.1 Weeding and mulching 51
3.9.2 Pruning and training 52
3.10 Intercropping 53
3.11 Nutrition 53
3.12 Fruiting 57
3.13 Irrigation 59
3.14 Pests and diseases 59
3.14.1 Pests 60
3.14.2 Diseases 64

Chapter 4. Reproductive biology 70
4.1 Introduction 70
4.2 Flowering habit 71
4.2.1 Male flowering 71
4.2.2 Female flowering 72
4.3 Pollination 72
4.4 Fruiting 72
4.4.1 Tissues of the fruits/ fruit morphology 73
4.4.2 Fruit maturation 75
4.5 Seeds 75

Chapter 5. Genetic resources and crop improvement 77
5.1 Introduction 77
5.2 Cytology 77
5.3 Current information on diversity 78
5.4 Germplasm collections 82
5. 5 Cultivars 83
5.6 Breeding 94
5.6.1 Current improvement efforts 95
5.6.2 Focus on genetic diversity 96
5.6.3 Further selection 97
5.6.4 Desirable criteria for improvement 98
5.6.5 Ideotypes 98
5.7 Genetic conservation 99
5.7.1 *In situ* conservation 99

5.7.2 *Ex situ* conservation 100
5.7.3 Field genebanks 101

Chapter 6. Harvesting, post-harvest handling and processing products 102
6.1 Ripening and maturity 102
6.2 Harvesting 104
6.3 Postharvest handling 107
6.4 Storage 108
6.5 Processing 110
6.5.1. Recipes 112

Chapter 7. Economics of production and marketing 127
7.1 Economics of production 127
7.1.1 Cost of cultivation 127
7.1.2 Tree establishment costs in household farms and small orchards 128
7.1.3 Maintenance cost 128
7.1.4 Returns 129
7.2 Marketing 129
7.2.1 Marketing channels 129
7.2.2 Products 130
7.2.3 Domestic marketing 136
7.2.4 International marketing 137
7.3 Socio-economics and marketing 139

Chapter 8. Conclusions and future research needs 142
8.1 Taxonomy 143
8.2 Genetic resources and crop improvement 144
8.3 Crop management 145
8.4 Post-harvest and processing 145
8.5 Future research 146

References 149
Appendix 1. Specialists and institutions engaged in jackfruit research and development 170
Appendix 2. Institutions with collections of jackfruit germplasm 180
Appendix 3. Seed suppliers 184
Glossary 186
Index 190

Tables

Table 1.1 Common names of jackfruit……. 10
Table 1.2 Other *Artocarpus* species bearing edible fruits……. 14
Table 1.3 Distribution of jackfruit by country…….. 16
Table 2.1 Composition of the edible parts …… 20
Table 2.2 Putative use of jackfruit in local medicine …….. 23
Table 3.1 Characteristics of selected superior phenotypes of jackfruit…… 33
Table 3.2 Use of growth regulators to promote rooting…… 37
Table 3.3 Use of growth regulators in air layering…… 39
Table 3.4 Results of success rates using different budding methods 43
Table 3.5 Recommendations for vegetative propagation methods of jackfruit in Asia…… 44
Table 3.6 Results of different *in vitro* methods for multiple shoot regeneration…….. 46
Table 3.7 Results of regeneration using different methods for rooting of regenerated shoots……... 47
Table 3.8 Yearly amounts of manure and fertilisers for jackfruit trees (per tree) in Bangladesh……... 54
Table 3.9 Application of fertilisers in four states of India ……... 54
Table 3.10 Fertiliser recommendations for jackfruit in Florida…… 56
Table 3.11 Annual production of jackfruit in Asia…… 58
Table 3.12 Yield of fruits per hectare in major jackfruit producing countries in Asia……... 58
Table 3.13 Pests which generally affect jackfruit……. 62
Table 3.14 Diseases which generally affect jackfruit…… 66
Table 4.1 Growth stages of parts of jackfruit ……..... 76
Table 5.1 Variation in morpho-agronomic characters……... 79
Table 5.2 Variation of qualitative characteristics of jackfruit accessions in Bangladesh……. 80
Table 5.3 Variation in fruit characteristics…… 82
Table 5.4 Jackfruit collections held in different countries…… 83
Table 5.5 Cultivars of jackfruit……. 93
Table 5.6 Names of principal types of fruits in different countries... 94
Table 5.7 Collection, characterisation, evaluation and selection of promising lines of jackfruit…….. 95
Table 5.8 Number of planting materials produced in each country.. 96
Table 5.9 Criteria used in jackfruit selection…… 98
Table 6.1 Yield of bulbs and non-edible portions and physical variations in bulbs at harvest at six stages of maturity……. 106

Table 7.1 Estimated cost of establishment (in Indian Rs.) of a jackfruit orchard in India…….. 128
Table 7.2 Availability of jackfruit in different countries…….. 133
Table 7.3 Socio-economic profile of *Artocarpus* growers in Nepal 140
Table 7.4 Farmer cited suggestions for market management…… 141
Table 8.1 Comparison of properties of tropical fruits……... 142
Table 8.2 Suggestions for research requirements and technology transfer…….. 147

Figures

Fig.1.1 A twig of jackfruit, *Artocarpus heterophyllus*…… 6
Fig.1.2 Morphological characteristics of fruit parts of *Artocarpus heterophyllus*…… 7
Fig.1.3 Indigenous and introduced areas of *Artocarpus heterophyllus*…… 17
Fig. 3.1 Percentage success in grafting using different graft types... 42
Fig.7.1 Producer to market chain for commercialization of fruits… 131

Plates

Plate 1. Whole fruit and bulbs…… 85
Plate 2. Fruits……. 85
Plate 3. High quality furniture…… 86
Plate 4. Goat fodder……. 86
Plate 5. Protective bamboo fencing…… 87
Plate 6. A seedling raised in a polybag…… 87
Plate 7a. Steps of epicotyl grafting…….. 88
Plate 7b. Steps of epicotyl grafting……. 89
Plate 8. Polybags with shading…… 90
Plate 9. Grafted tree without pruning…….. 90
Plate 10. Grafted tree pruned and trained to have a longer trunk… 90
Plate 11a. Fruits of different sizes…… 91
Plate 11b. Fruits of different shapes…… 91
Plate 12. Jackfruit products…….. 92
Plate 13. High quality fruits at market……. 92

Abbreviations

ADH	Alcohol dehyrogenase
ACP	Acod phosphatase
AFLP	Amplified fragment length polymorphism
BA	Benzyladenine
BAP	Benzyladenine purine
BARI	Bangladesh Agricultural Research Institute
BPI	Bureau of Plant Industries
CPA	p-chlorophenoxyacetic acid
DFID	Department for International Development (UK)
DMSO	Dimethyl sulphoxide
EDDHA	Ehylenediamine di- (o-hydroxyphenylacetate)
EDTHA	Sodium ferric dimethyenetriamine pentaacetate
FYM	Farmyard manure
GA	Gibberellic acid
GDH	Glutamine dehydrogenase
GOT	Glutamate oxalacetate transaminase
HORDI	Horticulture Research and Development Institute
HRC	Horticulture Research Centre
IAA	Indole acetic acid
IBA-	Indole butyric acid
IBPGR	International Board for Plant Genetic Resources
ICRAF	World Agroforestry Centre (formerly International Centre for Research in Agroforestry)
ICUC	International Centre for Underutilised Crops
IIHR	Indian Institute of Horticultral Research
IPB	Institute of Plant Breeding
IPGRI	International Plant Genetic Resources Institute
KJ	Kilo Joule
KMS	Potassium metabisulphite
IU-	International unit
MS medium	Murashige and Skoog medium
MT	Metric tonnes
NAA	Napthylacetic acid
MDH	Meta dehydrogenase
PPM	Part per million
PAB	Polyhydroxybutyrate
UTFANET	Underutilised Tropical Fruits in Asia Network

RFLP	Restricted fragment length polymorphism
RIFAV	Research Institute of Fruits and Vegetables
RH	Relative humidity
SCUC	Southampton Centre for Underutilised Crops
TDZ	Thiadiazuron
TSS	Total soluble solids

Preface

Tropical fruits are important constituents in the daily diets of billions of people; and many such fruits are harvested from a wide range of minor species - either from wild trees or locally cultivated ones. Many such fruit trees have multi-purpose uses and their plant products satisfy a variety of local non-food purposes ranging from timber to forest.

There are scores of lesser-known tropical fruits which have received little attention if any, from agronomists and breeders, yet a number of such fruits have, from time to time, been recognised as worthy of more focus. This is because they can supplement diets with important minerals, vitamins and carbohydrates and their production can also generate income thereby helping to alleviate poverty. Neglect of such fruits by the scientific community is often also coupled with poor market structures and practical constraints to transport and storage.

The International Centre for Underutilised Crops (ICUC) has been involved in prioritising a limited number of such lesser-known tropical fruits and promoting their use through technology development for better husbandry and marketing. National partners in Asia placed jackfruit high on the list for attention. ICUC's programmes include identification of suitable types for different purposes. The Centre and its partners are maintaining the diversity of underutilised fruits in on-farm and research field for domestication of cultivars to maximise utilisation (see Chapter 5).

Jackfruit is widely esteemed in tropical Asia where it originated as a cultigen, but its distribution is pantropic through introduction in the past. However, although it is well-known and widely used and cultivated it remains underutilised because it has hardly undergone any scientific improvement. This book aims to gather together the information relevant to the production and utilisation of jackfruit in order to highlight the current gaps in knowledge, to identify research constraints and to summarise appropriate technology for enhanced production.

The book takes the format of a monograph and will be disseminated to a wide audience in both developing and developed countries. A complementary manual for extension workers supplements this monograph which is also available to field workers, policy makers and others so that better use can be made of jackfruit.

The preparation and publication of this book has been funded by the UK's Department for International Development as part of a project called "Fruits for the Future". During its preparation a large number of national scientists were called upon for data and information. The interests of ICUC's partner international organisations, ICRAF and IPGRI, also meant that the role of the species in land use, especially in agroforestry and homegarden systems, and in providing food and nutrition security at the local level, were duly dealt with during the book's compilation.

The editors express their great thanks to Dr Nazmul Haq who found the time, whilst directing the overall Fruits for the Future project, to write the text for jackfruit. Thanks are also due to Zoë Dunsiger who has coordinated the production of the manuscript and to Rosemary Wise for the drawings of the species.

J.T. Williams
Chief Editor

Acknowledgements

I was in Bangladesh on a holiday and met a Britis friend who was living there. He knew of my interest in tropical and sub-tropical fruits and in particular in jackfruit. He asked me whether I was aware of any small fruits of 1-2 kg in weight which would be easy to transport. He had only seen large jackfruits in the UK market and felt that the size of the fruit and its short shelf life had been hindering the export market. I told him that I had observed variability in size, shape and quality but I had never seen 1-2 kg fruit. My friend's comments encouraged me to think about a project on the improvement of jackfruit.

During this holiday I had several meetings with the directors of the Horticulture Research Centre (HRC) of Bangladesh Agricultural Research Institute (BARI) and the Institute of Food Technology of Bangladesh Council for Scientific and Industrial Research (BCSIR) in Dhaka to discuss the present status of jackfruit in Bangladesh. We agreed to develop a joint project on jackfruit in Bangladesh and later the project was partly funded by ODA (now DFID, UK) and partly by the Commonwealth Science Council. Subsequently, I surveyed the genetic diversity of jackfruit in Bangladesh and was partly involved in eight other countries of Asia through the project, Underutilised Tropical Fruits in Asia Network (UTFANET). I took two Ph.D students with me, one worked on "Genetic Diversity of Jackfruit in Bangladesh and Development of Propagation Methods" and the other on the "Diversity of Homestead Farming in Bangladesh". I am pleased to say that we have now found cultigens which are small in size and produce fruits about 1.5 kg in weight.

My continued discussions with farmers, scientists in particular my students, and policy makers of nine countries in Asia as well as my own observations provided information on the benefits and constraints of production, and other field experiences. I gathered copies of valuable unpublished reports and as a result was able to draft this monograph.

Unfortunately, the information in producing areas in Africa and Latin America is very scarce. I have tried hard to collect data but failed to obtain information on genetic diversity, cultural practices adopted or any production figures. However, colleagues from Tanzania, Uganda, Kenya, Brazil and Costa Rica have provided some information which is included. I am grateful to them.

Numerous institutions and individuals have helped me but the list is too long to give in full. I should give credit to those farmers who gave their valuable time to tell me about their crop, to my colleagues from many countries and the team members of the UTFANET project. I thank particularly, Drs A. K. Azad, A. Mannan, A. Hossain, Farid Ahmed, A. Quasem and Mr. A. Bashar from Bangladesh, Drs B.M.C. Reddy, P. Patil, J. N. Daniel and Prof. S. K. Mitra from India, Dr Kudagamage and Prof. Gunasena from Sri Lanka, Drs K. P. Paudual and Shakya from Nepal; Drs P. Faylon, J. Eusebio and Mr Lito Carpio from the Philippines, Mr A. Susiloadi and Dr S. Sastrapradja from Indonesia, Dr Mohammad bin Osman from Malaysia, Dr Songpol Somsiri from Thailand, Drs Vu Manh Hai, Tran Van Lai and Thanh from Vietnam, Mr Campos from Costa Rica, Dr Charles Clement from Brazil and Dr M. Wilson from Tanzania.

I must not forget my colleagues at Southampton, Zoë Dunsiger, Colm Bowe, Angela Hughes, Sonia Bryant and Berekhet Berakhy who helped me in many ways to complete the book.

My thanks to Drs R.K. Arora and S. Azam-Ali and Mr Roger Smith who made very useful comments on the draft manuscripts and my sincere thanks to Prof. Trevor Williams, the Chief Editor of the Monograph Series who has gone through the draft manuscripts repeatedly and helped me to improve the final one.

I hope you all find this book useful.

Nazmul Haq
2006

Chapter 1. Taxonomy, origin and distribution

1.1 Introduction

The domesticated jackfruit tree, *Artocarpus heterophyllus* Lam., is important in tropical and sub-tropical regions, particularly in South and Southeast Asia. The tree is a major component of subsistence and small farmers' farming systems and the fruit often assumes the role of a secondary staple food as well as contributing to the livelihoods of the poor. Jackfruit has been in cultivation in India from ancient times. It was probably taken by Arab traders to the East African coast, and now it has spread throughout the tropics.

The genus *Artocarpus* is a member of the family Moraceae which is part of the tribe Urticales. The family includes a number of economically important species. In the Asian tropics *Broussonetia* species are cultivated for paper pulp and the bast of *Artocarpus elasticus* Reinw. (and other *Artocarpus* spp.) is used locally for fibre for rope and paper (Purseglove, 1968). However, in warm temperate regions and in the tropics, the other members of Moraceae such as species of fig of the genus *Ficus* produce important fruits for humans and for animal fodder. In temperate North America *Maehura* species (a member of Moraceae) provide sour orange-like fruits and in Europe and Asia *Morus* species provide mulberry fruits and also food for silkworms.

It is thought that jackfruit originated in the Western Ghats region of India but whether it is found wild or not is still debatable. Some authorities think there are related wild materials in the Andaman Islands (Haq, pers. comm.); others have proposed that jackfruit originated in Malaysia (Zielenski, 1955; Barrau, 1976).

The lack of knowledge on a precise area of origin relates to inadequate taxonomic research having been carried out, although the work of Jarrett (1959a, 1959b, 1960) has substantially contributed to clarifying much confusion. More recently, molecular research has provided important pointers to which species might form the primary and secondary genepools of jackfruit. However this recent work is preliminary because the research has been done only in Japan, Thailand

and the USA and a limited number of accessions were available for analyses (Kanzaki *et al*., 1997; Schnell *et al*., 2001).

Several *Artocarpus* species bear edible fruits that are economically valuable (Wester, 1921). Breadfruit, *A. altilis* (Parkins.) Fosb., widely grown in the Pacific islands, produces pulp which is cooked in various ways and used in numerous main and side dishes. Jackfruit is eaten fresh, as are fruits of *A. integer* (Thunb.) Merr., the chempedak, which is truly domesticated and locally important in Malaysia and Indonesia.

Two other species are more minor domesticates: *A. odoratissimus* Blanco is well known in Borneo and selected wild forms from Indonesia and Malaysia have been cultivated for fruits in the Philippines; and *A. rigidus* Blume from the Malesian archipelago (covering Malaysia, Indonesia and extending to Papua New Guinea) is another locally important cultigen. There is also a range of wild species of *Artocarpus* whose fruits are gathered for fresh consumption such as *A. lakoocha* Roxb. which is mainly confined to peninsular India and Nepal.

Jackfruit is regarded as a species worthy of research attention because of its wider potential use in nutrition and its potential to increase local incomes when grown in agroforestry and homegarden systems. It is locally sometimes of high value (Rehm and Espig, 1991) and has proved valuable when introduced to other parts of the world where it is fairly widely cultivated in suitable climates (Morton, 1965).

1.2 Moraceae

The Moraceae family contains over 50 genera and over 800 species which are mostly tropical and sub-tropical. However, a few are temperate. Most of the family members are trees and shrubs but all contain latex.

Genera which have stipules leaving amplexicaul scars when they drop off, and straight stamens and ovules near the top of the ovary are included in the sub-family *Artocarpoideae.* This includes *Artocarpus.* The fusion of individual fruits to make a syncarp is seen not only in *Artocarpoideae* but in several genera in other sub-families of Moraceae.

1.3 The genus *Artocarpus*

The name *Artocarpus* is derived from the Greek words *artos* (bread) and *carpos* (fruit) (Bailey, 1942). The genus contains about 50-60 species, distributed throughout the Indo-Malaysian region and in Southern China (Corner, 1938; Bailey, 1949; Campbell, 1984). All the species are monoecious, the male flowers in pseudo-catkins and the female in pseudo-heads. All produce a multiple fruit (a syncarp), the achenes being surrounded by fleshy pulp and the common receptacle becoming fleshy

The genus is usually divided into two sub-genera: *Artocarpus* and *Pseudojaca*. Sub-genus *Artocarpus* has spirally arranged leaves with amplexicaul stipules whereas subgenus *Pseudojaca* has alternate leaves and lateral stipules. In addition the characteristics of the syncarpy are different. In *Artocarpus* syncarps are usually ellipsoid or cylindrical; and the perianth segments are mostly free and always so at their apices. By contrast the syncarps of *Pseudojaca* are more uniform and sub-globose or slightly lobed; the perianth segments are often fused only at the base or along much of the length (Jarrett, 1959b).

Jarrett (1959a) subdivided subgenus *Artocarpus* further into two sections mainly on characters of the inflorescence, including those of the embryo and into several series based primarily, though not solely, on the distinctive, microscopic, capitate hairs on the leaves. They are *Artocarpus* and *Duricarpus* (Jarrett, 1959a). The section *Duricarpus* may represent either an offshoot of section *Artocarpus* or an independent line of evolution within the genus.

Artocarpus heterophyllus belongs to the sub-genus *Artocarpus* and series Cauliflori (Barrau, 1976). The series Cauliflori is distinguished by inflorescences which are cauliflorous or ramiflorous. The inflorescence of *A. heterophyllus* has a basal annulus formed by the enlargement of the top of the peduncle into a narrow flange. The series also includes *A. integer*.

1.4. *Artocarpus* species

Descriptions are provided below for the domesticated species and for some of the better known wild species with edible fruits.

1.4.1 Jackfruit: *Artocarpus heterophyllus* Lam.

The botanical or scientific name of jackfruit was originally reported by Lamarck. The synonyms of the species are: *A. philippinensis* Lam., *A. maxima* Blanco, *Soccus arboreus major* Rumph., *Polyphema jaca* Lour., *A. brasiliensis* Gomez (Corner, 1938; Soepadmo, 1992). However, there is some confusion in relation to taxonomic nomenclature because of various synonyms given to this species. *A. integrifolius* Auct. is often used as a synonym but it actually belongs to *A. integer* (Thunb.) Merr.

1.4.1.1 General morphology

An evergreen medium-sized to large tree, 10-20 m tall, occasionally reaching 30 m, with a long taproot and a dense crown. The crown is conical when the trees are young or grown under shaded conditions and reaches a diameter of 3.5-6.7 m at five years; becoming rounded and somewhat irregular when older. The trunk is unbuttressed and is usually about (80-) 100 (-120) cm in diameter but can be much wider in older trees. The bark is somewhat scaly and greyish brown or dark grey. Branches spread from low down the trunk and are inserted at angles ranging from 30-90º. Twigs are cylindrical and mostly glabrous but sometimes with minute, short, white hairs, becoming glabrous later.

1.4.1.2 Leaves

Leaves are oblong, obovate or elliptic; leaves on upper mature branches tend to be more obovate and those on young shoots more oblong and narrower. Leaves are (2-) 5 (-25) cm long and (2-) 3 (-12) cm wide at or just above the middle where they are broadest. The lamina is coriaceous, stiff and dark shiny green above and pale green beneath, at first hispidous but becoming glabrous underneath. Venation is pinnate with 5-8 (-12) pairs of veins; midrib and main veins are greenish white to pale greenish yellow. Leaves are cuneate or obtuse at the base and entire but irregular shaped leaves can be seen in young plants. The lamina is flat, wrinkled or with upward sides. Leaf apices are blunt, rounded or with a short tip. From the widest point the leaves taper to the

petiole which is dark green, (1-) 3.5 (-5) cm long and grooved on the side facing the stem.

Leaves are inserted alternately on horizontal branches but tend to be spiral on ascending branches with a 2/5 phyllotaxis. Stipules are present, ovate, about (1-5-) 4 (-8) cm long and (0.5-) 1 (-3) cm wide, deciduous , leaving noticeable scars on the stem (Figure 1.1).

1.4.1.3 Inflorescences and flowers

The inflorescences are solitary, both male and female produced separately on short axillary leafy twigs, either on the tree trunk or on older branches. In some cases they can also be borne on the underground parts of the tree, producing fruits protruding from the ground. The individual flowers are borne on an elongated axis and are grouped into a racemoid inflorescence, also called a spike or head.

A large number of flowers are borne on a club-shaped rachis. The female spikes are borne on footstalks while the male spikes are both on the footstalks as well as on the terminal shoots. The terminal shoots, measure about 0.4 cm in diameter, produce only male spikes and each shoot has seven to eight leaves clustered at its end. One male inflorescence is formed per terminal shoot in each flowering season (Manalo, 1986).

There are two types of footstalks: one type is non-bearing, as it produces only male spikes and the other type is fruit-bearing, as it produces female spikes. The non-bearing footstalks appear on branches or stems in early season. They appear as yellow-green, bud-like structures but later develop into leafy, twig-like laterals. These footstalks are thicker than the terminal shoot, 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 the footstalk emergence. The footstalks with female spikes are much more vigorous than those carrying only the male or both male and female spikes.

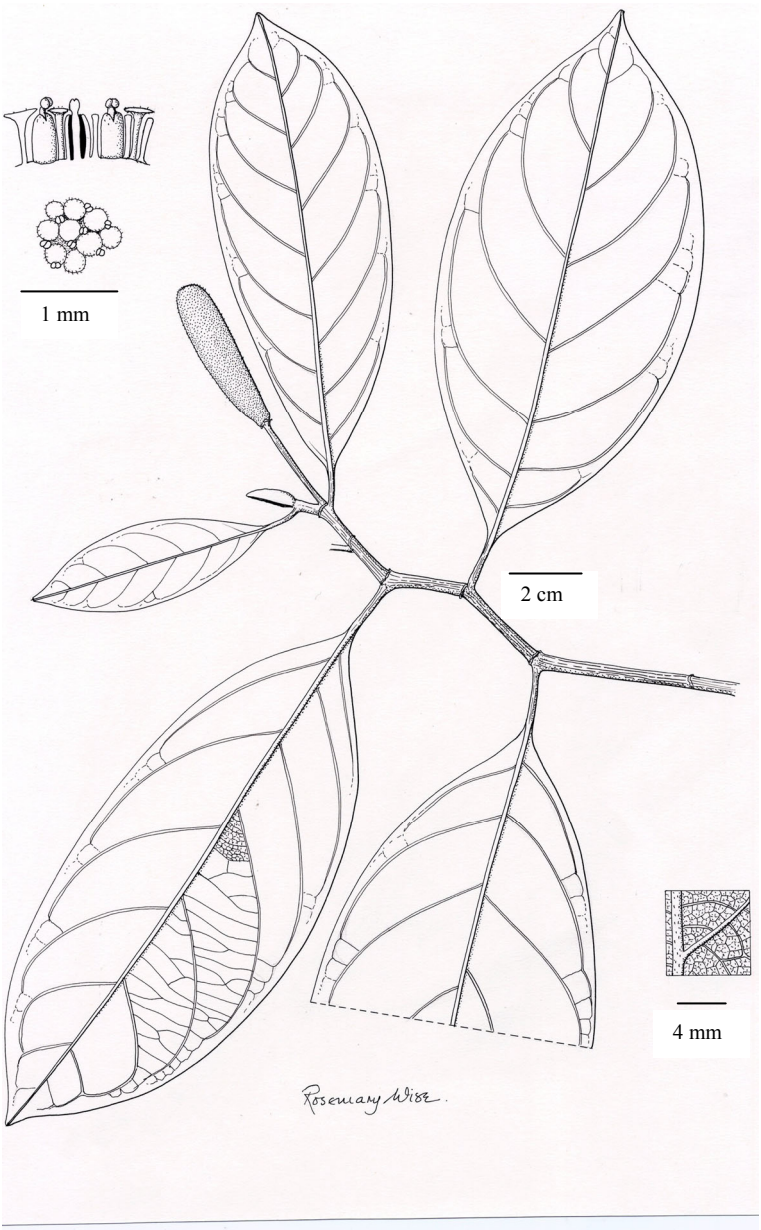


Fig.1.1. A twig of jackfruit, *Artocarpus heterophyllus.*

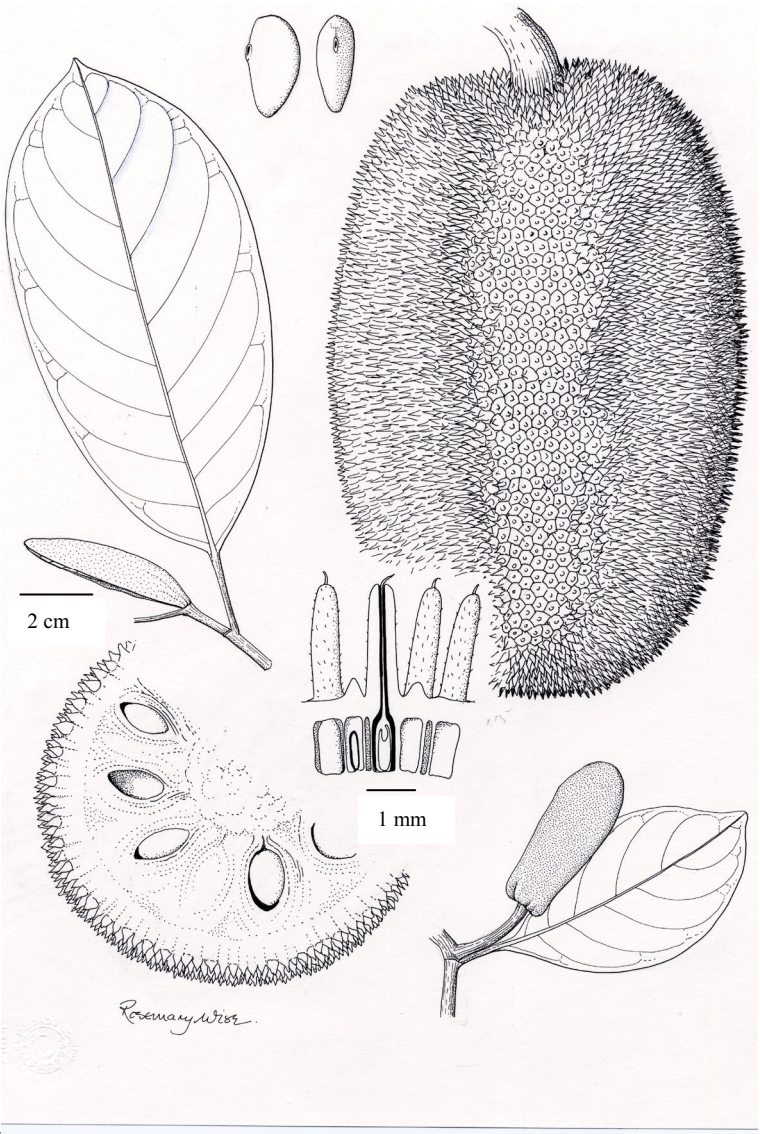


Fig.1.2 Morphological characteristics of fruit parts of *Artocarpus heterophyllus.*

The male inflorescence together with the bud and leaf primodial is sheathed with stipules. As the bud grows larger the stipules open to expose the bud, a new leaf and the spike. At emergence the male spike is 3-3.5 cm long and ca 1.5 cm wide but it increases in size, assuming an oblong clavate shape and reaching 5-10 cm in length and 2-3 cm in width. There are no interfloral bracts.

The male spike is densely covered with small male flowers. Each flower is borne on a peduncle with a green fleshy ring at the apex. Male flowers can be sterile or fertile. The sterile male flower has a solid perianth and the fertile male flower is tubular and bi-lobed. A male flower contains a single long stamen (1-2 mm) and four anthers (Moncur, 1985). These are enclosed in a green leathery tubular perianth which protrudes out of the perianth tube on the surface of the spike. The first stamen appears about 4-6 days after opening and the whole surface of the spike is covered with undehisced yellow anthers. The male spikes gradually turn black after dehiscence, due to growth of mould, and drop after about a week (Jarrett, 1959b).

Female inflorescences are 4-15 cm long and usually found distal to the male inflorescences. They tend to be more cylindrical or oblong than the male. Interfloral bracts are present. Otherwise they resemble the male spikes. The female spikes are composite, large bright green, and have a segmented surface (Alexander *et al*. 1983).

Female flowers have a tubular perianth of free segments when young but fusing in the mid point; perianth encloses a basal compressed ovary with an obliquely inserted terminal style with a club shaped stigma. Stigmatic points are persistently sharp (becoming blunt in mature fruits). Stigmata protrude after 4-6 days of opening of the spathes. The female spikes become woolly with numerous stigmata within another 4-6 days. The receptivity of the stigma remains for 28-36 hours (Sambamurthy and Ramalingam, 1954; Azad, 1989).

The female inflorescences are solitary or in pairs on footstalks (i.e. special leafy branches) and grow out of the trunk and large branches. The female inflorescences have a thicker peduncle than the male inflorescences and often have a fleshy ring at the base. Staminate spikes are produced on the terminal leaf axil and on the footstalks emerging

from primary and secondary branches. When young the spikes are enclosed in thick, leathery and deciduous spathes.

1.4.1.4 Fruits

Jackfruit produces a large yellowish syncarp 30-100 cm long and 25-50 cm in diameter, round-cylindrical to pear-shaped hanging on a stout stalk. The fruit surface is warty with numerous protruding pyramidal sections. The perianths of the individual flowers become the fleshy pericarp and surround the seeds, each pericarp and seed being an individual fruit. The pericarp is yellow-white or yellow and waxy-firm (Corner, 1938).

The fruit axis is the modified mature inflorescence axis and is somewhat dome shaped. It is rigid and slightly fleshy. The axis contains elongated broad parenchyma and vascular elements as well as numerous lacticifers rendering this part of the fruit non-edible. The lower free part of the perianth becomes exclusively fleshy and edible; the middle fused part and the upper free region make up the rind of the fruit; it is the latter which forms the conical studs of the rind and this can differentiate into hairs, sclerenchymatous hypodermis, thick walled ground tissue, vascular elements and fibrous sheathes and lacticifers making the conical regions of the fruit rigid and protective (Figure 1.2 and Plates 1 and 2).

1.4.1.5 Seeds

The seed is firm and waxy, oval, oblong or oblong ellipsoid in shape. Each seed is 2-4 x 1-2 cm in size and 2.5-14 g in weight (Gunasena *et al.,* 1996) with a coriaceous testa. Many flowers on the inflorescence do not produce seeds; normally there are 100-500 seeds in each fruit syncarp.

The testa is thin and leathery and is rather thick, tough, parchment-like and crinkly when dry. The inner seed coat is a thin, brownish membrane. The seed is thickened at the hilum, which is situated with the micropyle in the distal end or near the reticular 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. The endosperm, if present, is very small. The embryo has a superficial radicle (the basal lobe of the smaller cotyledon being undeveloped).

1.4.1.6 Vernacular names

The jackfruit is commonly named jak or jack in English, being adaptations of the Portuguese jaca (Popenoe, 1974). This in turn was derived from the Malaysian tsjaka or chakka. Table 1.1 lists some of the common names of jackfruit:

Table 1.1 Common names of jackfruit

Country	Common names
Bangladesh	Kanthal
Brazil	Jaca
Cambodia	Khnor or Khnaôr
China	Po-lo-mi
Columbia	Jaqueira,
Cuba	Rima
Guyana	Cartahar
India	Kanthal, Kathal, Kantaka, Jaka; Palaamaram (Tamil), Pilavu chakka (Malayan), Halasu (Kanarese), Panasa (Telagu)
Indonesia	Nangka, Nongka, Lamasa, Malasa
Laos	Mak mi, May mi, Miiz or Mizz hnang
Malaysia	Nangka, Tsjaka, Jaka
Myanmar	Peignai
Nepal	Rookh-Katahar
Nicaragua	Castaňo
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),
Sri Lanka	Jak, Palaamaram
Thailand	Khanun, Makmi , Banun
USA: Puerto Rico	Jaca
Vietnam	Mit
Zanzibar	Fenesi

Further common names in specific languages

English: Jackfruit, jak, jack, jaca-tree,

French: Jacque or jacquier, jack,

Spanish: Jaca, jacquero

Dutch: Nangka, jacca

German; Jacabaum, Jackbaum,

Portuguese: Jaqueira, Jaca, Jaca da Baia.

1.4.1.7 Domestication

Jackfruit is not known in the wild although some authorities believe that wild forms may be found in the Andaman islands. It is thought to have originated in evergreen rain forests of the Western Ghats of India between 400 and 1200 m above sea level. Its domestication took place in the distant past and it spread in cultivation throughout South and Southeast Asia until colonial times when it was introduced elsewhere.

Due to its natural cross pollination and protandry jackfruit trees show great variability. However, over time, a large range of cultivars have been identified and they tend to fall into two groups:

(i) those with soft-fleshed fruits, which are generally acid to sweet in taste with a strong odour; and

(ii) those with firm fleshed fruits, which are generally crisp, sweet to slightly acid and less odorous.

1.4.2 Chempedak: *Artocarpus integer* (Thunb.) Merr.

Syn: *A. champeden* (Lour.) Stokes. Two other synonyms are illegitimate: A. *integrifolia* L.f. and *A. polyphema* Pers.

1.4.2.1 Description

Chempedak is an evergreen tree similar to jackfruit and of about the same size. It differs by the leaves, twigs, buds and peduncles having large brown hairs (up to 3 mm), although some wild types are glabrous.

Leaves are smaller than those of jackfruit and narrow abruptly to the petiole and are sharply tipped. Stipules are large 5-25 x 2.5-12 cm. Leaf veins are curved forward.

The male and female inflorescences are cylindrical. Female styles are filiform. Fruits are yellow to orange and smaller than jackfruit, usually 20-30 x 10-15 cm and they often have a very strong smell. They are eaten as dessert fruits or cooked and the yellow pulp has a sweet aromatic taste.

The wood is used for a yellow dye and the bark for tannin.

1.4.2.2 Domestication

Chempedak occurs wild in Malaysia and Indonesia, especially in Borneo and Sumatra where it is restricted to primary and secondary forests in areas with a distinct dry season. Attempts have been made to classify the wild forms in primary and secondary lowland tropical rain forests as var. *silvestris* but this is not valid.

It is somewhat popular in Southeast Asia and cultivated in Thailand, Myanmar, Malaysia and Indonesia. It is also grown in Australia and the USA.

1.4.3 *Artocarpus odoratissimus* Blanco

Syn: *A. mutabilis* Becc.; *A. tarap* Becc.

1.4.3.1 Description

An evergreen tree up to 20 m tall with the mature trunk about 40 cm diameter, sometimes possessing buttresses. The bark is light brown and has obvious lenticels.

Leaves are much bigger than jackfruit although similar with 13-15 pairs of pinnate veins. Leaves, twigs and stipules are stiff and hairy on both surfaces.

Fruits are globose ca 12-15 cm in diameter and the flesh is white, aromatic and sweet. They are eaten fresh and also prepared into processed products.

1.4.3.2 Domestication

Unlike chempedak, this species is a canopy dominant which occurs in secondary forests below 1000 m altitude in the wild. It is cultivated in Sarawak and in many parts of Indonesia, and has been introduced to the Southern Philippines, especially in Mindoro, Mindanao, Basilan and the

Sulu Archipelago (Coronel, 1983). It is thought that maximum diversity occurs in wild forms in Brunei.

1.4.4 *Artocarpus rigidus* Blume

Syn: *A. dimorphophylla* Miq.

1.4.4.1 Description

A tall tree up to 35 m high with a dense dark green spreading crown supported by several major upward angled branches. The trunk is large and the bark is grey-brown and rough.

Leaves are larger than jackfruit with 11-15 pairs of veins. Leaf blades are obovate, elliptic, blunt or slightly tipped, narrowed to the base, dark shiny green, stiff and rigid. Blades are 4-9 cm long and the petioles have short hairs on their undersides but their upper sides (except midrib) are glabrous.

Male flower heads are globose and are flattened oval in shape and yellow in colour.

Fruits are roundish, 7.5-12.5 cm wide, thickly set with stiff conical spines, greenish yellow becoming dull orange. The stalks are 1-1.5 cm long, sunk in the fruit. The pulp is yellow and has a sweet, pleasant flavour.

The seeds are covered by the waxy pulp and are roasted and eaten in many parts of tropical Asia.

The wood is yellow to orange red, fairly heavy, durable and resistant to termites. Its sticky latex is used in batik and the wood is used for making furniture (Plate 3), native boats and building houses.

1.4.4.2 Domestication

Artocarpus rigidus is distributed in lowland forest in India, Myanmar, and Malaysia, and in Sumatra, Kalimantan and Java in Indonesia where it is also cultivated in homestead gardens.

1.5 Other *Artocarpus* species bearing edible fruits

Table 1.2 shows those wild species of *Artocarpus* from which fruits are gathered regularly in their native habitats. Data are from Burkill (1935); Jarrett (1959 a, b); Sastrapradja (1975); Arora (1985) and Martin *et al*. (1987).

Table 1.2 Other *Artocarpus* species bearing edible fruits

Species	Distribution
Artocarpus anisophyllus Miq. var. *sessilifolius* K. M. Kochum.	Malaysia
A. blancoi (Elm.) Merr.	Philippines
A. chaplasha Roxb.	India, Thailand, Myanmar, Indo-China
A. cumingiana Tréc.	Philippines
A. dudak Miq.	Sumatra, Malaysia
A. elasticus Reinw.	Malaysia, Indonesia, Philippines
A. fulvicortex Jarrett	Malaysia, Indonesia
A. glauca Blume	Java
A. gomeziana Wall.	Malaysia
A. involucrata K. Schum.	Papua New Guinea
A. kemando Miq.	Indonesia, Malaysia
A. lakoocha Roxb.*	India, Nepal, Malaysia, Bangladesh
A. lanceaefolius Roxb.	Malaysia, Thailand
A. lowii King	Thailand, Penisular Malaysia
A. maingayi King	Malaysia
A. nitidus Tré.	China, IndoChina, Thailand, Malaysia, Borneo, Sumatra
A. nobilis Thw.	Sri Lanka
A. rotundata Merr.	India, Malaysia
A. sarawakensis Jarrett	Sumatra, Malaysia

*Also occasionally cultivated

1.6 Origin and distribution of jackfruit

There is a controversy in the literature about the exact region of origin of jackfruit. Some authors believed that Malaysia could be the possible centre of origin (Ruehle, 1967), while Martin *et al*. (1987) reported that jackfruit is indigenous to tropical Asia. However, most authors believe that it originated in the rain forest of the Western Ghats of India (Hayes, 1953; Ochse *et al.,* 1961; Purseglove, 1968; Popenoe, 1974; Rowe-Dutton, 1985; Singh, 1985; Morton, 1987; Soepadmo, 1992). It then spread in cultivation to neighbouring South and Southeast Asian countries and to Southern China.

It is believed to have been introduced to the Philippines during the twelfth century AD, when the coastal Filipinos started to trade commodities, including plant produce with India, Malaysia and China (Pelzar, 1948).

Jackfruit is now widely grown in many Asian countries especially Bangladesh, Myanmar, Nepal, Sri Lanka, Thailand, Malaysia, Indonesia, India and the Philippines. It is also grown in Southern China and in the Indo-Chineese region in Laos, Cambodia and Vietnam (Manjunath, 1948; Morton, 1987; Narasimham, 1990; Gunasena *et al.,* 1996). From Asia it spread to tropical Africa especially the eastern part: Zanzibar, Kenya, Uganda and Madagascar. It is also grown in Mauritius.

From the mid-seventeenth century to the late nineteenth century, the species spread further to tropical and subtropical America (Brazil, Surinam, the Caribbean and USA) and Australia (Morton, 1965; Purseglove, 1968; Popenoe, 1974). Morton (1987) reported that in 1782, plants captured from a French ship bound for Martinique were taken to Jamaica where the tree is now common. In Australia it is grown mostly in the tropical regions of north Queensland and around Darwin in the Northern Territory where its fruits are available for most of the year. Jackfruit trees which might have been introduced from Sri Lanka were grown in Florida in the 1880s. Many seedlings were planted and they survived in South Florida. Jackfruit was introduced into northern Brazil in the mid-nineteenth century and is more popular there and in Surinam than elsewhere in the New World. Prior to 1888 it was planted in Hawaii but it is rare in other Pacific islands, as it is in most of tropical

America. Jackfruit has been dispersed even further to other tropical and warm subtropical regions where it is widely cultivated at low and medium elevations.

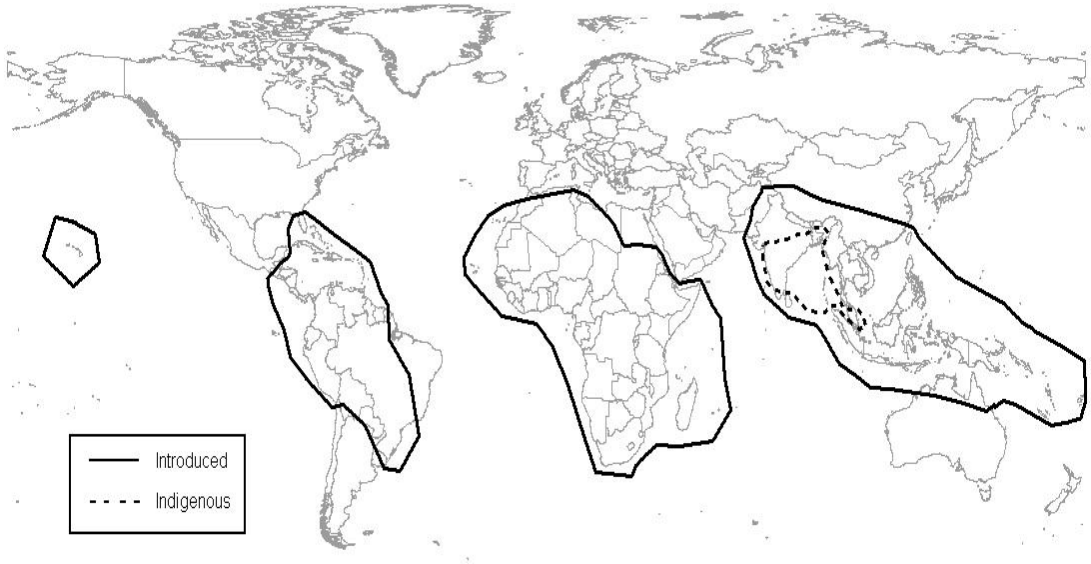
A compilation of the distribution from all known references is shown in Table 1.3 and Figure 1.3.

Table 1.3 Distribution of jackfruit by country

Indigenous	Introduced
Bangladesh	Algeria, Angola, Australia
India	Benin, Bolivia, Botswana, Brazil, Burkina Faso, Burundi
Malaysia	Cambodia, Cameroon, Cape Verde, Central African Republic, Chad, China, Comoros, Costa Rica, Cote d'Ivoire
	Democratic Republic of Congo, Djibouti
	Ecuador, Egypt, Equatorial Guinea, Eritrea, Ethiopia
	Fiji
	Gabon, Gambia, Ghana, Guinea, Guinea-Bissau
	Honduras
	Indonesia, Ivory Coast
	Jamaica
	Kenya
	Lesotho, Liberia, Libya
	Madagascar, Malawi, Mali, Mauritania, Mauritius, Morocco, Mozambique, Myanmar
	Namibia, Nepal, Niger, Nigeria
	Pakistan, Panama, Papua New Guinea, Paraguay, Peru, Philippines
	Rwanda
	São Tomé et Principe, Senegal, Seychelles, Sierra Leone, Somalia, South Africa, Sri Lanka, St. Vincents, Sudan, Surinam, Swaziland
	Tanzania, Thailand, Timor, Togo, Tunisia
	Uganda, United States (Florida, Hawaii)
	Vietnam
	Zambia, Zimbabwe

Sources: ICRAF Database, Bowe (pers.comm.)

Fig. 1.3 Indigenous and introduced areas of *Artocarpus heterophyllus*



Source: ICRAF database and Bowe (pers. comm.)

1.6.1 Climate and ecology

The jackfruit is adapted to humid tropical and sub-tropical climates. It thrives from sea level to an altitude of 1600 m. The species extends also into much drier and cooler climates than that of other *Artocarpus* species (Popenoe, 1974) such as breadfruit. Jackfruit can be grown in a wide range of climates from intermediate to wet and moist types in India and Sri Lanka. The tree bears good crops particularly between latitudes of up to 25º N and S of the equator, and up to 30º N and S (Soepadmo, 1992). Trees grown above 1330 m grow poorly and the fruits if any are of poor quality. The quality is better at the lower elevation, from 152-213 m (Crane *et al.*, 2003).

For optimum production, jackfruit requires warm, humid, climates and evenly distributed rainfall of at least 1500 mm (Baltazar, 1984; Concepcion, 1990). Growth will be retarded if rainfall is less than 1000 mm. Jackfruit trees are not tolerant of continuously wet and/or flooded soil conditions and trees may decline or die after 2-3 days of wet soil conditions. For the production of jackfruit the annual rainfall should be 1000-2400 mm or more.

Although it thrives in a moist tropical climate jackfruit is adapted to a wider range of conditions. It is tolerant of lower temperatures, and indeed mature trees are reported to have survived a temperature of -3º C in Florida. The leaves of the tree may be damaged at 0º C, branches at -1º C, and branches and trees may be killed at -2º C. The trees are tolerant of mild to moderately windy conditions. They have been observed to survive and recover from hurricane force winds when some branches have been damaged.

The tree prefers well-drained soils. It is grown on a variety of soils: deep alluvial, sandy loam, or clay loam of medium fertility, calcareous or lateritic soil, shallow limestone or stony soil with a pH of 5.0-7.5. In shallow soil the growth of the tree can be slow and the tree may not be tall, robust or vigorous. The tree exhibits moderate tolerance to saline soils.

Chapter 2. Properties and uses

The primary economic product of jackfruit is the fruit, used both when immature and when mature. The fruit pulp is sweet and tasty and used as dessert or preserved in syrup. The seeds contained in the ripe fruits are also cooked. The fruits and seeds are also processed in a variety of ways for food and other products. Processed products are described in Chapter 6. Additionally jackfruit is used in traditional medicine (leaves, bark, inflorescences, seeds and latex). The wood of the tree is used for a range of purposes.

2.1 Fruits

Immature green fruits are widely harvested for use as a vegetable and are cooked and used like potato, often sautéed with chicken, fish or egg. However, the bulk of fruits are allowed to mature to be harvested for dessert fruits despite a somewhat pungent odour.

The composition of ripe fruits and seeds is shown in Table 2.1. The texture of the pulp varies according to variety. The sweetest varieties tend to have juicy soft flesh. Less sweet varieties have firm and crisp pulp.

2.1.2 Pulp

Apart from use as a dessert fruit, ripe pulp is used to flavour products such as ice cream and beverages. The pulp can also be made into concentrate or powder to be used to prepare drinks. Fresh pulp is used to prepare jams, chutneys, jellies or candies. It can be canned in syrup, sometimes on its own, but especially with other mixed fruits. “Pulp leather” is popular in many countries.

Canned pulp can be mixed with ethyl and n-butanol esters of 4-hydroxybutyric acid at 100 ppm to improve the flavour.

In some areas fresh pulp is mixed with milk, and then drained off to leave an orange coloured custard. In Malaysia pulp is sometimes fermented and distilled to produce liquor.

The pulp of young raw fruits can be canned in brine, canned in curried form or mixed with other vegetables. These products are then used for sour or sweet pickles in oil or in vinegar. If dehydrated, the powder can be used to flavour papadams. Dried pulp is made into chips.

Table. 2.1 Composition of the edible parts (100 g edible portion) of jackfruit (on the basis of fresh weight).

Composition	Young fruit	Ripe fruit	Seed
Water (g)	76.2-85.2	72.0-94.0	51.0-64.5
Protein (g)	2.0-2.6	1.2-1.9	6.6-7.04
Fat (g)	0.1-0.6	0.1-0.4	0.40-0.43
Carbohydrate (g)	9.4-11.5	16.0-25.4	25.8-38.4
Fibre (g)	2.6-3.6	1.0-1.5	1.0-1.5
Total sugars (g)	-	20.6	-
Total minerals (g)	0.9	0.87-0.9	0.9-1.2
Calcium (mg)	30.0-73.2	20.0-37.0	50.0
Magnesium (mg)	-	27.0	54.0
Phosphorus (mg)	20.0-57.2	38.0-41.0	38.0-97.0
Potassium (mg)	287-323	191-407	246
Sodium (mg)	3.0-35.0	2.0-41.0	63.2
Iron (mg)	0.4-1.9	0.5-1.1	1.5
Vitamin A (IU)	30	175-540	10-17
Thiamine (mg)	0.05-0.15	0.03-0.09	0.25
Riboflavin (mg)	0.05-0.2	0.05-0.4	0.11-0.3
Vitamin C (mg)	12.0-14.0	7.0-10.0	11.0
Energy (Kj)	50-210	88-410	133-139

Sources: Arkroyd *et al,* (1966); Narasimham (1990); Soepadmo (1992); Gunasena *et al,* (1996); Azad (2000).

2.1.3 Rind

Rind from the fruits (including the perianths of unfertilised fruits) is often mechanically processed for syrups and jellies. It can also be the basis for pectin extracts.

Rinds and other waste parts of the fruits have high value as a nourishing feed for livestock, especially for sheep (Sudiyani *et al.,* 2002). The digestibility is optimised when supplemental nitrogen is provided. For cattle, molasses-urea cake is fed along with the jackfruit waste for this purpose.

2.2 Seeds

Jackfruit seeds are nutritious, rich in potassium, fat, carbohydrates and minerals. They are ingredients for many culinary preparations. The seeds are eaten after boiling or roasting, or dried and salted as table nuts, or ground to make flour which is blended with wheat flour for baking. Jackfruit seeds can be used in brine alone or in curried form, similar to the use made of immature fruits, by eliminating trypsin inhibitors through heating (Siddappa, 1957)

2.3 Leaves and flowers

The leaves are not eaten by humans but are used as food wrappers in cooking and fastened together to make plates in many parts of the Indian subcontinent. However, young leaves are readily eaten by cattle and other livestock. Sole feeding of jackfruit tree leaves can meet the maintenance requirements of goats (Plate 4). Similar results have been reported from the evaluation of digestibility of leaves for pigs (Ly *et al.,* 2001).

Jackfruit leaves are good sources of calcium (Ca) and sodium (Na) and if combined with rice bran give better growth for ruminants. Islam *et al*. (1997) reported that the digestibility was higher when jackfruit leaves were supplemented with black gram bran for goats. Thanh Van *et al*. (2005) found that mixtures of jackfruit

foliage with *Flemingia macrophylla* gave higher intake than jackfruit foliage alone when fed to cattle.

Flowers are used as food in salads and they can also be cooked as vegetables for humans.

2.4 Use of jackfruit in traditional medicine

Although several authors have mentioned the use of various parts of the jackfruit tree in local medicine (Fernando *et al*., 1991; Blasco *et al.,* 1996; Sato *et al*. 1996; Uniyal, 2003 and Tirkey *et al.*, 2001) its use for such purposes is not substantiated nor common. The recommendations of a range of medical practitioners in tropical Asia are shown in Table 2.2. However no major clinical evidence is available.

Current information on the possible efficacy of some of the remedies might be based upon some limited phytochemical screening and the very limited amount of clinical testing that has been done (Tirkey *et al.*, 2001).

Extracts of leaves have been found to promote glucose tolerance when tested on diabetics. Khan *et al.* (2003) reported that the butanol fraction of root bark and fruit extracts were active against a range of bacteria and protozoa. Hot water extraction of leaves contains flavonoids, anthocyanins, tannins, and proanthocyanidin which increase the glucose tolerance of diabetics.

The heartwood shows 2 active compounds : 6-(3methyl-l-butenyl)-5,2',4'-trihydroxy-3-isoprenyl-7-methoxyflavone and 5,7,2', 4'-tetrahydroxy-6-isoprenylflavone. These isoprenylflavones are potent compounds for the prevention of dental caries (Sato *al.,* 1996).

Table 2.2 Putative use of jackfruit in local medicine (no clinical evidence is available)

Plant part	Use
Roots	An extract of roots is used in treating skin diseases, asthma and diarrhoea.
Leaves	An extract from leaves and latex cures asthma, prevents ringworm infestation and heals cracking of feet. Leaf extract is given to diabetics as a control measure. Heated leaves are reported to cure wounds, abscesses and ear problems and to relieve pain. An infusion of mature leaves and bark is used to treat gall stones. A tea made with dried and powdered leaves is taken to relieve asthma. The ash of jackfruit leaves burned with maize and coconut shells is used alone or mixed with coconut oil to heal ulcers.
Flowers	Crushed inflorescences are used to stop bleeding in open wounds.
Fruits	Ripe fruits are laxative.
Pulp	The Chinese consider jackfruit pulp and seeds to be a nutritious tonic and "useful in overcoming the influence of alcohol on the system".
Seed	The seed starch is given to relieve biliousness. Roasted seeds are regarded as an aphrodisiac. Increased consumption of ripe jackfruit kernels alleviates vitamin A deficiency. Extract from fresh seeds cures diarrhoea and dysentery. Extract from seeds (or bark) helps digestion.
Bark	An extract from bark and rags (non-edible portion of ripe fruits) or roots helps cure dysentery. The bark is made into poultices. Ash produced by burning bark can cure abscesses and ear problems.
Latex	Mixed with vinegar, the latex promotes healing of abscesses, snakebites and glandular swellings.
Wood	The wood has a sedative property, its pith is said to aid abortion.

Seeds contain two lectins, jacalin and artocarpin. These have attracted considerable attention for their diverse biological activities and have been recognised as a Gal beta 1-3GalNAc (T) specific lectin. Jacalin has been seen to inhibit the herpes simplex virus type 2 and has proved to be useful for the evaluation of the immune status of patients infected with human immunodeficiency virus 1 (HIV1). The abundant source of materials for the production of jacalin, its ease of purification and its yield and stability have made it an attractive cost-effective lectin. This is used for the isolation of human plasma glycoproteins (IgA1, Cl-inhibitor, hemopexin, alpha 2-HSCG), the investigation of IgA-nephropathy, the analysis of 0-linked glycoproteins and the detection of tumours (Kabir, 1998).

2.5 Jackfruit wood

Jackfruit trees are an important source of timber throughout the whole of the Indian subcontinent. The timber is easily seasoned and resembles mahogany. It takes polish beautifully and a smooth surface can be achieved with appropriate tools.The wood tends to change colour with age from yellow or orange to rich brown red. It is classed as a medium hardwood. The natural durability of the timber against fungi, bacteria and termites is very high (Soyza, 1973). The timber has a high market demand, second to teak in many Asian countries (Gunasena *et al.,* 1996). India exports jackfruit timber to Europe.

Wood from four to seven year old trees is often used for furniture, house construction and a range of wooden products such as masts, doors, chairs and musical instruments. In Indonesia the timber is valued for use in chieftains' palaces and in Indochina it has often been used in temple constructions.

In Sri Lanka small holders recognise the multi-purpose uses of the jackfruit tree when deciding which trees to plant in homegardens. In that country jackfruit tree is included in a special commercial class and there is an official requirement to obtain a permit to cut

or to transport jackfruit timber although much is used at the farm level without obtaining such a permit. Jackfruit timber commands a good price, similar to that of mahogany but lower than that of teak, in the local market. Use for timber is not part of the survival strategy by small-scale farmers (Wickramasinghe, 1992). If felled for timber, smallholders consider the need to regenerate trees, in relation to the other, mostly food uses of the jackfruit. However, in some homegardens jackfruit trees make up to 17-29% of the trees in the gardens (Wickramasinghe, 1992).

The composition of jackfruit wood has been determined (Komarayati, 1995). It contains 56% cellulose, 28.7% lignin and 18.64% pentosan. When used as fuelwood it can yield 38.74% charcoal with a calorific value of 7183.37 cal/g (Komarayati, 1995). Charcoal briquette properties are also good, with 5.10% moisture, 3.06% ash, 71.23% fixed carbon, 25.51% volatile matter, density 0.63% g/cm^3, compression strength 350kg/cm^3 and a calorific value 6487.28 cal/g.

The tree bark produces a dark, water-soluble, resinous gum that contains ca 3.3% tannin. The inner part of the bark is occasionally made into cordage or cloth (Purseglove, 1968).

Heartwood chips or sawdust yield a yellow dye when boiled with alum. Buddhist priests use this to colour silk and cotton robes. In addition to the yellow colourant, morin, the wood contains the colourless cyanomaclurin and a newly discovered yellow colouring matter, artocarpin.

Splinters of heartwood are stored in bamboo tubes and used to colour sugar yellow in Indonesia.

2.6 Latex

The latex contains 71.8% resins consisting of 63.3% yellow fluavilles and 8.5% white albanes) which are valuable in varnishes. The latex is used to mend earthenware and other utensils, to seal leaks in boats and for trapping birds (the use of which should be discouraged in the interests of biodiversity conservation). The latex has been used as a substitute for rubber in India and Brazil. The dried latex yields artostenone, convertible to artosterone, a compound with androgenic action (Morton, 1987), (http://216.239.59.104/search?q=cache:eFTYNyFe4-MJ:212.49.82.53/egranary/NonScrapedContent/Agriculture/FOWC/jckfruth.pdf+artosterone&hl=en&gl=uk&ct=clnk&cd=6).

2.7 Use in agroforestry

Jackfruit has become a component of village gardens in many parts of the tropics including countries where introduced and as such has been documented e.g. in Brazil and Costa Rica. (Falacao and Clement, 2001)

There is currently a great deal of interest in expanding the use of jackfruit in agroforestry and household farming systems. Jackfruit is often planted in coconut groves in the Philippines (Acedo, 1992) and has been used as an intercrop in durian (*Durio ziberthinus*) orchards in Malaysia (Acedo, 1992). In the Indian subcontinent it is intercropped with other fruit trees such as mango, *Mangifera indica,* and *Citrus* species. The trees are also used as shade for coffee or areca nut and as living supports for black pepper (*Piper nigrum*) vines (Hossain and Haq, 2006). In Bangladesh it is a dominant tree on household farms where it is grown with many perennial trees and annual crops (Mannan, 2000). Haq (2003a) recommended jackfruit use in the high and medium highlands in Asia as well as in homesteads in association with different species. Differing systems are however needed for the different agro-climatic conditions in Bangladesh. For example, jackfruit trees have been planted on bunds or dykes surrounding rice or wheat field margins on small farms to increase the land use. Although both crops grow well, the results of trials show that this

production system is not economic as the loss of annual crop yield near the borders is not compensated by the income from the jackfruit (Hocking *et.al*., 1997). However, further work in developing this system is justified before a final conclusion can be reached. Jackfruit trees around margins are found in many traditional systems in Asia. A favoured one in Arunachal Pradesh in India is a range of trees interspersed with bamboos either *Dendrocalamus hamiltonii* or *Bambusa tulda* (Deb *et al*., 2005).

Jackfruit as a component of village forests or homegardens is seen in the Kebun of Malaysia and the Kampong of Indonesia (Soepadmo, 1992). The village multi-storey tree orchards are called Pekarangan and may account for 40% of the land. Jackfruit trees form part of the middle layer of the upper canopy along with fruits such as rambutan, mangosteen and several palm species. In this species combination, it is a seasonal producer.

Jackfruit is reported to be a good tree to use on degraded lands in Asia and Africa where it can benefit reforestation programmes intended to protect watersheds (Haq, 2003a).

Jackfruit is sometimes found growing near the sea shore in Bangladesh indicating that some ecotypes are moderately tolerant to saline conditions and can therefore be grown on saline areas if truly tolerant genotypes are available (Mannan, 2000; Haq, 2002).

2.8 Socio-cultural aspects

There is an old saying in Sri Lanka that "with a jak and a coconut in your backyard you will never starve". Jackfruit leaves are often used in Hindu temple worship.

The following fable indicates the long association of jackfruit with human culture:
(www.ecolanka.net/gmsl/heraliya/legends_and_society.htm)

Long ago, before historic times, a severe famine occurred and a large number of men, women and children died due to starvation in the country which is now called Sri Lanka. The chief of all Gods, Sakkra Deva, realised that this was a signal of some sort of impending calamity in the human society. Deva, became watchful and saw the dreadful devastation caused by the famine. He then disguised himself as a beggar and quietly stepped into a cottage in a village where he saw a very feeble, starving old woman. The beggar asked for something to eat and the woman said that she did not have any food at home. The beggar then asked her to pluck one of those thorny nuts, peel it and boil the axils for him. The woman did as she was told but was so hungry she served herself and kept on eating and finished all of it. The beggar came back and found nothing in the pot and cried "Heraliya! Herilaya!" (thief woman! thief woman!). This thorny fruit is known as Herilya and today the jackfruit is called Heralia in Sri Lanka.

In Nepal, people refrain from travelling in the vehicle in which jackfruit is transported as they believe that accidents will occur because of the jackfruit smell. This superstitious belief hinders transportation of fresh fruits for marketing (Shakya, pers. comm.).

2.9 Environmental value

The jackfruit canopy provides perennial cover to the soil, acting as a shade tree and absorbing the impact of rain on the soil. In upland situations jackfruit trees are usually planted on slopes and hills to help control soil erosion (Hossain and Haq, 2006). They can also be planted to help absorb groundwater to minimise flooding, as the tree has a widespread root system.

The rate of decomposition of jackfruit leaves is rapid, adding to soil organic matter and helping to maintain soil moisture through the mulching effect. The trees are tolerant of mild to moderately windy conditions and have been observed to survive and recover from hurricane force winds with only minor damage to branches. The trees are occasionally planted as windbreaks in orchards in Peninsular India. The trees can reduce the effects of wind, if planted around a homestead.

Chapter 3. Agronomy

3.1 Field establishment

Jackfruit is often planted in homestead gardens, in orchards, or as an intercrop in other plantations such as a shade tree in coffee, arecanut, cardamom and pineapple plantations and as a support for black pepper vines. It performs well as a part of many agroforestry systems. However, it grows at its best in open areas in full sunshine. It can be planted in any tropical or sub-tropical soil type other than in saline, waterlogged or flood prone soils.

The intended scale of production and the condition of the land determine the type of field preparation required. For homestead gardens and small orchards land preparation only requires the digging of planting holes large enough to accommodate the ball of soil and roots that goes with the planting material (Coronel, 1983). For commercial or large scale plantations on virgin sites the areas should be cleared, then ploughed and harrowed several times until a desired tilth is attained. Where the land has secondary forest growth the trees should be cut down, the stumps removed or burned, and the whole area cleared before digging holes.

Under average conditions jackfruit can begin fruiting three to five years after planting, but most cultivars take about seven to eight years to reach good levels of production. In Bangladesh, *in vitro* propagated plants begin fruiting at three years and the fruiting season lasts about four months.

3.2 Direct seeding

Direct seeding is a common practice in homestead gardens. Small holes or planting pits approximately 50 x 50 x 50 cm in size are dug and then filled with soil mixed well with cowdung or compost at the rate of 20-30 kg per pit. The pits are then watered liberally to settle the soil in the planting pit.

Two or three freshly extracted seeds from ripe fruits collected from a desirable mother tree are planted 2-3 cm deep into the soil, the soil is pressed firm with the thumb and watered lightly. The seeds should be planted in a triangular formation 30 cm apart. After sowing, pits are covered with mulch and regularly watered, depending upon the soil moisture conditions and the weather. However, excess watering needs to be avoided as this may cause rotting of seeds and germinating seedlings.

Shortly after germination the most vigorous seedling should be retained in each pit and others should be removed. In order to protect the young plants from grazing damage, fencing is necessary as illustrated in Plate 5.

Seed propagation is still the most popular method of reproduction in all jackfruit growing countries. However, due to variation in the growth and performance of seedlings, this is being discouraged. Seed propagation is also necessary to raise rootstocks for vegetative propagation (see section 3.4) which removes such variation in planted trees. Also, trees produced from seed take a longer time to bear fruit and grow taller (making them more difficult to manage and harvest) than do trees produced by vegetative propagation (see section 3.9.2). There are some advantages gained from seed propagation. The method is simple and easy to repeat; the new trees are also generally deep rooted with a strong tap root, facilitating firm anchorage, access to a wider nutrient base and greater resistance to drought. The tall trees grown from seed tend to produce a substantial trunk which is valuable for timber.

3.2.1. Seed germination

In Sri Lanka seeds are germinated in coconut husks containing sufficient soil to cover them and then planted in the field along with the husks after one or two years (Gunasena *et al*., 1996).

Seeds cannot survive desiccation and cannot be stored for long periods since they lose viability. It is advisable to sow seeds as soon as possible after extraction from the fruit. Seeds should be washed to remove the slimy coating. Storage in bags for as little as

21 days can cause loss of viability. Where seed storage is necessary, seeds should be stored at 40% of their original moisture content in airtight polythene containers at 20^0C, when they can remain viable for about three months. Seeds can also be stored for a short period if they are buried in dry sand or coir dust for a month (Soepadmo, 1992) but their viability deteriorates rapidly thereafter. If they have been extracted for some days they should be soaked in water for 24 hours (Singh, 1969).

Eighty-five percent of seeds germinate if planted within 15 days of extraction. Under suitable conditions germination begins within 10 days and 100% germination is achieved within 35-40 days after sowing. Germination rate declines to 40% if planted after 30 days of storing. Large seeds tend to germinate better and produce more vigorous seedlings (Sonwalker, 1951; Khan, 2004).

Various authors have shown that various growth regulators at different concentrations can promote germination. Ninety-eight percent germination has been obtained with seed soaking in gibberellic acid. The time required for maximum germination was about 11 days (Maiti *et al*., 2003). When seeds were soaked for 24 hours in 25 ppm 1-naphthalenacetic acid NAA (Sinha and Sinha, 1968) 76.7% germination was obtained and 100% germination was obtained when seeds were soaked in up to 500 ppm gibberellic acid GA_3 (Shanmugavelu, 1971). GA_3 is found to be more effective for promoting germination than 3-Indolebutyric acid IBA and p-chlorophenoxyacetic acid CPA. Singh and Bhatacharya (2003) recorded 85% germination when seeds were pre-treated with 10^{-3} M ferulic acid.

Germination of jackfruit seed is either sub-epigeal (Corner, 1938) or hypogeal (Soepadmo, 1992). Poly-embryony also occurs in jackfruit and the phenomenon is induced by presoaking the seeds in gibberellic acid.

A jackfruit seedling is shown in Plate 6.

3.3 Transplanting

Seedlings raised in polybags in a nursery or vegetatively propagated (grafted) plants are increasingly being used for field planting. Pit planting is the accepted and common method of planting jackfruit trees. For grafted plants the spacing is 8 x 8 m. A square pattern is usually adopted but this may be hexagonal on less fertile soil. The pits are dug at least four weeks before planting, kept open for two weeks and then filled in as described for direct seeding. One to two year old seedlings or grafted plants about 1-2 m tall are planted in the centre of the pits with the root collar at ground level ensuring that they are planted at the same depth as they were grown in the nursery.

During transplanting the nursery polybags should be completely removed before planting and care must be taken not to disturb the delicate root systems. It is recommended that leafy branches and unwanted shoots or leaves be pruned by about half or two-thirds to avoid excessive transpiration of the newly planted trees. After planting, the soil in the pit is firmly pressed and flattened around the base of the tree and watered immediately. A circular bund about half a metre away from trunk will facilitate retention and distribution of irrigation and rain water into the root zone (Hossain and Haq, 2006).

A stake should be inserted by the side of each tree to provide support making sure that the tree tie does not damage the stem of the young plant. The tree stake should be removed when the plant is established and able to support itself, usually after about one year. The saplings need to be protected from animals by fencing either individual trees or the whole area. Banana leaves or other materials are used in many countries to protect the transplanted trees from scorching in strong sunlight.

Transplanting time varies due to climate and weather but is best done at the start of the rainy season. However, planting can be done at any time of the year if water is available.

3.4 Propagation

The selection of quality mother plants is important for propagating jackfruit. Seed and/or vegetative material should be collected from trees selected for their desirable characteristics. The desirable characteristics of mother plants (Table 3.1) are that the trees should be older than 15 years and should show good growth with a strong trunk and a good crown. Trees should have no signs of insect pest infestations or diseases. Trees should have regular bearing and high production of fruits and the fruit shape should be uniform and attractive with excellent quality.

Table 3.1: Characteristics of selected superior phenotypes of jackfruit

Characteristics	Requirements
Vigour and health of mother plants	The tree should be vigorous and older than 15 years and have the reputation of abundant bearing of fruits every year.
	Fruit shape is uniform and quality is excellent.
	Free from any diseases and pests
Yield	50-300 fruits/tree/season (variability exists in different locations)
Fruit characteristics	2-5 kg in weight
Good quality	Highly juicy and sweet
Flesh colour	Golden colour of flesh
Flesh texture	Medium soft to soft texture
Sweetness of fruits	>20% Brix
Seasons	Early and late
Seeds	Small in proportion to pulp

3.4.1 Raising seedlings as rootstocks for vegetative propagation

Seeds are sown in the nursery, either in flat seedbeds or in various types of containers/pots. When seedlings are at the four-leaf stage in seedbeds they should be potted on into large polybags (15 x 23 cm) to avoid injury to the long and fragile tap roots during planting.

3.4.2 Methods of vegetative propagation

Vegetative propagation produces progeny which are genetically identical to the mother plant. The most common vegetative propagation methods include: taking cuttings, layering and air layering, budding and grafting onto seedling rootstocks and *in vitro* tissue culture. The success of the different vegetative propagation methods varies and it also depends on the local climate, water availability and, in the case of grafting, on suitable rootstocks (see figure 3.1).

Vegetatively propagated plants tend to be relatively shorter in stature than those propagated from seed, which makes management and harvesting easier. Trees produced from physiologically mature vegetative material bear fruits earlier than trees grown from seed. Disadvantages of vegetative propagation may include trees which are shallow rooted and which form branches from a low level, thus affecting the trunk length if good quality timber is a major requirement for growing the tree.

Vegetative propagation should be carried out at the end of the rest period of vegetative growth during spring and summer, or alternatively in the autumn.

3.4.2.1 Cuttings

Cuttings are parts of a plant separated from the parent and treated in various ways to encourage production of a new complete plant. The cuttings may be a piece of leaf, stem, branchlet or root.

Mowry *et al*. (1941), Bailey (1949) and Dhua *et al*. (1996) reported successful propagation by jackfruit cuttings. Morton (1965) also reported growing cuttings from young wood of jackfruit under mist, but detailed results were not given. Khan (1946) and Naik (1963) reported that hardwood cuttings of jackfruit failed to root from heeled, slit or ordinary shoots when the cuttings were made in November and February. Rowe-Dutton (1985) reviewed investigations on using current, previous season's or old wood throughout the year to determine the most suitable stage for faster rooting.

3.4.2.2 Growth regulators to promote rooting

Many scientists note that stem cuttings of jackfruit are not successful unless they are treated with growth regulators (Mukherjee and Chatterjee, 1978, 1979; Chatterjee and Mukherjee, 1980; Dhua *et al*., 1983 and Biswas and Kobayashi, 1989). The most common growth regulators used for rooting of cuttings and in layering (layering is a method by which adventitious roots are encouraged to form on an aerial stem while it is still attached to the parent plant) are: Indole-3-butyric acid (IBA), Indole-3-acetic acid (IAA), α-naphthalene acetic acid (NAA) ferulic acid and Gibberellic acid (GA_3).

Mukherjee and Chatterjee (1978) and Chatterjee and Mukherjee (1980, 1982) used 1000 and 5000 ppm IBA, followed by etiolation and reported success of over 75% rooting and 70% survival. Dhua *et al*. (1983), and Dhua and Sen (1984) established that ringing, etiolation for 15-30 days and then striking cuttings using combined growth regulators, 3000 ppm IBA and 2000 ppm ferulic acid gave 90% success of rooting with 100% survival, when planted in a ventilated mist. They concluded that etiolation and treatment with IBA could increase the survival rate. Stem cuttings of jackfruit produced roots when treated with 750 ppm IBA for two minutes on ringed or etiolated healthy shoots (35 cm long) from 15-month old seedlings (Rahman and Blake, 1988a). Biswas and Kobayashi (1989) reported that rooting of jackfruit stem cuttings was not possible without the use of IBA. They girdled the branch of semi-hard wood using 10,000 ppm of IBA to promote the rooting of cuttings and confirmed that wounding had no effect on rooting. Soepadmo (1992) was successful in propagating

jackfruit through cuttings (from forced, etiolated shoots treated with 5 gl^{-1} IBA) but he did not record the success rate. Dhar (1998) reported 37.5% rooting when stem cuttings were treated with 0.5% (5000 ppm) of IBA. He suggested that the success rate could be increased to 60% by using juvenile shoots obtained by heading back of branches of the tree. The above results are summarised in Table 3.2.

3.4.2.3 Air layering

As mentioned earlier, air layering is a method by which adventitious roots are encouraged to form on an aerial stem while it is still attached to the parent plant. Little information is available on air-layering for jackfruit, unlike its wider use in fruits such as, citrus, mango and litchi.

The air layering method involves removing a ring of bark from a stem. It is covered with a moist rooting medium such as moss or moistened soil and held in place with polythene. Roots develop from the girdled stem, which can then be cut off and planted.

Growth regulators to promote rooting of air layers

Several authors have attempted to determine the effects of different levels of IBA for air layering of jackfruit. Singh (1951) obtained 72% rooting in air-layers of jackfruit when treated with 0.025% (250 ppm) IBA. He reported 100% rooting with 1% (10000 ppm) IBA (Singh and Sharma, 1995).

Sen and Bose (1959) also reported 100% rooting using 5000 ppm IBA when the air layers were prepared in the rainy season. When a combination of 7500 ppm of IBA with 7500 ppm of NAA for air layering of jackfruit was used and 100% rooting was obtained in the dry season but the success was much lower in the rainy season. Singh and Singh (2004) also reported rooting of air layers with 5000 ppm IBA.

Table 3.2 Use of growth regulators to promote rooting

IBA concentration (ppm)	Ferulic acid concentration (ppm)	Percentage rooting	Investigators
750	0	Not stated	Rahman and Blake (1988b)
1000	0	75%	Mukherjee and Chatterjee (1978) Chatterjee and Mukherjee (1980, 1982)
5000	0	75%	Mukherjee and Chatterjee, (1978) Chatterjee and Mukherjee (1980, 1982)
3000	2000	90%	Dhua *et al*. (1983)
3000	2000	90%	Dhua and Sen (1984)
5000	0	Not stated	Soepadmo (1992)
5000	0	37.5%	Dhar (1998)
10,000	0	Not stated	Biswas and Kobayashi (1989)

Data from Singh *et al.* (1995) and Lavania *et al.* (1995) show that IBA concentrations need to be high (over 5000 ppm) for jackfruit layering but Dhar (1998) obtained better results at 3000 ppm. Also Azad (2000) reported that application of 2000 ppm of IBA on 3-4 months old shoots of the current year's growth of jackfruit by air layering gave 86% rooting success and he recommended this treatment as the optimal use of growth regulator for vegetative propagation of jackfruit.

Dutta and Mitra (1992) reported that pre-treatment of layers of stock trees of jackfruit with cycocel (1000 ppm) followed by treatment with IBA (5000 ppm) and poly-3-hydroxybutyrate PHB (200 ppm) gave 100% rooting after 60 days. Seventy percent plant survival was noted six months after planting of the rooted layers. The original plants may be cut back to encourage many new shoots to grow from the base. After the new shoots grow, soil is mounded around the base. Roots will grow into the surrounding soil from the new growth. This is described as mound layering. IBA helped rooting (Alia *et al.,* 1997).

Hore and Sen (2004) reported success in rooting during air layering in the period of June-July in India when they used a combination of 5000 ppm IBA + 1000 ppm p-hydroxybenzoic acid, or 5000 ppm IBA + 1000 ppm ferulic acid applied to the air layering.

The above findings on the use of growth regulators are summarised in Table 3.3.

Table 3.3 Use of growth regulators in air layering

IBA conc. (ppm)	Other chemicals	Percentage rooting	Percentage survival	Investigators
250	None	72%	n/a	Singh (1951, 1995)
2000	None	86%	n/a	Azad (2000)
3000	None	73.3%	n/a	Dhar (1998)
5000	None	100%	n/a	Sen and Bose (1959)
5000	None	n/s	n/s	Singh and Singh (2004)
5000	None	33.3%	38.1%	Dhar (1998)
5000	cycocel 1000 ppm PHB 200 ppm	100%	60%	Dutta and Mitra (1992)
5000	p-hydroxybenzoic acid 1000 ppm	n/s	n/s	Hore and Sen (2004)
5000	ferulic acid 1000 ppm	n/s	n/s	Hore and Sen (2004)
7500, (0, 2500, 5000, 10000 also tested)	None	Ns	52.5%	Lavania *et al.* (1995)
10000	None	100%	n/a	Singh (1951)
8000, 12000, 16000	None	n/s	ns	Singh *et al*. (1995)

n/s- not stated; n/a-not applicable

3.4.2.4 Grafting

Grafting is the joining together of parts of two plants that will continue their growth after union as one plant. The part above the point of grafting is known as the scion and the lower part as the rootstock. A number of factors including the season, physiological age, dormancy of scions, age of source tree for scions, length of storing of scions after collection and age and growth of rootstocks, might influence the success of grafting. The common methods of grafting are veneer, cleft, splice, epicotyl (Plate 7) and inarching (or approach) grafting. Different methods of grafting have been used in jackfruit and several workers reported different grafting techniques for jackfruit with variable success. However, it is concluded that these methods still need to be further refined (Soepadmo, 1992).

Veneer and epicotyl grafting are the methods most commonly practised for jackfruit (Reddy *et al.* 1998). Veneer grafting involves collection of a 4-5 month old terminal shoot from a selected mother tree and grafting it onto a one year old rootstock. Epicotyl grafting is done on a 20-25 day old seedling with slightly thicker stock and 4-5 leaves. Rootstocks selected are headed back to 8-10 cm height from the ground level. The exuded latex is removed with tissue paper. A 5 cm slit is made vertically on the root stock. Scions with a growing bud present are prepared by making a wedge cut on both sides. The scion stick is inserted into the slit made in the rootstock and tied with polythene tape.

Grafting carried out during April-May had variable success (50-90%) and grafts were of saleable size within a year (Gunjatee *et al*., 1982). Epicotyl grafting on a 15 day old rootstock resulted in 46% sprouting but only 3% of the grafts survived (BARI, 1990). Epicotyl grafting with a 3-4 month old scion gave 29.5% success and 21.6% survival when grafted on a five day old rootstock in the month of June in Bangladesh. However, the success rate in India was found to be up to 90%. Deshai and Deshai (1989) reported 33 -80% success when they used softwood for grafting in jackfruit. Jose and Velsalakumary (1991) investigated soft wood and epicotyl grafting on 5, 10 and 15 day old root stocks under intermittent mist. The soft wood grafting gave 83.3% sprouting

and 61.6% survival when a 3-4 month old scion was used for grafting.

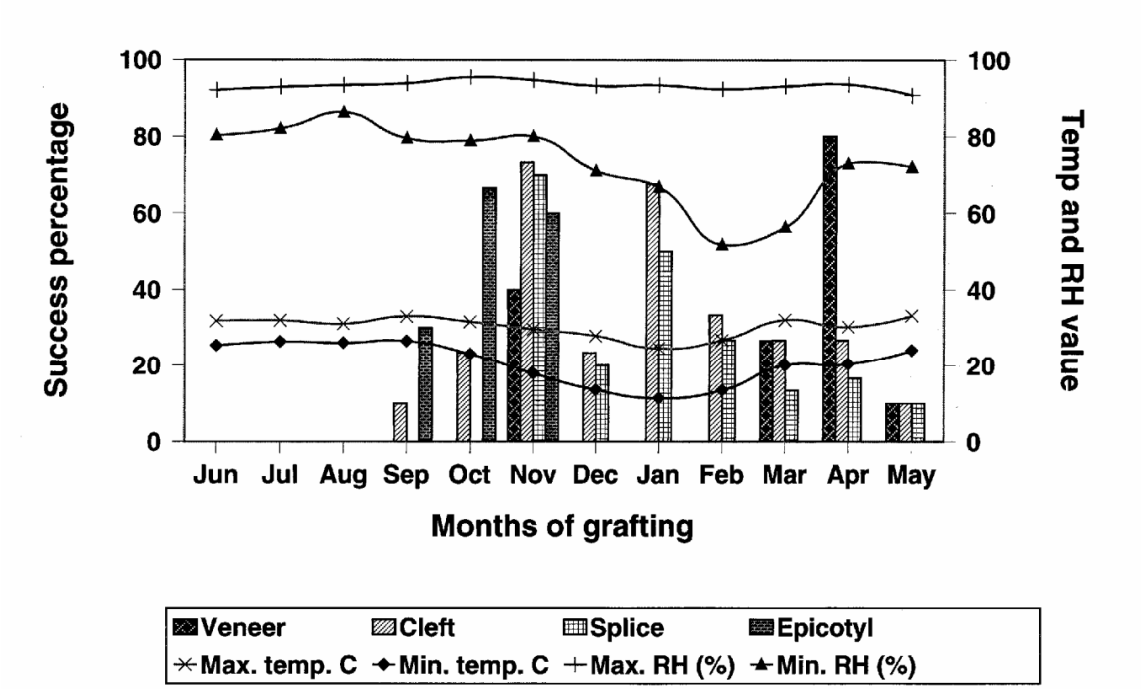
Dhar (1998) made a comparative study of epicotyl, cleft, splice grafting and veneer methods in jackfruit and obtained higher success (68.8%) using splice grafting. Vijayakumar *et al.* (1991) concluded that green wood cleft grafting was a quick and easy method of vegetative propagation of jackfruit compared to other methods.

Azad (2000) compared veneer, cleft, splice and epicotyl grafting throughout the year in Bangladesh to determine the optimum method and the best time of the year for high success. He obtained 80% success with veneer in April and 70-73% success with cleft and splice grafting when tried in November. He concluded that in Bangladesh higher success could be achieved by epicotyl grafting in October and by veneer grafting in April (Fig.3.1).

Naik (1952) achieved 60-70% success when jackfruit was inarched onto seedling rootstocks of the related species *A. hirsutus* and *A. champedak*. Raman (1957) selected seven superior varieties of jackfruit and attempted inarching on seedlings of six of these varieties onto rootstocks for their multiplication and recorded up to 90% success. Kannan and Nair (1960) established that inarching on rootstocks of *A. heterophyllus* gave better success and growth than on *A. hirsutus*. Quasem (1982) reported 90% success from modified inarching on 3-4 month old rootstock of jackfruit. Quasem and Shakur (1984) also reported 81% success for veneer grafting when it was carried out on one year rootstocks of jackfruit during the month of April. Swaminathan and Ravindran (1989) reported 60-90% success for inarching in jackfruit. In Thailand the inarching method produced good results and this can be used at any time of the year (Haq, 2003b).

In Australia good results were obtained for wedge grafting onto young vigorous rootstalks in enclosed polythene covers.

Fig. 3.1 Percentage success in grafting using different graft types (Source: Azad 2000)



Maiti and Sen (1999) looked at the effect of different pre-treatments of the scion to improve grafting success in India. They found scion ringing and blanching for three days followed by dipping in 1% Banistin (benomyl) gave 60% success in grafting.

3.4.2.5 Budding

Budding is the insertion of a single scion bud into a rootstock in such a manner that growth continues as one plant. The common methods of budding are: patch, shield (T-budding), flute (or chip), ring budding and forked budding. The success rate reported by various authors are summarised in Table 3.4 and below.

Table 3.4 Results of success rates using different budding methods

Graft type	Success	Month	Investigators
Patch	100%	unknown	Teaotia *et al.* (1963)
Patch	60%	unknown	Ahmad and Quasem (1969)
Patch	41%	unknown	Samaddar and Yadav (1970)
Patch	90%	June	Singh *et al*. (1982)
Ring	80%	May	Biswas and Hossain (1984)
Ring	20%	June	Biswas and Hossain (1984)
Patch	80%	July-August	Konhar *et al*. (1990)

Patch, chip and T-budding were investigated by Singh *et al*. (1982) from February to September and the highest success (90%) was obtained with patch methods in June to July. Chip budding carried out in March was not very successful. T-budding appears to be the most unsuccessful method.

Biswas and Hossain (1984) experimented with five methods of budding viz. ring budding, patch budding, flute budding and T-budding using scions from selected trees budded onto one year old seedlings. They obtained 80% success with ring budding in the month of May but the success was reduced to 20% in June.

Konhar *et al*. (1990) reported the effect of different seasons, from July to December on different budding methods (shield, patch, chip) and recorded the highest (80%) success from patch budding during the months of July and August.

Kelasker *et al.* (1991) investigated the physical and environmental requirements for patch budding. They observed that retention of leaves on the rootstock during budding had no effect on the success rate. They concluded that greenhouse conditions and open sunlight versus partial or complete shade had no effect on the success rate. They recommended polythene strips for tying the bud in place in order to maintain high humidity at the graft.

3.5 Recommended methods

Based on diverse results on the application of different grafting methods and differences exhibited between regions, Haq (2003b) recommended specific methods of vegetative propagation suited to different countries (Table 3.5).

Table 3.5 Recommendations for vegetative propagation methods of jackfruit in Asia

Country	Methods
Bangladesh	Veneer, cleft and epicotyl grafting
India	Softwood and epicotyl grafting
Indonesia	Top grafting
Nepal	Splice and cleft grafting
Pakistan	Stem cuttings
Philippines	Modified cleft grafting
Sri Lanka	Wedge grafting
Thailand	Modified inarching grafting
Vietnam	Cleft, epicotyl grafting

Source: Haq (2003b)

3.6 *In vitro* propagation

In vitro propagation is the development of a large number of plants from very small pieces of tissue, such as shoot tips, root tips, embryos, other parts of seeds, stems, callus or single cells, in a culture medium under aseptic conditions. The methods involve three distinct steps, namely shoot proliferation, rooting of regenerated shoots, and the establishment of rooted plantlets in the nursery. Each step needs to be fully functional for any successful propagation. Data on growth regulators needed in the medium in relation to explant are shown in Tables 3.6, 3.7.

3.6.1 Rooting of regenerated shoots

It has been found that regenerated shoots grow best when cultured on half strength MS medium supplemented with auxins.

Rahman and Blake (1988a) reported that a high level of agar reduced the humidity in the culture and affected the rooting but that did not affect the establishment of plantlets in the glasshouse. Rahman and Blake (1988b) also reported that a low level or absence of nutrients in the substrate for at least 20 days resulted in significantly more growth and survival of plantlets in *ex vitro* conditions. Nutrient feeding after 20 days improved further growth and survival. Nitrogen, particularly as ammonium, was shown to be the most inhibitory nutrient during the early stages of establishment. (Table 3.7).

The transfer of plantlets out of the aseptic conditions of the culture room involves getting them acclimatised to *ex vitro* conditions. There are two important steps: hardening and establishment (Susiloadi *et al*., 2002b). The protocols for hardening and establishment of *in vitro* plantlets of different plant species are variable as they are transferred to soil.

Table 3.6 Results of different *in vitro* methods for multiple shoot regeneration

Explant	Media additives	Investigators
Axillary buds	BAP	Rao *et al*. (1981)
	NAA	
Nodes	BAP	Rahman and Blake (1988a)
Nodes	1.0 mg l^{-1}BAP	Roy *et al*. (1990)
	0.5 mg l^{-1} kinetin	
n.s	1.0 mg l^{-1} BAP	Roy *et al*. (1991)
	0.5 mg l^{-1} NAA or IAA	
n.s	8.8 µM 6-benzyladenine (BA)	Roy *et al*. (1993)
	2.7 µM NAA	
Shoot tips and axillary buds	1.0 mg l^{-1} BAP 0.05 mg l^{-1} NAA	Roy and Hadiuzzaman (1991)
Shoot tips, apical bud	4.5, 9.0, 18.0, 36.0 µM BAP	Amin and Jiswal (1993)
	kinetin	
Shoot apices	1.0-2.0 mg l^{-1} of BAP kinetin	Dhar (1998)
n.s	TDZ (N-phenyl-N'-1,2,3-thaidiazol-5-ylurea)	Murthy *et al*. (1998)
Shoot apices	2.0 mg l^{-1} of BAP	Azad (2000)
	0.5 mg l^{-1} of TDZ	
	GA_3	
	NAA	

n.s - not stated

Table 3.7 Results of regeneration using different methods for rooting of regenerated shoots

Media additives	Percentage rooting	Investigators
IBA and NAA (0.1,0.5, 1.0,0.5 and 10.0 ppm)		Rao *et al*. (1981)
sucrose level of 20 g l^{-1}		Rahman and Blake (1988a)
10^{-6} M indole butyric acid (IBA)		(Rahman and Blake 1988b).
IBA 2mg/l, NAA 2 mg l^{-1}, sucrose 30 mg l^{-1} and agar 6 g l^{-1}	80%	Rajmohan and Mohanakumaran (1988)
1.0mg l^{-1} of NAA or IBA.		Roy *et al*. (1990)
½ MS + 0.05 mg l^{-1}, kinetin + 1.5 mg l^{-1} IBA	98.6%	Roy and Hadiuzzaman (1991)
0.1 mg l^{-1} each of IAA, IBA and NAA		Roy *et al*. (1992)
10µM of IBA or NAA	60-80%	Amin and Jiswal (1993)
1.0 mg l^{-1} each of IAA, IBA and NAA		Dhar (1998)

Roy and Hadiuzzaman (1991) reported about 80% survival of plantlets when rooted plantlets were transferred from culture tubes to earthenware pots containing sterile sand, soil and humus (1:2:1) and covered with a transparent plastic bag.

Amin and Jiswal (1993) reported that the survival of regenerated plantlets under *ex vitro* conditions was 5%. Dhar (1998) failed to establish plantlets due to poor rooting *in vitro*.

By contrast, Azad (2000) obtained 88.2% success in the establishment of plantlets. The plantlets were routinely sprayed with fungicide to overcome the potential problem of diseases.

Much more work is needed to establish the protocols for successful *in vitro* propagation.

3.6.2 Establishing and using a nursery

The nursery is where young plants are raised either from seed or vegetatively propagated plantlets, including tissue culture materials. Seedlings raised in the nursery may be planted later in the field, sold or used as rootstocks for grafting. The size of the nursery depends on the number of trees required.

While selecting a site for a nursery the following factors need to be taken into account. Nurseries should be:

- On a raised site with good drainage and not liable to waterlogging or flooding.
- Close to a good water source since frequent watering is necessary for the young trees.
- Located in a sunny place and protected from high wind.
- Located in or near the homestead in order to facilitate easy and frequent participation of the family members in nursery activities.
- Suitably fenced to protect the planting materials from trespassers and stray animals.

The land should be cleared of vegetation, dug over or ploughed to a depth of 30 cm and levelled to make the area suitable for preparing nursery beds. Individual nursery beds should be 1 m wide, but may be as long as it is convenient. Beds should be 50 cm apart from one another and raised approximately 10 cm above ground level. About 10 kg well rotten farmyard manure or compost should be thoroughly mixed into the soil of each bed.

When planting seeds in the nursery it is sensible to plant 30% more seed than the number of plants required, to account for any reduced germination.

Seeds are sown 2-3 cm deep in rows. Seeds germinate within 15-20 days and seedlings should be nurtured for 8-10 months. An overhead low-cost shade structure can be built over the nursery bed to reduce sunlight intensity, to prevent leaf scorch and rapid moisture loss as illustrated in Plate 8. For vegetatively propagated trees, it is also advisable to prepare a slightly larger area than for the final number of trees required. Seeds should be sown *in situ* in the beds or preferably in containers as bare rooted jackfruit seedlings are difficult to transplant.

If potting in polybags the following practices should be followed:

- The polybags are usually filled with a mixture of top soil, sand and compost in the ratio of 2:1:1. The mixture depends on the availability and composition of medium available. However, care should be taken to select top soil with good physico-chemical properties e.g. washed sand free from silt and compost or manure which is well rotted. Care should be taken to avoid air gaps in the bags and the bags should be kept moist until the seeds are sown. NPK can be added to the mixture. Once the polybags are ready, one seed is sown per bag and covered lightly with potting mixture.

- Planted polybags should be kept under 75% shade for 2-3 days and then 50% shade for about 60 days. Watering is needed twice a day until the seedlings are about 10-15 cm in height. Additional nitrogen fertiliser may be added as required.

- The bags have to be kept free of weeds and watering and shading should be reduced after 30 days. Diseased and weak seedlings should be discarded and the others kept in the nursery for up to 10 to 12 weeks before being used.

- Nursery raised seedlings have to be carefully handled during lifting from the beds, packing, transporting and transplanting in the field to ensure a good survival rate.

3.7 Spacing

A design layout is to be prepared for the area to be planted, the land is then cleared, ploughed, harrowed and leveled. Pits of 1 x 1 x 1 m size are opened at a spacing of 8 x 8 to 12 x 12 m for orchards. Spacing in homestead gardens invariably depends on the other species grown.

A spacing of 12 x 12 m between plants and rows may be given for both direct seeded and transplanted seedlings of jackfruit trees in fertile soils and 10 x 10 m spacing in poor soils. These spacings result in the recommended populations of 70 and 100 trees per hectare of land, respectively. However, a closer spacing of 8 x 8 m is recommended for grafted trees. At this spacing more than 150 trees can be accommodated per hectare.

In the Philippines a spacing of 7.5-12 m on a square or triangle is used for plantations or orchards (BPI, 1991). For vegetatively propagated materials a closer spacing in the rows, creating a rectangular pattern, is often used. When trees are used as a windbreak a spacing of about 5.5 m apart set in double rows in alternating order is used. A closer spacing is also used for timber production to minimise branching and to promote development of straight and long trunks. In Australia spacing is generally given at 6 x 12 m (Alexander *et al*., 1983)

Trees planted in 11 litre pots are easy to handle. A handful or two of a well-decomposed organic matter can be mixed with the soil in the planting hole which should be 60-80 cm wide and 40-50 cm deep in the pot. After planting, it is advised to make a circular barrier about half a metre away from the trunk to facilitate watering and holding rain water around the root system.

3.8 Time of planting

The best time in Asia for planting, whether direct seeding or transplanting, is at the beginning of the rainy season. If water is available, direct seeding may be done in early summer so that the seedlings are established before the beginning of the rainy season. The rainy season ensures plenty of water and generates a favourable environment for the establishment of trees in the field. In addition, transplanting is best when carried out in the late afternoon to early evening rather than in the heat of the day

In south Florida, planting may be done at any time provided irrigation is available for the newly planted trees and they can be protected from any cold weather or frosts (Morton, 1987). Otherwise the best time to plant in Florida is in late spring or early summer.

3.9 Management

3.9.1 Weeding and mulching

The young trees must be kept weed free during the first three to four years. Weeding is best done manually where there are few trees in household gardens or small orchards. In larger plantations or orchards, inter-row and circle weeding is practised and can be done using herbicides or mechanically. The space between the trees may be ploughed and harrowed twice a year at the beginning and end of the rainy season. If cover crops are not grown, inter-row weed control may involve shallow cultivation by hoeing, ploughing or disking. Circle weed control consists of hand weeding or hoeing a ring at the base of the tree with a diameter equivalent to that of the lower canopy. The tree base can be mulched with straw or with other mulching materials. A 5-10 cm mulch will be good for suppression of weeds as well as to maintain soil moisture, particularly during the dry period. Weeds compete for water and nutrients and may slow tree establishment. Prior to planting trees in household farms a ring of sod of 45-91cm diameter should be removed. After planting, grass should be kept

away from the tree trunk. The canopy will also suppress weed and grass growth and hold soil moisture.

3.9.2 Pruning and training

Jackfruit does not respond well to indiscriminate pruning and it is not commonly practised. Young trees do not need pruning in the first year. However, when older trees are not pruned a strong central leader usually develops which is desirable for its timber value. Nonetheless, where fruit production is the main purpose pruning of the first lateral branches should be carried out in year two to slow upward growth and enhance the spreading of the canopy. One or two prunings of shoot tips during summer causes lateral bud break and makes the tree more compact. Grafted trees have a dwarfing tendency but produce a large number of branches from the beginning. These branches should be continuously pruned to get a reasonable trunk. Thereafter, branches may be allowed to remain but removal of vigorously growing upright shoots is recommended. Inner branches of the canopy should be removed to allow more light and air within the canopy.

Regular pruning of weak, dead and diseased branches, and removal of parasitic plants at the end of the rainy season is recommended. This prevents insect infestation and disease infection. Tree height and size may also be controlled, if desired, by pruning. Plates 9 and 10 illustrate pruned and non-pruned grafted trees.

Old flowering shoots should be removed after harvesting, and after the harvest is complete branches should be thinned out to increase light penetration to the inner canopy. The height of the tree might be maintained at about 4-5 m by periodic selective pruning. Selective pruning is also effective for equipment movement and other management operations. Trees may also be mechanically topped at about 4-5 m and hedged at a 5-10º angle from the vertical.

Fruit thinning is also recommended to prevent damage to branches as heavy fruit loads break branches and can result in death or

stunting of the tree. Limiting the number of fruits per limb may also improve the quality of the fruits and increase their size.

3.10 Intercropping

Jackfruit requires a long time before the canopy closes and it fully occupies the land. It makes good sense for the space between trees to be utilised by growing intercrops such as short duration pulses, spices and vegetables, particularly if irrigation is available. The selection and growing of intercrops should be well planned so that there is no interference with orchard operations. If the cultivation of field crops is not possible a leguminous cover crop can be planted to help control weeds and conserve soil fertility and moisture. However care should be taken that the growth of any cover crop is not too thick. A well timed tree relay planting or replanting scheme can maximise productivity of the trees and the farm as a whole. Since jackfruit takes about eight to ten years to attain full bearing, intercropping will benefit the growers and encourage them to plant more trees.

3.11 Nutrition

Generally jackfruit trees are not given fertilisers and thus little is known about the fertiliser requirements of jackfruit. Farmyard manure (FYM) or home produced compost is sometimes used to advantage, especially in homegardens. However, the trees need good nutrition to promote regular and good bearing. The quantity and type of fertiliser required depends on the vigour and age of trees, and the fertility of the soil. The recommended amounts of manure and fertilisers in Bangladesh are presented in table 3.8. The yearly amount should be applied in two doses. The first dose is applied at the beginning of rainy season and the second instalment soon after the rainy season is over. For mature trees, fertiliser should be applied from onset of flowering until after harvesting and pruning have been completed.

Table 3.8 Yearly amounts of manure and fertilisers for jackfruit trees (per tree) in Bangladesh.

Doses of manure and fertilisers per tree per year	Age of tree in years				
	2-4	**5-7**	**8-10**	**11-20**	**>20**
FYM (kg)	10	15	20	25	30
Urea (g)	200	250	300	350	500
Triple super phosphate (g)	250	250	500	750	1000
Mauriate of potash (g)	100	200	250	300	500
Gypsum (g)	100	100	200	300	500

Source: Hossain and Haq (2006)

In India recommendations for applications to bearing trees are shown in Table 3.9.

Table 3.9 Application of fertilisers in four states of India (kg/tree)

State	Distance (m)	N	$P_2 0_5$	$K_2 O$	FYM
Assam	10 x 20	210	150	1000	20-30
Karanatka	10 x 10	600	300	240	50
Maddya Pradesh	10 x 10	800	430	1050	100
Tamil Nadu	6 x 6	750	400	500	50

Source: Tandon (1987)

In the Philippines three recommendations for fertilisers have been made as follows (Yap, 1972; BPI, 1991):

- 100-150 g ammonium sulphate (20-0-0) per tree in the first year, increasing to growing trees 0.5-1.0 kg complete fertiliser (14-14-14) per tree at the start of fruiting and 2-3 kg complete fertiliser for a full grown tree (15-20 years old).
- 50-60 g ammonium sulphate in the first year increasing to 200-300 g and 400 g ammonium sulphate on 2^{nd} 3^{rd} and 4^{th}

year respectively. 1 kg complete fertiliser (5-10-5 or 6-12-6) in the 5th year and for the growing trees 1.5 kg complete fertiliser (12-24-12) is applied.

- 200-300 g complete fertiliser (14-4-14) per tree at planting time, 300-500 g complete fertiliser (14-14-14) plus 200-300 g urea (45-0-0) per young trees; 1.5-3 kg complete fertiliser and 200-300 g of muriate of potash (0-0-60) for full bearing trees.

Fertiliser can be applied in a 5-10 cm deep trench or in holes made along the periphery of the tree canopy and then covered with soil. However, further studies are needed to determine the optimal fertilisation requirements of jackfruit.

At planting 113 g of fertiliser per tree (i.e. 6-6-6 with minor elements and 30% of nitrogen from organic sources) is recommended. After one year fertiliser application needs to be repeated, and thereafter a gradual annual increase in the amount is needed. Application of a soil drench of chelated iron once or twice per year per tree is recommended. For calcareous soils apply EDDHA (sodium ferric ethylenediamine di-(o-ydroxyphenylaceatte) iron chelate and for neutral and acid soils EDTHA (sodium ferric diethylenetriamine pentaacetate) iron chelate.

In Florida chelated iron drenches are most effective from May to September and foliar sprays from April to September (see table 3.10).

All the manure and fertilisers should be applied around the tree between the trunk and the edge of the canopy in two equal installments, at the beginning and at the end of rainy season. It is also recommended that gypsum should be applied in alternate years.

Table 3.10 Fertiliser recommendations for jackfruit in Florida

Year	Time of year	Amount per tree	Total amount per tree	No. of minor element sprays per year	Chelated iron soil drenches (oz/tree/year)
1	6	0.25-0.5	1.5-3.0	6	0.5-.75
2	6	0.5-1.0	3.0-6.0	6	0.75-1.0
3	6	1.0-1.5	6.0-9.0	6	1.0-1.5
4	4	1.5-2.5	9.0-10.0	6	1.5-2
5	4	2.5-3.5	10.0-14.0	4-6	2-4
6	4	3.5-4.0	14.0-16.0	4-6	2-4
7	4	4.0-4.5	16.0-18.0	4-6	2-4
8	4	4.5-5	18.0-20.0	4-6	2-4

Source: Crane *et al*. (2003)

3.12 Fruiting

Varieties of jackfruit trees differ widely in their bearing age. Early varieties such as "Singapore Jak" bear in 2-3 years in India and Sri Lanka. Other vegetatively propagated trees also bear in 4-5 years. In Bangladesh tissue culture propagated plants bear fruits from three years after transplanting (Azad *et al.,* 2006). Some varieties however may take 8-10 years to bear fruits. Regional differences in the fruiting habit exist. In south India trees mature in 6-7 years but in the cool weather of north India fruiting is delayed and bearing is also delayed at higher elevations.

A well-grown tree will produce up to 200-250 fruits, each weighing 5-35 kg, but under good conditions, fruits can weigh 55 kg (Ghosh, 1996). Because jackfruit is an underutilised species there are no reliable statistical data on its production from producing countries. Table 3.11 below shows data that are available from various sources in Asia.

The yield of fruits per tree differs greatly on the basis of plant age, cultivars, season and localities. On an average 100-250 fruits/plant are harvested by most farmers. However, some cultivars give more fruiting because they grow through all seasons.

In Nepal 50-300 and sometimes 3000 fruits per tree have been harvested, however, there is no developed cultivar in Nepal and fruits are mostly collected from the wild (Chaudhary and Khatari, 1997).

In Vietnam the most popular variety is cv. MIT GIAI and it is widely grown from the north to the south of the country. It is a large sized, sweet flavoured variety and its yield is about 238 ± 21.7 kg/tree (45 t/ha from 200 trees at a spacing of 7 x 7 m). This also provides almost 5.8 t of seeds for food and animal feeding (Lai, 2002). The other cultivar Cv Mit MAT is characterised by a special taste as it is sweeter and juicy but its yield is low (213 ± 17.8 kg/tree).

Hence yield per hectare varies greatly. Some estimates are provided in Table 3.12.

Table 3.11 Annual production of jackfruit in Asia

Country	Area in hectares (ha)	Production in metric tonnes (MT)
India	102,552	1,436,570
Bangladesh	24,958	257,360
Philippines	13,286	67,500
Malaysia	24,186	1,126,284
Indonesia	Not available	6,000,000
Nepal	1479	17,161
Thailand	Not available	450,000
Vietnam	23,730	Not available

Sources: Ghosh (1996), AEC (2003), Osman (M. bin Osman, Universiti Kebangsaan Malaysia, pers. comm.)

Table 3.12 Yield of fruits in tonnes per hectare in major jackfruit producing countries in Asia

Country	Yield (t/ha)
Bangladesh	10.5
India	2-27
Philippines	4.8
Malaysia	3-19
Indonesia	2.4-14
Nepal	1.5-3.7
Thailand	3-20
Vietnam	1.4-2.3

Source: Haq (2003b)

3.13 Irrigation

The species is intolerant to poor drainage (Soepadmo, 1992) 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 be raised to prevent water stagnation.

In dry areas, however, for optimum tree growth and fruit production trees should be irrigated during dry periods to enhance growth. Costa *et al*. (2000) reported the effects of shade and water stress on growth in jackfruit.

In household gardens and small orchards jackfruit is not normally irrigated in spite of the fact that it suffers from drought. Newly planted trees should be irrigated regularly during dry periods for three to four years after planting until the roots have penetrated deep enough and the plants are fully established. Hand watering is necessary during the first one to two years. To economise in the use of water a ring system or a drip system may be adopted. For mature trees irrigation is recommended during the dry periods if they occur between onset of flowering and until the fruit is fully developed. The frequency and quantity of irrigation will depend on the weather and soil moisture conditions, but jackfruit responds well to irrigation between flowering and fruiting. Irrigation timing and rates can be improved by monitoring the soil moisture using a tensiometer or other measuring equipment.

3.14 Pests and diseases

Diseases and pests are not a serious problem in jackfruit. IPGRI has issued a list of descriptors for characterisation and evaluation of germplasm (IPGRI, 2000) and this list includes pests and diseases. However, Gunasena *et al.* (1996) reported that the jackfruit is relatively free from serious diseases. Soepadmo (1992)

stated that crop protection is not a major concern for growers of jackfruit.

Nevertheless, there are some diseases and pests, such as fruit rot (*Rhizopus artocarpi*) and fruit borers (*Ochyromera artocarpi*, *Diaphania caesalis*) which commonly occur in jackfruit (Butani, 1978; IPGRI, 2000) and can reduce the price for fruits. The reported pests and diseases occurring on jackfruit in the major production countries are discussed below:

3.14.1 Pests

Thirty five species of insect pests have been recorded on jackfruit from India. Major pests can be shoot and trunk borer, brown weevil, mealy bug and jack scale. Pests are summarised in Table 3.14: these are those found to be associated generally with jackfruit (Tandon 1998).

In Bangladesh the most important pest is the caterpillars of *Diaphania caesalis*, the shoot borer, which tunnel into buds, young shoots and fruits (Azad, 2000). Eggs of the borers are laid on the tender shoots and flower buds. The reddish brown caterpillars of *Diaphania* cause the affected parts to show signs of wilt and subsequently to dry up and severe infestation may cause fruit drop.

The bark eating caterpillars (*Indrabela tetraonis* and *Batocera rufomaculata*) are also found to attack jackfruit. (Azad, 2000).

A number of wood borers that attack trunks and branches are reported from Florida. These are *Elaphidion mucronatum*, *Nyssordrysina haldemani* and *Leptostylopsdis terraecolor.* In Asia, they include *Apriona germani* (Soepadmo, 1992).

The simple remedy for controlling borers is to remove the affected parts and destroy them as soon as the attack is first noticed. Fruits should be covered with polythene bags to protect them from

oviposition. Fumigating the holes in trees can also destroy the borers.

Jack scales is the name given to a number of different species: the lesser snow scale (*Pinnaspis strachan*)*i*, coconut scale (*Aspidiotus destructor*), mango shield scale (*Protopulvinaria mangiferae)*, and pyriform scale (*Protopulvinaria pyrifomis)*.These can be found on leaves, stems and fruits.

The brown weevil, (*Ochyromera artocarpi)* is a specific pest to jackfruit. The small whitish grubs bore into tender flower buds and fruits and induce premature drop. Two more weevils, namely *Ocychocenemis careyae* and *Telurops ballardi* have been reported feeding on leaves in South India (Tandon, 1998). To control these weevils, the affected shoots, leaves, flower buds and fruits should be removed and destroyed.

Aphids, such as *Greenidia artocarpi* and *Toxopetra aurantii* have been found feeding in clusters on tender shoots and leaves which are covered with sooty mould. Dry weather followed by rains favours the multiplication of aphids, resulting in severe infestation.

To control aphids, spraying of mahua oil (2%) or dimethoate (0.03%) or monocrotophos (0.05%) can be effective but harvesting should not be done until at least 15 days after spraying. (Tandon, 1998).

Other pests affecting jackfruit include sucking insects such as mealy bugs, fruit flies and thrips (Soepadmo, 1992).

Reddy (1998) reported *Crossononema malabaricium* and *Neolobocrilonema palamiensis* from soil around the roots of jackfruit in India.

Table 3.13 Pests which generally affect jackfruit
(Gaps in information show that recommendations have not clearly been made)

Common name	Scientific name	Nature of damage	Bio-control	Chemical control
Shoot borer	*Diaphania caesalis*	Developing fruit, buds, young shoots	Removal of affected shoots and branches	0.5% malathion, 0.5% methomyl, or 0.1% endosulfan
Stem borer	*Mangaronia caesalis*	Shoot borer mainly in nursery stock	Pruning out infested tree parts, sanitation, fruit bagging	
Stem borer	*Batocera rufomaculata*	Bores in wood		
Fruit fly	*Dacus umbrosus*	Attacks maturing fruit		
Trunk borer	*Apriona germari*	Trunks, branches. Affected parts show signs of wilt and subsequently dry up and severe infestation may cause fruits to drop		
Brown weevil	*Ochyromera atrocarpi*	Brown weevil bores into buds, shoots and fruits and causes fruit drop.	Affected shoots, flower buds and fruits should be removed	

Common name	Scientific name	Nature of damage	Bio-control	Chemical control
Aphids	*Greenidia artocarpi, Toxapetra aurentii*	Aphids feed on tender shoots and leaves and honeydew leads to growth of sooty mould	Remove the affected parts	2% mahua oil, 0.03% dimethoate, 0.05% monocrotophos
Mealy bug	*Malabrys pustalata,* *Lymantria grandis,* *Planococcus lilacinus*	Mealy bugs feed on sap and cause leaf defoliation		Lime sulphur wash or dusting with sulphur
Short-horned grasshopper	*Melicodes tenebrosa*	Affects leaves		
Citrus green locust	*Melicodes* species	Affects leaves		
Root grub	*Anomala* species. *Leucopholics irrorata*	Affects roots		
Termites	*Nasutitermes luzonicus*	Affect trunk and branches		
Fruit fly	*Chaetodacus ferrugineus*	Maggots feed on ripe and rotten fruits		

Source: Azad (2000), Tandon (1998)

3.14.2 Diseases

Major diseases of jackfruit are: leaf spots, die-back, fruit rot and pink disease (see Table 3.14).

Leaf spots are caused by *Colletotrichum orbiculare, Phyllosticta artocarpina* and *Septoria artocarpi* and are common on jackfruit. These are characterised by dark brown to brick red spots on both surfaces of the leaf. Later, the spots turn greyish white in the centre and dark brown at the edges. Dark coloured acervuli of the fungus, which ooze out profuse spore masses are observed on the greyish region. The fungus has been seen to infect the young tender shoots and petioles of the leaves. The disease is effectively checked through spraying of carbendazim (0.1%), methyl thiophanate (0.1%), captafal (0.2%) or chlorothaloni (0.2%) (Rawal and Saxena, 1997).

Die-back is caused by *Botryodiplodia theobromae* or *Erwinia carotovora.* The fungus affects growing shoots and spreads downwards and eventually kills the tree. The onset of die-back becomes evident by discolouration and darkening of the bark at some distance from the tip. The affected leaves turn brown and their margins roll upwards. At this stage, the twigs or branches die, shrivel and fall, and there may be an exudation of gum from affected branches. Such branches have also been found to be affected by shoot borers and shot hole borers. The infected twigs show internal discolouration when split open. In the early stages, epidermal and sub-epidermal cells of twigs are often slightly shrivelled. To control the disease, remove the infected twigs and follow with a spray of carbendazim (0.1%), Topsin M (0.1%) or chlorothalonil (0.2%), which have been found effective (Rawal and Saxena, 1997).

Fruit rot or blossom rot, caused by *Rhizopus artocarpi* is reported as a serious disease in jackfruit (Soepadmo, 1992) which results in a 15-32% crop loss. The inflorescence or tip of the flowering shoots, or the stalks of the tender fruits are infected and blackened by sporangia. As a result they rot and drop.

Pink disease in jackfruit is widespread in tropical and subtropical regions. It is a pinkish powdery coating on the stem caused by *Botryobasidium salmonicolor, Botryodiplodia salmonicolor, Rhizopus stolonifer,* or *Pellicularia salmonicolor*. The pink colour is that of the

profuse conidial spores. Young woody branches of the affected trees lose their leaves and show die-back.

In Florida, flowers and fruits are attacked by *Rhizopus* fruit rot (*Rhizopus artocarpi)* and fruits by grey mould (*Botrytis cinerea*). Trees are also susceptible to root rot (*Pythium splendens, Phytophthora* spp*., Fusarium* spp*., Rhizoctonia* spp.) especially when subjected to flooding. Several fungi such as *Gloeosporium* spp. and *Phyllostica artocarpi* can cause leaf spotting.

In Bangladesh a number of jackfruit diseases are reported. Among them, *Rhizopus artocarpi* is reported to be the major disease. Ghosh (1994) reported that 18.9% female spikes dropped due to infestation of *Rhizopus,* but it can be treated with the application of Folicur or Tilt.

Table 3.14 Diseases which affect jackfruit
(Gaps in information represent the lack of specific recommendations)

Common name of disease	Scientific name of causal pathogen	Nature of damage	Bio-control	Chemical control
Leaf spot	*Botryodiplodia theobromae,* *Cercospora* species, *Colletotrichum orbiculare,* *Gleosporium* species, *Phomopsis* species, *Septoria* species, *Phyllosticta artocarpina,* *Alternaria* species	Dark brown to brick red spots on both surfaces of leaf which later turn into greyish white in the centre and dark brown in the boundary		0.1% carbendazim, 0.1% methyl thiophanate or 0.2% captafal or 0.2% chlorothalonil
Leaf spot	*Phomopsis artocarpi*	Attacks the leaf causing defoliation		
Leaf disease	*Curvularia* species.	Infects the young tender shoots and petioles of the leaves.		
Dry rot	*Phellinus* species			

Common name of disease	Scientific name of causal pathogen	Nature of damage	Bio-control	Chemical control
Gray blight	*Pestalotia elasticola*			
Charcoal rot	*Ustilina zonata*			
Anthracnose	*Colletotrichum* species.			
Die-back	*Botryodiplodia* species, *Erwinia carotovora*	Affects growing shoots and spreads downwards and eventually kills the tree	To check the disease, prune infected twigs	0.1% carbendazim, 0.1% Topsin M, or 0.2% chlorothalonil. Also trunk injection with antibiotics
Fruit rot	*Rhizopus artocarpi, Phyllosticta* species, *Phytophthora* species, *Rhizoctonia solani, Physalospora rhodina*	Affects the flowering shoots or the stalk of the tender fruits so affected fruits develop soft rot.	Collect affected fruits and destroy	Application of Folicur or Tilt 250 EC at 0.5 ml per litre of water or Bordeaux mixture 6:6:100 spray
Fruit soft rot	*Rhizoctonia artocarpi*	Rot of inflorescence, young fruits and ripening fruits		Bordeaux mixture 2:2:50 spray Spray Dithane M-45 (Mancozeb 75% WP) at 0.2% and Bavistin at 0.05% 3 times at 1 day intervals.

Common name of disease	Scientific name of causal pathogen	Nature of damage	Bio-control	Chemical control
Rust	*Uredo artocarpi*			
Pink disease	*Botryobasidium salmonicolor* *Botryodiplodia salmonicolor,* *Rhizopus stolonifer,* *Pellicularia salmonicolor*	Young woody branches of the affected trees lose their leaves and show die-back	Affected branches should be pruned	Bordeaux paste or copper oxychloride
Canker	*Corticium salmonicolor*	Twig blight and stem canker	Affected branches should be pruned	Bordeaux paste or copper oxychloride
Stinking root disease	*Sphaerostible repens*			

Common name of disease	Scientific name of causal pathogen	Nature of damage	Bio-control	Chemical control
Root rot	*Pythium splendens*, *Phytophthora* species, *Fusarium* species, *Rhizoctonia* species, *Gonoderma* species, *Macrophomina phaseolina, Rosellinia arcuata, Rosellinia bunodes*	Affects roots and the stem base of seedlings	Improving cultural practices	
Root disease	*Fomes durissimus*			

Sources: Azad (2000), IPGRI (2000)

Chapter 4. Reproductive biology

4.1 Introduction

Jackfruit trees are monoecious. In Asia, in general, flowering in jackfruit starts in December and continues until March (Samaddar, 1985; Azad, 1989). Flowering in off-season, September to October, is not uncommon (Singh, 1992) and geographical differences affect flower initiation.

Attempts have been made to induce flowering. For example, chemicals, such as Ethephon, at 550 ppm, sprayed onto the foliage in early October improves the number of female spikes (Das *et al.,* 1981) and the application of potassium nitrate at 1% by trunk injection induces flowering (Angeles, 1983).

Due to uneven wind pollination the fruits develop unevenly. Fruit setting can be improved by hand pollination. However, stigmas are only receptive for about 1½ days (Sambamurthy and Ramalingam 1954).

Jackfruit trees start bearing fruits about four to eight years after planting although some local genotypes and the recorded variety "Singapore Jack" always bear early and some can start bearing at three years. Clonally propagated stocks usually bear earlier than those raised from seed.

Fruit set is normally 70-75% through open pollination. The fruits develop during Spring (February) or Summer (June). The fruiting season of about four months means ripe fruits are generally harvested from June onwards in most Asian countries. Geographical differences in harvest periods tend to be from April to August or September to December in Malaysia, January to May in Thailand, July to October in Nepal, and June to October in India (Soepadmo 1992).

4.2 Flowering habit

Male and female inflorescences are borne on footstalks which appear on branches or stems initially as yellow-green, bud like structures (see p. 5-6).

The ratio of male to female inflorescences varies. Samaddar and Yadav (1982) reported 96% male inflorescences while Srivastava (1961) reported 80% male inflorescences per tree. Azad (1989) reported very low numbers of female inflorescences (3-5%) while Sahadevan *et al.* (1950) reported 3-40%. There is always a higher proportion of male than female inflorescences. The spike can easily be identified when small, as the length and diameter of female inflorescences are larger than those of males. The surface of a young male spike is smooth while that of the female is granular. Male and female inflorescences develop more or less simultaneously but male spikes tend to reach maturity 3-5 days before the female ones. On any one tree male and female flowers open over a long period (Soepadmo, 1992).

4.2.1 Male flowering

The stamen has four anthers and emits a sweet scent (Purseglove, 1968). This splits to expose a mass of sticky, spherical, yellow, pollen grains. A few inter-floral bracts are shed immediately after anthesis. The peak of anthesis is between 2-3 pm (Samaddar andYadav, 1982).

Among the male flowers, sterile ones are also found. The sterile male flower has a solid unlobed perianth, whereas the fertile male flower is tubular and bi-lobed.

The abscission of male spikes starts with a change in colour from green to yellow, turning to brownish yellow, and finally brown to black. Spikes generally fall off two to four weeks after emergence (Querijero, 1988). However, they may remain on the tree longer, before falling to the ground as a black mass.

4.2.2 Female flowering

Creamy white stigmas protrude out of the surface of the spike when receptive, usually 4-6 days after opening of the spathes. Stigmas tend to be receptive for 28-36 hours (Sambamurthy and Ramalingam, 1954, Azad, 1989).

4.3 Pollination

The production of more male than female flowers in jackfruit is a characteristic of a typical anemophilous species (Purseglove, 1968). Pushpakumara *et al.* (1996) from their studies of pollination biology in Sri Lanka suggested that jackfruit is most likely to be wind-pollinated. Pollen grains are not shed readily if there is a light physical disturbance, as would be expected from a wind-pollinated plant (Moncur, 1985). The flowering male inflorescences have a sweet scent of honey and burnt sugar which attracts small flies and beetles and other insects. Their activity promotes the release of pollen grains from the protruding anthers. Nonetheless, very few insects visit the female flowers and this reduces the chances of direct pollination by insects. The wind and insect activity together may act as a pollination mechanism.

If the flowers of the female spikes are not adequately pollinated, fruits do not develop normally: fruit size is small and the shape may be irregular. Lack of pollination may lead to the dropping of female spikes (Azad, 1989), but this should not be confused with early fruit drop which appears to be a natural physiological thinning mechanism.

Sinha (1973) reported that pollen viability in jackfruit is affected by different ranges of relative humidity and temperature. Gopinath *et al.* (1983) reported on pollen fertility of 94.5% when kept on 1% agar and 10% sucrose. Pollination can be improved by hand pollination.

4.4 Fruiting

Fruits are syncarps composed of the individual fertilised ovaries each developing into a fruitlet with soft, yellow, fleshy perianths developing into pulp and surrounding the seeds. The fruitlets, or true fruits, are sometimes called bulbs, pods or pips. Unfertilised female flowers

develop into tough, strap or string-like structures, called perigones, white pulp or rags. They occupy spaces between fruitlets. Whereas the perianths of fertilised flowers form edible pulp, the ovary wall does not become fleshy and it develops into a pericarp.

Initially, fruitlets appear as tape-like structures. The ovary enlarges and the embryo becomes distinct after one week of fertilisation. In some genotypes the fruitlet becomes highly visible and differentiated only at the eighth week of flower emergence (Laserna, 1988). Each fruitlet develops to 4-11 cm long, 2-4 cm wide, and weighs 6-53 g. It is composed of the fleshy aril and the seed. The aril is the part which is usually consumed fresh and is sometimes referred to as flesh. It can be waxy, firm or soft. Its colour ranges from yellow to yellow orange.

The whole fruit, depending on the genotype, varies from 20-100 cm in length and 15-50 cm in diameter and weighs 0.5-50 kg. Each fruitlet is large and oblong or reniform and the overall fruit's shape may be oval, oblong or oblong-ellipsoid (Plates 11a and b). The white pulp is firmly attached to a core. The core or receptacle is pithy and 4.2-10.5 cm thick. The fruit colour is pale or dark green at the immature stage but it becomes greenish yellow, yellow or brownish when ripe. The fruit has a green stalk or peduncle 2-10 cm long and 1.2-3.5 cm thick. It is covered by rubbery rind and spines that are hard, pyramidal, and either pointed or blunt. The spine is formed from the tip part of the perianth. Spine lengths vary 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.

4.4.1 Tissues of the fruits/ fruit morphology

According to Manjunath (1948) there are two well-defined groups of jackfruit cultivars, based on fruit size, either small or large. Dissection of several fruits of *A. heterophyllus* revealed that on average the larger type had 10,000-12,000 florets in the composite fruit and the number of normal seeds produced varied from 50-200 per fruit. Additionally there are about 200 or more ill-developed seeds, intermixed with the normal ones. The smaller type has 8000-10,000 florets per composite fruit and only 20-50 seeds are produced in a fruit. In one underdeveloped fruit of about 12.5 x 7.5 cm in size, there were only four normal and about 10 poorly developed seeds found and these were all in the upper half of the fruit.

Each syncarp or fruit contains three sections as follows:

(i) The fruit axis is the modified mature axis of the inflorescence and is dome-shaped. It is rigid and slightly fleshy. It measures about 30 x 8 cm or more when the fruit is mature. The bulk of the fruit axis is made of elongated broad parenchymatous tissues and the dimension of the axis increases mainly due to the enlargement of cortical cells.

Sclerenchyma is well developed in the cortical region of the axis. The central pith and the peripheral cortical region of the axis have numerous large laticiferous tissues. The latex from these tissues is milky when fresh but becomes yellowish brown on exposure to the air.

The axis region of the fruit is non-palatable and useless for food because of the absence of sufficient starch and the presence of enormous amounts of latex.

(ii) The pulp and structures derived from the flower perianths constitute the bulk of the fruit. In the early stages, the perianth tubes are entirely free from one another but are deeply bi-lobed at the tips. During the development process they begin to fuse in the middle region leaving the upper and lower regions free. Thus the perianth has three regions: (a) the lower free and fleshy region, (b) the middle fused region, and (c) the upper free and horny region. The first one is exclusively fleshy and edible while the second and third regions become the outer rind of the fruit.

(iii) The true fruits or fruitlets, strictly known as achenes, are large, oblong in shape; glabrous and armed with short triangular-hexagonal, pyramidal, and acuminate spines. Each achene is indehiscent and has only one seed, which is separable from the ovary walls.

The rind thickness increases from about (0.4-) 1(-2) cm (Angeles, 1983) at maturity. Similarly the pithy core or receptacle enlarges from about 1.9-7.5 cm in width. However, the core constitutes only about 16% of the total fruit width. The amount of latex in the core increases as the fruit matures but decreases as the fruit ripens. As the fruit grows larger and heavier it becomes pendulous (Moncur, 1985).

4.4.2 Fruit maturation

The fruit can mature in 79-163 days or may be as long as 180-240 days after the emergence of flowering spikes (Yap, 1972). The criteria for maturity are given in Chapter 6.

Fruit maturation can be divided into 10 stages according to growth parameters (Narasimham, 1990). The increase in fruit size and its different parts during maturation indicates that the growth rate from stage to stage is more or less uniform as shown in Table 4.1. However, there is a slight indication of slow growth in fruit length between stages five and six. At the maturity of the fruit the whole fruit and its edible region increases in size at a faster rate between stages 9 and10. The perianths of the non-fertilised flowers have similar growth rates as fertilised ones but they do not increase much in breadth and thickness whereas the perianth of the fertilised flowers attains a size of 3-5 cm in breadth and 0.5-1 cm in thickness.

4.5 Seeds

The seeds originate from a meristematic tissue of the ovary wall called ovule primordium (Copeland, 1976). The seed is firm and waxy, oval, oblong or oblong ellipsoid in shape (Corner, 1938). There are are numerous seeds in each fruit.

The development of the seeds occurs in parallel with the development of the ovary which begins with the successful pollination of the flower. A seed-like structure coated with a white, loose covering starts to fill the ovary a month after pollination. 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. The seed may become fully developed within four months of pollination. The developed single large seed remains free from the fruit wall and is attached to the pericarp at one point only, i.e. the funicle.

Table 4.1 Growth stages of parts of jackfruit (in cm).

Stage of growth	Length of perianth		Diameter of fruit axis	Total length	Length of bulb	Length of rind	Length of spikes
	Length of fruit	Diameter of fruit					
1	4.5	2.5	1.2	0.35	0.1	0.07	0.2
2	7.8	3.6	2.2	0.7	0.2		0.37
3	12.5	7.5	2.7	2.4	1.0	0.8	0.6
4	16.0	10.0	8.8	3.1	1.6	0.9	0.6
5	26.0	14.0	6.0	4.0	2.5	0.9	0.6
6	28.0	16.0	7.0	4.5	2.9	1.0	0.6
7	35.0	18.5	8.0	5.25	3.5	1.0	0.75
8	40.0	22.5	9.0	6.5	4.5	1.2	0.75
9	44.0	25.0	10.0	7.5	5.6	1.2	0.7
10	50.0	34.0	10.0	12.0	10.0	1.3	0.7

Source: Narasimham (1990)

Chapter 5. Genetic resources and crop improvement

5.1 Introduction

As pointed out in Chapter 1 jackfruit is largely a cultigen found only under cultivation. Due to its spread over very wide areas of Asia long ago it is important that an assessment is made of the patterns of genetic diversity that exist so that genetic resources can be identified for conservation and current or future utilisation.

Genetic diversity can be defined as the extent to which heritable materials differ within a group of plants (van Hintum, 1995). The diversity of the population of a cultigen is the result of evolution and domestication. It is also the result of natural selection, spontaneous mutation, dispersion (geographical distribution) and selection by human beings whether consciously or subconsciously. Modern plant breeding plays an important role in modifying patterns of genetic diversity in major crops and scientists are interested in studying their genetic diversity for its better utilisation and conservation. However, in the case of underutilised crops these activities have been overlooked by scientists, possibly due to a lack of knowledge of the crop. It will be noted from the rest of this chapter that the primary and secondary genepools of *A. heterophyllus* have not been identified.

5.2 Cytology

Artocarpus heterophyllus is a tetraploid and the somatic chromosome number is (2n) 56 (2n=4x=56), hence the basic chromosome number (x) is 14 (Darlington and Wylie, 1956; Habib, 1965). Although it is an out-crossing species, it freely crosses with *A. integer*. *Artocarpus lanceaefolius* and *A. rigidus* are closely linked to *A. heterophyllus* according to Kanzaki *et al*. (1997) whereas *A. nitidus* appears to be quite separate. No reports have been found on interspecific crosses involving these species or any clear chromosome counts. However in *A. integer* there are both diploid and tetraploid representatives.

This means that, at present, with hardly any information on the cytology within the *Artocarpus* genepool scientists have considered relationships based on morphological variation and assessment of numerous characteristics that are likely to be polygenic. Much more research is needed.

5.3 Current information on diversity

Jackfruit trees are cross-pollinated and are mostly propagated by seed. They exhibit a wide range of variation in morpho-agronomic characteristics (Table 5.1). Variation exists in the fruits (Tables 5.2, 5.3) density, size and the shape of spines on the rind. Their fruits vary in sweetness, flavour and taste (Azad, 2000).

IPGRI in 2000 issued a list of descriptor and descriptor states covering those for characterisation of germplasm, also those for further evaluation. The summary of ranges of variation relates to traits of major interest to local producers (Tables 5.2, 5.3).

A few attempts have been made to understand the extent of genetic diversity in jackfruit from the study of morphological characters, and to select superior types of jackfruit. There has been limited collection of jackfruit germplasm for evaluation and selection in India, Indonesia, Nepal, Malaysia, Thailand, the Philippines, Sri Lanka, Vietnam and Bangladesh (IPGRI, 2000; Bhag Mal and Rao, 2001; Haq, 2002) and thus limited information is available on performance of the accessions. Germplasm introduced to Australia and Florida has also been evaluated (Crane *et al.,* 2003). Hossain and Haque (1977) studied the morphological characteristics of a few selected jackfruit trees in one location in Bangladesh. Azad (1989) reported on the variation of fruit characteristics in different jackfruit trees which originated from seeds. Saha *et al.* (1996) also studied the morphological variability of some selected jackfruits from one location in Bangladesh but these studies did not consider environmental factors. Bashar and Hossain (1993) carried out a survey in Bangladesh to identify diversity in jackfruit through farmers' interviews. In Nepal the variation estimated was based on early, mid season and late season flowering, and of fruiting all the year round. Mitra and Mani (2000), Susiloadi *et al.* (2002a), Mitra and Maity (2002), Reddy *et al.* (2001), Crane *et al.* (2003) and Haq (2003b) summarised information on the diversity of jackfruit in South Asia and

Southeast Asia and also for the introduced accessions in Florida (see Tables 5.1, 5.2, 5.3).

Variation exists between and among populations and this can be selected for clonal propagation. Therefore, there is ample scope to identify genetic diversity and to select superior clones from existing jackfruit trees.

Table 5.1. Variation in morpho-agronomic characters

Tree habitat	Open, spreading, low spreading, sparse upright
Tree growth rate	Fast, moderate, slow
Canopy	Dense, mostly dome-shaped, slightly pyramidal or flat topped. It ranges from 3.5-6.7m
Leaf shape	Elliptic, elliptic-obovate, obovate, oblong, lanceolate, oval
Leaf size	4-25 cm in length; 2-12 cm in width
Leaf petiole	1.2-4.0 cm long
Fruit maturity	Variable
Fruiting seasons	Variable
Fruit shape	Oblong, ellipsoid, triangular, spheroid, claviform, round
Fruit numbers/kg	9-30
Fruit weight (g)	280-985
Fruit thickness	Thin, medium and thick
Fruit texture	Fibrous, firm, course, melting, crisp
Seed shape	Oblong, ellipsoid, irregular, reniform, elongate, spheroid
Seed weight (g)	250-1230

Table 5.2. Variation of qualitative characteristics of jackfruit accessions (N=70) **in Bangladesh**

Characteristics	Types	Frequency	Percentage
Fruit shape	Round	22	31.4
	Roundish	8	11.4
	Oblong	33	47.1
	Long oblong	7	10.0
Fruit colour	Deep green	2	2.9
	Greenish yellow	3	4.3
	Greenish brown	4	5.7
	Yellowish brown/straw	4	5.7
	Reddish	2	2.9
	Light brown	1	1.4
	Brown	1	1.4
	Deep brown	17	24.3
	Bottle green	6	8.6
	Green	1	1.4
	Light green	9	12.90
	Greenish	9	12.9
	Green with yellow patches	1	1.4
	Yellowish green	3	4.3
	Brownish green	3	4.3
	Yellowish	4	5.7
Flesh aroma	None	1	1.4
	Mild	48	68.6
	Strong	19	27.1
	Bad aroma	2	2.9
Flesh colour	Creamy white	1	1.4
	Light yellow	24	34.3
	Yellow	30	42.9
	Deep yellow	12	17.1
	Reddish	2	2.9

	Red/golden	1	1.4
Characteristics	**Types**	**Frequency**	**Percentage**
Flesh texture	Crisp	19	27.1
	Coarse	3	4.3
	Fibrous/coarse	2	2.9
	Fibrous	31	44.3
	Smooth	15	21.4
Quantity of fibre	Nil	13	18.6
	Scarce	7	10.0
	Medium	29	41.4
	Abundant	21	30.0
Juiciness of pulp:	Very juicy	1	1.4
	Juicy	29	41.4
	Medium juicy	20	28.60
	Less juicy	16	22.9
	Dry	4	5.7
Shape of seeds	Ellipsoid	40	57.14
	Semi-ellipsoid	9	12.86
	Semi-spheroid	11	15.71
	Spheroid	10	14.29

Source: Azad (2000)

Table 5.3 Variation in fruit characteristics

Characteristics	Range		Mean ±SE	CV%
	Min.	Max.		
Fruit weight (kg)	2.44	21.00	7.49±0.45	46.32
Fruit length (cm)	20.5	60.6	36.10±0.97	22.46
Fruit diameter (cm)	16.42	29.50	21.89±0.35	13.47
Fruit girth (cm)	50.5	95.8	68.83±1.13	13.71
No.of bulbs/fruit	24.2	580.2	140.41±10.93	65.21
Pulp (%)	18.39	60.97	37.07±1.17	26.51
Seed (%)	2.58	23.14	9.40±0.47	41.75
Rachis (%)	1.54	21.37	6.37±0.38	49.45
Rind (%)	20.62	71.90	47.16±1.39	24.72
Wt. of 100 bulbs	1.02	5.87	2.72±0.12	36.90
Wt. of 100 seeds	290.0	1068.0	529.20±20.22	31.98
Brix (%)	13.80	25.20	18.74±0.34	15.36

Source: Azad (2000)

5.4 Germplasm collections

Several jackfruit producing countries have attempted sporadically to collect germplasm. The collection, characterisation, documentation and evaluation of accessions (or provenances) from the region of origin and centre of diversity are far from complete. There is an urgent need to establish targeted collections from the Indian sub-continent and also from Southeast Asia.

Haq (2003b) reported on participatory collecting of jackfruit germplasm and preliminary work on its characterisation by member countries of the Underutilised Tropical Fruits in Asia Network (UTFANET). A list of collections of jackfruit germplasm held in different countries before 1995 and after 1995 is provided in Table 5.4. Collections held by different institutions/organisations are listed in Appendix 2.

Table 5.4 Jackfruit collections held in different countries

Country	No. of accessions
Bangladesh	70
Brazil	45
Costa Rica	15
India	347
Indonesia	155
Malaysia	60
Nepal	350
Pakistan	10
Papua New Guinea	8
Philippines	178
Seychelles	4
Sri Lanka	77
Thailand	87
Vietnam	202
USA (Florida)	3

Sources: IBPGR (1986), IPGRI Database and Haq (2003b), Campos (pers.comm.)

5. 5 Cultivars

Samaddar (1990) reported that there is no distinct cultivar of jackfruit. Hossain (1996) also reported that there is no recommended variety of jackfruit for cultivation. Different types of jackfruit have come into commercial cultivation with different local names for the cultivars. In reality, there is little comprehensive or reliable information on any true variety of jackfruit which has been developed through any breeding programme anywhere. However, the cultivars 'Rudrakshki' and 'Singapore Jack' ('Ceylon Jack') in India are known to breed more or less true to type from seed (Soepadmo, 1992). These produce 5-20 kg in weight within 2-5 years of planting the seedlings.

In most jackfruit producing countries there are many local names given to clonal selections which are propagated (e.g. in India the cultivars are known as 'Gulabi', 'Chamooa', 'Hazari'; in Bangladesh 'Gala', 'Khaja',

'Hazari' etc.) but how these are to be distinguished from each other is not yet established. Selections from one country moved to another have been given separate names. This causes confusions. In Sri Lanka a variety called 'Vela' with characteristic soft pulp is the same as one described by da Costa as 'Gerisssa' in India and he classified 'Barica' as a firm and harder fleshed type. Under these two names there are many sub-types which differ in taste, colour, fibrousness and sweetness and they have their local names. Many of the local names relate to attributes rather than places e.g 'Gulabi' means 'rose scented'; 'Champa' means taste like champedak, 'Hazari' means 'producing a large number of fruits' (Samaddar, 1990) (Table 5.5).

Manjunath (1948) also classified jackfruit into two types on the basis of size, (i) 'Barka'- a smaller fruit and (ii) 'Kapa'- large fruit. The 'Barka' is locally (in Uttar Pradesh of India) called 'Katahali' and yields small fruits which are somewhat sour in taste and weigh 2-8 kg each. 'Kapa' is called 'Kathal' in Uttar Pradesh and neighbouring regions, yields large fruits weighing up to 40 kg and at ripening has fleshy sweet bulbs.

Srinivashan (1970) reported a local cultivar, 'Muttam Varikha', with an average weight of 7 kg in Tamil Nadu (India) produced at ground level and with a large fruit weighing up to 55 kg. Singh (1985) also reported local selected strains, 'Hairialyalva', 'Bhadunha', 'Zarda' and 'Bhusala' from northern India. Morton (1987) reported selected cultivars of jackfruit and these are, 'Safeda', 'Khaja', 'Bhusila', 'Bhadaiyan', 'Handa', 'T-Nagar Jack'. She also reported 'Velipala' as a local selection from the forest having large fruits with superior quality large bulbs.



Plate 1. Whole fruit and bulbs



Plate 2. Fruits



Plate 3. High quality furniture



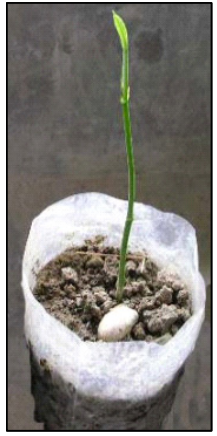
Plate 4. Goat fodder



Plate 5. Protective bamboo fencing



Plate 6. A seedling raised in a polybag



10 day old rootstock



Uprooted rootstock



Scion



Defoliated scion

Plate 7a. Steps of epicotyl grafting

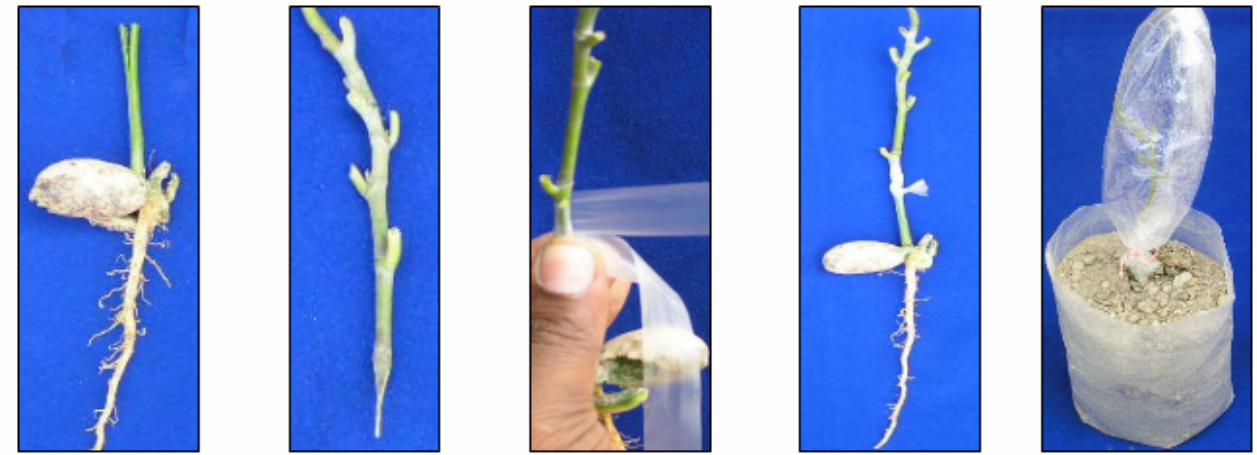


Plate 7b. Steps of epicotyl grafting



Plate 8. Polybags with shading



Plate 9. Grafted tree without pruning



Plate 10. Grafted tree pruned and trained to have a longer trunk



Plate 11a. Fruits of different sizes

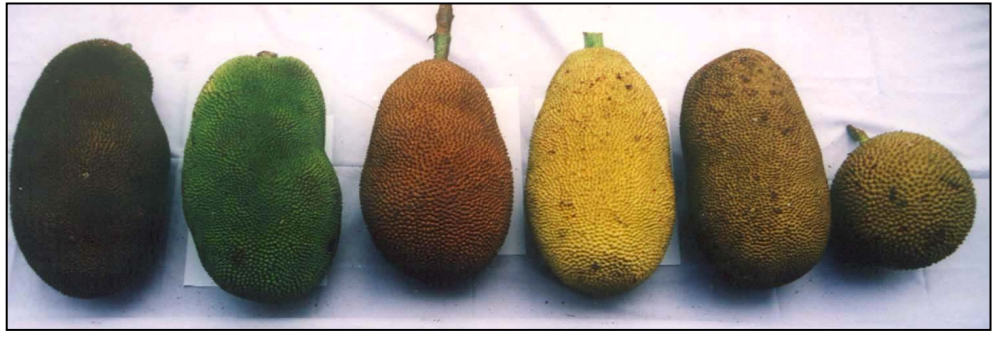


Plate 11b. Fruits of different shapes



Plate 12. Jackfruit products



Plate 13. High quality fruits at market

Table 5.5 Cultivars of jackfruit

Country	Cultivar names
Australia	Golden nugget, Black gold, Honey gold, Lemon gold, Cheena*, Chompa Gob, Coching, Galaxy, Fitzroy, Nahen, Kapa, Mutton, Varikkha
Bangladesh	Topa, Hazari, Chala, Goal, Koa, Khaja
India	Kooli, Varika, Gerissal, Barica, Ghila, Karcha, Rudrakshi, Champa, Hazari, Gulabi, Safeda, Khaja, Bhusila, Bhadaiyan, Handia, T-Nagar jak, Velipala, Gulabi, Champa, Hazari
Indonesia	Kandel, Mini, Tabouey
Malaysia	J-30, J-31, NS-1, Na2, Na29, Na31
Myanmar	Talaing, Kala
Philippines	J-01, J-02, TVC, Torres
Sri Lanka	Vela, Varaka (Waraka), Peniwaraka, Kuruwaraka, Singapore Jak/Ceylon jak
Thailand	Dang rasimi, Kun Wi Chan, Kha-num nang, Kha-num lamoud
USA: Florida	Black gold, Cheena, Dang Rasimi, Galaxy, Golden Nugget, Honey Gold, Lemon Gold, J-30, J-31, NS-1, Tabouey, Delightful

Sources: www.fairchildgarden.org/research/jackfruit-cultivars.html; Morton (1987), Samaddar (1990), Soepadmo (1992), Mitra and Maity (2002)

* hybrid

However, these names are based on three groups of fruit characters: i) Flesh soft when ripe, the pulp is thin, fibrous, soft, juicy and the fruit yields easily to the thrust of a finger, ii) Flesh firm the pulp is thick, firm and crispy and the taste is variable (Table 5.6) and iii) There are some cultivars which are intermediate between the two and are known as Adarsha types (Azad and Haq, 1999). Samaddar (1990), Narasimham (1990) and Soepadmo (1992) also made a similar classification of jackfruit. More work is needed on the geographical dispersion of cultivars and their relationships.

Table 5.6 Names of principal types of fruits in different countries

Country	Firm-fleshed type	Soft-fleshed type
Bangladesh	Khaja, Chaula	Gala, Gila
India	Karcha, Khaja, Khuja, Koozha puzham, Varaka, Kapa, Kapiya, Varikha, Barica, Kooza-xhala, Kooza puzham, Khujja or Karcha	Ghula, Ghila, Koozha chakka, Tsjakapa, Barka, Berka, Koolai, Gerrisal
Indonesia	Nangka salak	Nangka bubur
Malaysia	Nangka bilulang	Nangka bubur
Myanmar	Kala	Talaing
Philippines	Tinumbaga	Sinaba
Sri Lanka	Waraka	Vela, Peniwaraka
Thailand	Kha-num nang	Kha-nun lamoud
West Indies	-	Vela

Of the diverse types described some bear fruits of superior quality while others bear fruits of inferior quality. There are trees which bear fruits round the year or two or three times a year. Much more needs to be done to substantiate these cultivars and note which are the more promising.

5.6 Breeding

Little is known about breeding of jackfruit. This may be due to its status as a "minor" fruit although it has high nutritive value and a wide range of uses. Any attempts to produce improved jackfruit cultivars would be targeted at commercial production but would also be of value for homegardens. To initiate improvement requires a basic understanding of the existing clones. Farmers have selected the clones from natural populations for their desirable characters but the selection has not been rigorous. Hence, some trees produce sweet aromatic fruits; others are nearly dry and sour. Better selection and vegetative propagation of clones is practicable and efforts should be made also to extend the fruiting season. Although little work has been done on rootstock and scion compatibility the evidence so far is that there is a wide variability in scion performance with different rootstocks (Azad *et al*. 2006).

5.6.1 Current improvement efforts

A major effort has been made to initiate selection by carrying out standard characterisations and identification of trees with desirable characteristics.

Table 5.7 Collection, characterisation, evaluation and selection of promising lines of jackfruit

Country	Collection characterisation evaluation	Selection
Bangladesh	70	10
India	281	54
Indonesia	28	4
Nepal	350	47
Pakistan	10	5
Philippines	148	1
Sri Lanka	77	3
Thailand	81	2
Vietnam	202	8

This was done under the auspices of UTFANET (Underutilised Tropical Fruits in Asia Network). The effort was intended to be participatory with farmers. Table 5.7 shows the number of accessions of germplasm, which were characterised and evaluated in the participating countries of UTFANET. Selection of "superior" mother plants is shown in the second column. These were then used for vegetative propagation by grafting to produce relatively large numbers of plants for homegardens and commercial use (Table 5.8). These trees can be grown with ease and with little or no care and it should prove to be profitable for farmers.

Table 5.8 Number of planting materials produced in each country

Bangladesh	130
India	59
Indonesia	20
Nepal	48
Pakistan	100
Philippines	280
Sri Lanka	11
Thailand	117
Vietnam	300

The selection of superior mother trees and their clonal development may be faster and may have greater impact than conventional breeding.

5.6.2 Focus on genetic diversity

Most morphological traits are influenced by environmental factors and many quantitative traits are of polygenic inheritance and expressed only after several years of growth (Hamrick *et al.,* 1992). As a result, the level and pattern of genetic diversity determined by morphological traits and characterisation are not very accurate, although characterisation should be based on high heritability of characters. In recent years, the isozyme techniques and molecular markers have been used to assess the genetic diversity more accurately (Gan *et al.,* 1981; Weeden and Lamb, 1987; Islam, 1996; Anand, 1998; Azad, 2000). Molecular methods will also allow the identification of cultivars as well as determining the parentage.

Azad (2000) studied four isozymes, alcohol dehydrogenase (ADH), glutamate oxaloacetate transaminase (GOT), malate dehydogenase (MDH) and acid phosphatase (ACP), and found variation in enzymatic patterns in jackfruit populations. He indicated that this may be due to genetic differences. Schnell *et al.* (2001) who studied genetic diversity of 26 accessions from eight countries using AFLP markers provided a picture of the diversity within the accessions. The results showed that 49.2% are polymorphic based on 12 primer pairs.

Further variation might be due to hybridisation as jackfruit is known to cross with chempedak (*Artocarpus integer)*. This is supported by chloroplast DNA (cpDNA) studies by Kanzaki *et al.* (1997).

By RFLP and cpDNA analyses, Kanzaki *et al*. (1997) confirmed that *A. heterophyllus* and *A. integer* were monomorphic for all restrictions. Schnell *et al.* (2001) analysed a known hybrid of the two species using AFLP markers, showing it was clearly separate from *A. heterophyllus* cultivars but related. Hence it would appear that *A. integer* is in the primary genepool of *A. heterophyllus*.

With the present information available it should be justifiable to undertake surveys and collecting of wild species from the Western Ghats, the Andaman Islands and the south eastern part of India to achieve a better understanding of their distribution. More Indian wild species need to be analysed for their relationships.

However, in terms of genetic resources, collecting of wild species to put into germplasm collections will not be justified unless they are known to be genetic resources of major importance and the material is likely to be used in crop improvement.

5.6.3 Further selection

The genetic improvement of a tree species is time consuming as it requires 15-20 years to provide a cultivar for farmer use. There are two reasons for this. Firstly, jackfruit trees require 4-8 years to reach the fruiting stage, and secondly the germplasm has to undergo several stages of screening including on-station and on-farm evaluation. Farmers' participation must be considered during the screening process because the farmers are the producers as well as the consumers.

Cultivars mentioned in table 5.5 have been recommended for cultivation in several countries. The recommendations have been based on farmers' participatory evaluations.

Azad (2000) studied the diversity of jackfruit in five regions of Bangladesh to select potential superior tree types based on farmers' information and on field observations. Farmers' criteria included high

yield, fruit quality, sweetness, early fruiting types and off-season types. It has been found from the study that those considered superior by farmers also received high scores from laboratory analysis for quality (Azad, 2000). On the basis of this analysis and scoring, 10 trees were selected. Two were early maturing (one is also high-yielding), one was late-maturing and one belonged to the off-season type. Five were high-yielders (one is highly sweet) and two were quality fruit types. Among them, three are from high rainfall lowland areas and two are from high rainfall hilly areas. Two are from mid-rainfall areas and two are from low rainfall areas. Specific types are now recommended for cloning. (Haq, 2003b)

5.6.4 Desirable criteria for improvement

The desirable criteria are shown in Table 5.9.

Table 5.9 Criteria used in jackfruit selection

Fruit production	Timber
Moderate canopy	Tree height
Regular bearing	Good diameter/thickness
Early fruiting	Clear trunk height
High yield	Straight trunk
Fruiting season	Good branching pattern
Small fruit size	Good quality
Fruit quality	
Sweetness (Brix %)	

In future, further attention will have to be given to developing improved fruiting cultivars with good timber characteristics, especially for homegardens. In many cases the use requirements can conflict since good timber types are not necessarily also good fruiting types.

5.6.5 Ideotypes

It is advisable to identify ideotypes for different purposes, localities, environments and cultural practices. The several characters considered important in a superior cultivar of jackfruit have been noted above. Nevertheless, ideotype identification should focus on specific services

and products that could be marketed, either locally and internationally. According to Haq (1995) the most important characteristics of a jackfruit ideotype are:

(a) architecture of canopy with acceptable form which is easy to manage and requires less or no pruning for fruit production. In the case of timber, long straight trunks would be appropriate. This would be acceptable for crop diversification and agroforestry systems.

(b) vigorous and prolific plants compatible with one or more rootstocks with early flowering and regular bearing.

(c) good quality fruits with acceptable flesh colour and texture, good flavour and sweetness.

(d) fruits with symmetrical form and acceptable size types and fruit borer and die-back and flood resistant.

(e) wider adaptation.

(f) time of fruit maturity.

(g) off-season type.

(h) long post-harvest life. and

(i) above all, high yield.

5.7 Genetic conservation

The wealth of genetic diversity of jackfruit is the basis for present and future use. Any erosion of germplasm resources will not only result in loss of genetic materials, but also hinder the improvement of the crop. Conservation of jackfruit and related genepool diversity thus needs more attention.

Moderate genetic erosion of jackfruit was indicated by Sastrapradja (1975) to be occurring in Southeast Asia, as a result of the replacement of seedlings by clonal cultivars. Haq (2002) reported that there is some erosion of diversity because of persistent flooding in Bangladesh. However, the majority of the variation is not yet threatened.

5.7.1 *In situ* conservation

Based on studies carried out by Reddy *et al*. (2001), Haq (2002) there is a need to identify/locate precise areas of diversity and possible natural wild populations of *A. heterophyllus* in forest habitats such as the

Western Ghats of India for *in situ* conservation. Such wild populations will in several cases form parts of large natural areas of ecosystems demarcated as biosphere reserves.

Jackfruit, as a cultigen, is mostly grown throughout its range in homegardens and a few in small orchards. Here *in situ* conservation is possible but not practised. In order to develop "on-farm" conservation farmers will need to be persuaded to conserve trees which they find useful. There should be some form of incentive to these small farmers to do so as the economic environment determines the will of farmers for conservation. It may be necessary to encourage farmers to continue to grow trees in traditional agro-ecologies.

5.7.2 *Ex situ* conservation

Jackfruit seeds are recalcitrant (IPB, 1990), i.e. they cannot be dried and stored for more than about five weeks at low or ambient temperatures (Sonwalker, 1951). As they lose viability quickly; seed storage is not possible.

In vitro storage of vegetatively propagated clonal material can be done by using slow growth techniques for medium-term conservation. *In vitro* methods also help to eliminate pathogens and thus conserve disease-free samples; exchange of these materials will also be disease-free. Some recent work has been carried out by IPGRI (see http://www.ipgri.cgiar.org/index.htm).

Cryogenic storage of embryos has been investigated for jackfruit. This technique involves the selection of fruits of correct maturity and the subsequent processing of seeds and embryos prior to treatment. Lowered moisture content (16-26%) of seeds is essential for cryogenic storage (Fu and Xia, 1993). Chandel *et al.* (1995) showed changes in physiological characteristics, desiccation and freezing sensitivity for embryonic axes with increasing seed maturity. Problems occur when the embryo is not uniform within the fruit. Embryos measuring 4-5 mm from mature, unripe fruits are best for survival and can be regenerated repeatedly. The selected fresh embryos have to be partially desiccated (to 60% moisture content) prior to treatment with dimethysulphoxide (DMSO) and 0.5% proline mixture. Freezing has to be carried out in stages i.e. pre-freeze

slowly at 1° C per minute down to -40° C after which they are plunged directly into liquid nitrogen at -196° C.

In theory seeds under cryogenic storage are in a state of suspended animation and should survive for infinity. However, long-term effects after storage need further study. Thamsiri (1999) reported a 50% survival rate of cryopreserved axes extracted from jackfruit seeds and they could be developed into whole plants. Cryogenic storage techniques offer many advantages besides longer storage life, such as the need for less labour and lower running costs.

Although techniques for cryogenic storage are available, limited work has been done on developing protocols and a great deal more work is needed to standardise methods for *in vitro* storage of jackfruit (Mandal, 1997).

5.7.3 Field genebanks

The majority of jackfruit germplasm is maintained in field genebanks/orchards (also called repositories or collections of living plants). These face risks of disease and pest infestation and natural disasters.

The basic principle of the field genebank/orchard is to establish a collection in an area where jackfruit germplasm can be grown and managed. The advantage of a field orchard is the accessibility of the germplasm, because evaluation can be carried out on the growing plants. Disadvantages are the high costs of establishment and maintenance and the risks of losing skilled personnel and loss of germplasm. Recently several field orchards for jackfruit conservation have been established by government institutions in India, (at IIHR), Bangladesh (at HRC), Sri Lanka (at HORDI), Thailand (at Plew and Chantaburi Research Stations), Philippines (at Babatngon, Leyte and IPB, Los Banos) and Vietnam (at RIFAV). In addition to this, some universities in these countries have also maintained field orchards, such as the Agricultural University in Maymensingh (Bangladesh) and Kalyani Agricultural University (West Bengal, India) and other state university field stations in India. These collections are a valuable source of genetic materials to initiate improvement programmes and/or testing.

Chapter 6. Harvesting, post-harvest handling and processing products

6.1 Ripening and maturity

The age at which jackfruit trees bear fruit varies with cultivar. Early forms and vegetatively propagated trees can fruit at two to five years. Some however, may take 8-10 years to bear fruits. There are regional differences in the age at which trees bear fruit. In South India trees can mature in six to seven years but in North India it is later. Similarly bearing is delayed at higher elevations.

In Asia, jackfruit ripens primarily from March to June, April to September or June to August depending on the climatic region, with some off-season crops from September to December or even a few fruits at other times of the year (Gunasena et al.,1996; Azad, 2000). In South India the fruit harvesting season lasts about 4 months, May-August. In the West Indies, it ripens in June and in Florida it is in late summer or autumn. In Darwin, Australia it ripens any time from June to April. In Jamaica the apex of jackfruit is cut to speed ripening and improve flavour.

In Sri Lanka the tree flowers in November to December and fruit ripens from March to June, depending on genetic and environmental factors (Gunasena et al., 1996). At higher elevations off-season fruits ripen during October to December. Some trees at lower elevations may bear a few fruits during the off season. Normally the fruits mature in two and a half to five and half monthsafter flowering. This variation may be due to varietal differences or growing conditions.

The fruit ripens normally at tropical ambient temperatures (20-35º C) in three to ten days depending on the stage of maturity at harvest and with no problems to delay ripening. Starch is the principal storage material in the bulb and during ripening it is converted to sugars. The colour of the bulbs changes from pale to light yellow to an attractive golden yellow colour and is accompanied by the characteristic, sweet aroma. Fruit growth and maturation normally takes 5 months after fruit set but

harvesting can be done even after 4 months. In cooler places and higher altitudes fruit maturation takes longer.

Three stages of maturation are distinguished here: immature; mature for cooking; and ripe for eating fresh. Immature fruits, those that are dark green with closely spaced spines, are usually cooked as vegetables. In Nepal 60% of jackfruit is consumed as green vegetables.

The fruits are harvested at different stages of maturity depending on the intended use. Jackfruit matures 3-8 months after flowering. Since the ripening proceeds normally even when the fruits are harvested a little earlier than at the optimum mature stage, it is not essential to wait until the fruits are fully mature before harvesting. There is however, some differences in the taste from fruit to fruit, probably due to variation in maturity. Larger fruits give bulbs tastier than smaller ones. Young fruits which are green to yellowish in colour and with well expanded spines, are harvested for use as vegetables during the first two to three months after fruit-set, before the seeds harden, and mature fruits are harvested after four months for dessert purposes. However, the timing depends on the date of emergence of the inflorescence.

There are several characteristics of the fruit that can be used as indicators of maturity, either on their own or together for a particular cultivar (Palang and Cajes, 2000). The best indicator may be a solid sound when tapped. This indicates readiness for harvesting as green fruit whereas ripe fruits have a hollow sound. In many cultivars the skin colour changes from green to light green or yellow and usually develops a strong aroma, and the spines on the skin become flattened and wider.

The characteristics of fruit maturity were described by Yap, 1972:

- Rind changes colour from green to yellow or greenish yellow
- Spines become well-developed and well-spread and yield to moderate pressure
- Last leaf on the footstalk turns yellow, and
- Fruit produces a dull hollow sound when tapped by a finger.

Among these indicators of maturity, the last is claimed to be the most reliable. The other indicators, particularly the yellowing of the last leaf of the footstalks, 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 colour as a basis for determining fruit maturity is not a dependable indicator. Some cultivars turn light green, greenish-yellow, yellow, yellowish-brown or rusty brown at the mature stage. At maturity, the flag leaf on the fruit stalk turns yellow.

Teaotia and Awasthi (1968) reported that with advancement of fruit maturity the ratio of edible to non-edible portions improves. It was reported that the first harvested fruit at 135 days after appearance of spike had only a 45.8% edible bulb, while the yield of edible bulb was 60.4% of the fruit at 195 days maturity (Table 6.1). In northern India the optimum maturity period is around 180 days from the spike emergence, and these fruit give good finished products (Teaotia and Awasthi 1968).

6.2 Harvesting

Harvesting is carried out by cutting the peduncle with a sharp knife and by traditional methods, such as the use of ropes and sickles for upper fruit harvesting and hand picking for lower fruits. If fruits fall on the ground they will bruise and deteriorate, unless consumed immediately. They should be harvested into a sack or lowered by a rope to avoid damage. If not harvested at maturity the fruits ripen further on the tree giving a characteristic aroma. These fruits should be consumed soon after harvest.

Deformed fruits are harvested early because the flesh will not develop well. Harvesting of the fruits as soon as they reach maturity facilitates handling and transport. For the processing of jackfruit a uniform maturity of harvest is needed to obtain a quality processed product.

Jackfruit taste is substandard if harvested from young plants. Old trees are preferred. Sweetness and taste increasingly improve with the advancing age of the tree. Fruit growth and maturation normally takes five months after fruit set but harvesting of immature fruits can take place as early as four months. In cooler places and higher altitudes fruit

maturation takes longer. For culinary purposes tender jackfruits are harvested within two to three months after fruit set, before the seeds harden. Under North Indian conditions the optimum maturity for harvesting good quality ripe fruit is about 180 days from the date of spike emergence (Teaotia and Awasthi, 1968). In South India the fruit harvesting season lasts about four months, from May through to August.

Table 6.1 Yield of bulbs and non-edible portions and physical variations in bulbs at harvest at six stages of maturity

Harvest date and age of fruit		Edible-non-edible parts (%)			Variations in bulb quality	
No. of days after spike emergence	Colour of rind	Yield of bulbs	Non-edible portion	Texture	Colour	Flavour
135	Dark green	45.8	54.2	Hard	White	Poor
150	Dark green	49.5	50.5	Hard to firm	White	Fairly good
165	Green	55.0	45.0	Firm	Yellowish white	Good
180	Green	58.0	42.0	Firm	Yellowish white	Good
195	Light green	60.4	39.6	Firm to Soft	Whitish	Good
210	Light straw (slightly yellow)	60.0	40.0	Soft	Yellowish	Ripe

Source:Ghosh(1996)

6.3 Postharvest handling

Harvested fruits are carried individually by holding the stalk, and are generally loaded into bullock-carts or push-carts and transported to nearby town or village markets for retail sales, or wholesale to visiting tradesmen from larger towns. However, during the peak production season jackfruits are carried by trucks to markets or towns. The fruit is sometimes transported over 1000 km in order to attain better market prices. Generally, for transporting no packaging material is used. Fruits are carried manually in baskets or bags up to the road point. Post-harvest losses can be as much as 30-34%.

There are several steps that can be taken to improve the quality of jackfruit and reduce post-harvest losses. The first of these is careful handling and packaging to avoid bruising during transport and storage. For efficient marketing and utilisation of the fruits, harvested fruits should be stored according to the stage of maturity and ripeness. This allows the most mature and ripest fruits to be sold first. The less ripe fruits can be put aside and allowed to ripen. For marketing, the fruits should also graded according to size, large fruits weighing over 16 kg, medium fruits weighing between 8-16 kg and small fruits below 8 kg. Prior to use, fruits should be washed to remove latex stains and dust. It is not appropriate or necessary to wash the fruits prior to transport.

ICUC (2005) recommended that post-harvest operations of jackfruit should be practised in seven steps: (i) post-harvest operation, (ii) packaging and storage of fresh fruits, (iii) ripening, (iv) pre-processing into fruitlets, (v) packaging and storage of jackfruit fruitlets, (vi) pre-processing into pulp, and (vii) packaging and storage of pulp. There is a need to wash fruits before processing to remove dirt, latex stains and any field contamination and drain them properly to remove excess moisture from the surface of the fruit.

6.4 Storage

As mentioned earlier, jackfruit has a storage life of three to ten days depending on the maturity, ambient temperature and relative humidity (RH) conditions. Jackfruit is not normally stored in cold storage.

.

Mathur *et al.* (1952) studied a range of temperatures from 0-28° C and relative humidity (RH) ranging from 85-90% and reported that 11-13° C 85-90% RH is the optimum for storing jackfruit. Singh (1972) also reported a storage life of six weeks at 11-12.7° C and 86-90% RH.

During storage the sucrose content decreases from an initial value of 9.5% to around 5% and is accompanied by a rise in reducing sugars from 2% to 6%. However, the ascorbic acid reduction from an initial 8.2 to 3.5% also occurs.

Selvaraj (1993) summarised the metabolic changes which take place during ripening of jackfruit. These relate to storability and are outlined below.

Sugars: The edible bulb contains fructose, glucose and sucrose. Sucrose is the major sugar besides fructose and glucose in varikka type fruits. 20.6% total sugar was reported by Ghosh (1996). A threefold increase in sucrose content is observed during ripening. The concentration of glucose and fructose increases six- and five-fold respectively from the mature to ripe stage.

Acids: The total titrable acidity in jackfruit is low (0.13% as citric acid) and it shows little change during ripening. Citric and malic acids are the non-volatile acids present. Their concentration declines, more for malic acid, and results in an increased citric:malic acid ratio in the ripe fruit (Selvaraj and Pal, 1989)

Proteins and amino acids: Protein content ranges from 1.5-2.3% in edible pulp at the ripe stage. The total soluble amino acids are 270-670 µg and their concentration decreases during ripening.

Sixteen amino acids, namely α-aminobutyric acid, asparatic acid, asparagines, cystein, glutamine, glycine, isoleucine, leucine, lysine, methionine, phenylamine, proline, serine, threomine and tyrosine were identified and their concentrations change markedly during ripening. Asparangine, α-aminobutyric acid, aspartic acid, glutamine, glutamic acid, glycine, phenylalanine and praline are the major soluble amino acids in jackfruit.

Vitamins and minerals: At the ripe stage 100 g edible pulp contains 5.8-10 mg vitamin C, 30-90 µg thiamine, 126 µg riboflavin, 400 µg niacin and 5.3 µg folic acid. Vitamin A content is moderate (540 IU) and increases during ripening (Selvaraj and Pal, 1989). The fruit has 30 mg magnesium, 35 mg sodium, 0.5 to 1.1 mg iron and 220 µg copper in 100 g edible pulp (Selvaraj and Pal, 1989)

Lipids: Total lipids, total fatty acids, unsaponifiables and total sterols increase whereas phospholipids and free fatty acids decrease during ripening (Selvaraj and Pal, 1989). The fatty acids identified are lauric, myristic, palmitic, palmitotelic, linoleic and linolenic.

Aroma: The mild aroma of jackfruit is due to the predominance of esters. Jackfruit contains, in addition to the sixteen esters, four other components including aliphatic alcohols. The volatiles (0.02%) extracted from ripe fruit have been resolved into 38 components (Selvaraj and Pal, 1989). Sensory evaluation of ripening fruit revealed that the fruit had no aroma at harvest maturity. The characteristic aroma is noticed on the second day after harvest and increases considerably on the fourth day reading a maximum at the ripe stage (8^{th} day).

Pectins and Tannin: Appreciable amounts of pectins are found in all parts of the fruit. The pectin content (as % calcium pectate) is 3.2 - 5.8 in bulbs, 1.02-2.66 in aborted flowers (fleshy ribbon-like structure), 3.06-4.6 in seeds, 2.86-3.64 in rind and 1.95-2.23 in cores. Low ester pectins can form into gels in the presence of a small quantities of divalent ions (Vilasachandran *et al.,* 1982). The pulp contains very little tannin and its concentration decreases during ripening.

At the farmers' level, harvested mature fruits are stored in the corner of houses to ripen for one week. Some farmers insert common salt into the floral stalk for quicker ripening. Sometimes farmers dig holes in the ground and store jackfruit if it is not yet ripe.

6.5 Processing

A large proportion of fruits are lost through spoilage. To overcome this, producers sell their marketable surplus within a short time from harvest at low prices. However, income can be increased significantly if produce is stored correctly or processed, since fruit prices double or even triple only a few months after the harvest (Roy, 2000).

Oliveros *et al*. (1971) reported that the demand for ripe jackfruit has increased 100-fold in the Philippines following modern advances in food technology. Reduced post-harvest losses, increased shelf-life and preserved fruit for the out of season period can improve the use of fruits through processing. Raw materials transformed into edible products can increase food security and add variety to the diet improving nutrition and health. Creation of employment opportunities in production areas is an added bonus.

The bulbs possess a desirable texture and a rich appetizing taste. In shredded form they may be eaten raw or used as an ingredient of ice cream, candies and other forms of desserts. Local demand has made the fruits very expensive in many jackfruit growing countries.

Oliveros *et al*. (1971) extracted an essential oil from the rind by steam distillation. However, the yield was low (0.03%). It was colourless with a refractive index (np)25=1.48 and density (d)25=0.912. They concluded that for profitable commercial extraction of the essential oil more work was needed in the food and perfumery industries. Abraham (1971) suggested that steam distillation destroys the aroma and possibly is not the best method for extracting the flavour components of jackfruit. Nataranjan and Karunanithy (1974) have shown that the natural aroma could be added back in preserved products, i.e. canned products and nectars, by the addition of a few milligrams per litre of two esters

synthesised from gamma-butyrolactone. Swords *et al.,* (1978) and later Rasmussen (1983) identified 20 major flavour components from jackfruit.

Freezing: Singh and Mathur (1954) investigated the freezing of jackfruit bulbs. The edible bulbs from ripe fruits (excluding the seeds) were sliced and packed (i) with dry sugar, and (ii) in 50% sugar syrup with 0.5% citric acid (on the basis of syrup), into jam cans. The product was frozen at -29° C and subsequently stored at -18°C. Slices packed in 50% sugar syrup containing 0.5% citric acid gave excellent results. The colour, taste and flavour of the product were preserved for one year. Moreover, the individuality of the slices was maintained for the year. The product prepared with dry sugar had a lower quality.

Processed products: A number of products have been developed from raw, tender and ripe fruits and seeds (Plate 12). There are at least five products prepared from tender fruits. They are (i) canned in brine, (ii) canned in curried form (in combination with other vegetables), (iii) made into dehydrated products, (iv) papadam or papad, (v) sweet or sour pickles in oil and (vi) sweet and sour pickle in vinegar. These products have been standardised (Bhattacharjee, 1981).

The ripe fruit bulbs (excluding seed) and the rind of the ripe fruit (including perianth and unfertilised flowers) have been used for processing in a number of products. Ripe jackfruit bulbs are canned in syrup, made into jams either pure or mixed with dehydrated bulbs, chutney, preserves, candy, and concentrate and powder. Rinds of ripe fruit are made into syrup, pectin, jelly, pectin extracts, biscuits and papadam.

The seeds of ripe fruits are used as vegetables when cooked with grated coconut, chilli, salt and spices and are a popular side dish with rice (Thomas, 1980). Roasted or fried seeds are tasty to eat when stewed with meat. Seeds can be processed: (i) canned in brine, (ii) canned in a curried style such as in combination with other vegetables, (iii) canned in tomato sauce, (iv) dried to make flour, and (v) roasted.

6.5.1. Recipes

Gunasena *et al.* (1996) have given the recipes and ingredients for some food preparations (for 8 persons) and these are as follows:

Young jackfruit curry:

TYPE 1

Ingredients

1 medium sized young jackfruit
1 dessertspoon coriander powder
2 teaspoons cumin powder
2 teaspoons sweet cumin powder
8 peppercorns
a sprig of curry leaves
10-15 dry chillies or 2-3 dessertspoons chilli powder
2-3 cardamoms
2-3 cloves
¼ teaspoon Maldive fish
6 pieces of goraka (fruit)
7 g garlic
4 teaspoons salt
850 ml second extract of coconut milk
½ teaspoon fenugreek
60 g red onions
280 ml first extract of coconut milk

Method

Peel jackfruit and cut into convenient pieces. Score deep on skin side of pieces and put into water. Chop the onion. Roast the spices except the chilli powder to golden brown.

Put the jackfruit pieces with all the other ingredients, and second extract of coconut milk into a pan. Bring to boil and simmer until the gravy has reduced and the jackfruit is soft.

Add the first extract of coconut milk bring to the boil and simmer till gravy is reduced. Remove the goraka (a fruit).

(Use a small pan so that the coconut milk covers the fruit. The first extract of coconut milk may also be added with other ingredients.)

TYPE 2

Ingredients

450 g young jackfruit

¼ teaspoon turmeric powder

4½ teaspoons salt

40 g onions and a thin slice of ginger

2½ dessertspoons chilli powder

4 teaspoons coriander powder

2 teaspoons cumin powder

2 teaspoons fenugreek

2 teaspoons sweet cumin powder

2 pieces goraka

15 g garlic

4 cardamoms

2 cloves

2½ cm cinnamon

coconut milk (extract of one coconut)

Method

Peel fruit and cut into big pieces. Chop the onions.

Put all the ingredients together and mix well. Bring to boil and simmer till the fruit is soft and the gravy is thick.

TYPE 3

Ingredients

450 g fruit pulp and seeds

2 ounces onions

1 teaspoon pepper

½ teaspoon turmeric

2 teaspoons salt

2 cardamoms

1 teaspoon fenugreek

½ dessertspoon Maldive fish

2½ cm of cinnamon

7 g of green chillies

280 ml second extract of coconut milk

110 ml first extract of coconut milk

Method

Cut flesh into strips. Clean seeds. Wash well

Chop onions and green chillies

Boil all the ingredients except the first extract of coconut milk, until the seeds are partially cooked

Add pulp and cook on a slow fire till tender

Add the first extract of coconut milk. Bring to the boil, cook for five minutes.

TYPE 4

Ingredients

450 g fruit pulp

55 g onions

3 teaspoons chilli powder

¼ teaspoon turmeric

1½ teaspoons salt

a sprig of curry leaves

2½ cm rampe (pandan leaf used for flavouring)

2 green chillies

4 dessertspoons oil

Method

Wash and cut the pulp into strips. Chop the onions and green chillies. Heat the oil in a pan till very hot, add the rampe, curry leaves, and onions. When the onions are light brown, mix all the other ingredients with the pulp and keep tossing until cooked.

Cover with a lid and lower the heat. Stir occasionally.

TYPE 5

Ingredients

450 g seeds

1 teaspoon salt

55 g coconut roasted to a dark colour

2 teaspoons coriander powder

2 teaspoons chilli powder

570 ml second extract of coconut milk

1 piece goraka

Method

Wash the seeds. Cover with cold water, add 1 teaspoon salt and boil till tender. Remove the outer skins.

Add all the other ingredients and simmer for about half an hour till gravy has reduced and is thick.

TYPE 6

Ingredients

450 g seeds

4 teaspoons chilli powder

1 teaspoon cumin powder

2 teaspoons coriander powder

¼ teaspoon turmeric

1½ teaspoons fenugreek

Small piece of cinnamon

1 clove

1 cardamom

1½ teaspoons salt

a sprig of curry leaves

570 ml second extract of coconut milk

Method

Crack the seeds with a hard object to break the skins. Boil, but do not make them pulpy. Remove the skins.

Mix all the other ingredients together. Add the boiled seeds and cook until the gravy is thick. Reduce the gravy to half or less. This curry should be cooked on a slow fire throughout.

TYPE 7

Ingredients

450 g pulp

2 green chillies

2 cloves of garlic

2 teaspoons chilli powder

1 teaspoon cumin powder

1 teaspoon salt
1 teaspoon sweet cumin powder
1 pint together of second and third extracts of coconut milk
1 teaspoon fenugreek
¼ teaspoon turmeric
110 ml first extract of coconut milk
a sprig of curry leaves
55 g onions

Method

Wash and cut pericarps into strips and put in pan. Chop the onions and chilli. Add them with all the dry ingredients and the second and third extracts of coconut milk. Bring to the boil and cook.

Add the first extract of coconut milk. Bring to the boil and simmer for five minutes.

TYPE 8

Ingredients

450 g young fruit
25 g green chillies
110 g onions
1 teaspoon chilli powder
¼ teaspoon cumin powder
1-2 dessertspoons Maldives fish
3-4 teaspoons lime juice
Add salt to taste
¼ teaspoon pepper powder
a pinch of turmeric
a sprig of curry leaves
bread crumbs
flour and water batter
oil for deep frying

Method

Peel and cut the fruit into small pieces, cover with water, add one teaspoon of salt and boil till tender. Mince finely.

Chop the onions and green chillies. Heat one dessertspoon oil and fry onions and curry leaves. Add Maldives fish, curry powder, chillies, salt and pepper and minced fruit, and fry for a few minutes mixing well. Form into cutlets; dip in a medium batter, crumb and deep fry until golden brown.

Pickles

Ingredients

1 kg peeled jackfruit

salt to prepare 5% brine solution (50 g/l)

2.5 g turmeric powder

25 g coriander seeds

10-20 g chilli powder

10 g salt

150 g sugar

10 ml vinegar

Method

Small tender green jackfruits are cut into several pieces, then the bulbs are removed by hand, the seeds may be removed and the bulbs are sliced into pieces. Jackfruit slices are required to be cured in brine solution for 8-10 days prior to pickling. Jackfruit pickle in oil is possible. Different types of pickles (sweet, spiced, sour) prepared from raw jackfruits have been described by ICUC (2005).

Peel the skin

Cut the peeled fruits into 12-18 mm thick slices

Prepare a 5% common salt solution by mixing salt with water, 50 g salt/l.

Place the slices in a container and cover with brine solution. Weigh them down to keep them submerged in the brine.

Drain the slices after 24 hours using a stainless steel sieve and wash them to remove the excess salt.

Grind and mix the following spices (for 1 kg peeled jackfruit): 2.5 g turmeric powder, 25 g coriander seeds, 10-20 g chilli powder, 10 g salt. 150 g sugar. Add the spice mix and vinegar (10 ml/kg) to the jackfruit slices and cook the mix in a stainless steel boiling pan for 30 minutes while stirring. Pour the pickle into pre-sterilised jars and seal. Cool the jars at room temperature, then label.

Jam

Ingredients

Jackfruit pulp	1 kg
Sugar	1 kg
Citric acid	2½ g
Pineapple essence	½ kg
Orange essence	½ ml

Method

Ripe fruits are cut into several pieces and the bulbs are removed by hand. The bulbs are then cooked for 15 minutes and pulped, the core being removed. Cut the end of the bulb to remove the seeds, and grind the bulbs to pulp using a blender. The pulp is mixed with other fruit pulp (jackfruit: other fruits=1:1). Dissolve 10 g pectin per kg mixed fruit pulp in some water and add to the mixture. Add 1 kg sugar per kg mixed fruit pulp and mix. Heat the mixture in a stainless steel vessel while stirring continuously until the total sugar content is 68-70º C, pour into pre-sterilised jam jars and seal. The ideal pouring temperature is 82-85º C. Cool jars at room temperature, then label.

The colour of the final product is yellow, TSS is 68° Brix, the consistency is semi solid, and the flavour is pleasant. But the product is somewhat sticky, so further refinement of the process is needed to develop a marketable product.

Jelly

Jelly is a product of gelatinous consistency prepared by boiling strained fruit extract with sugar. It is a sparkling product which is transparent with an attractive colour.

Ingredients for jackfruit extract

Jackfruit extract (perigones and rind of ripe jackfruit)	1 kg
Water	1½ kg
Boiling time	40 minutes
TSS	100º Brix

Ingredients for jelly preparation

Quantity of extract	1kg
Quantity of sugar	1kg
TSS	75º Brix
Final weight	1.02 kg
Number of bottles	500 x 2

Jackfruit beverages (ICUC, 2005)

Ingredients

Pulp	150 g
Sugar	140 g
Water	710 ml
KMS (Potassium metabisulphite)	140 mg
Final weight of the product	1 kg
Fruit TSS	14º Brix
Taste	Refreshing
Colour	Yellow orange

Method

Cut ripe fruit in half lengthwise

Carve out the core of the fruit

Scoop out the bulbs

Cut the end of the bulbs to remove the seeds

Homogenise the pulp using a pulper or blender

Boil the pulp for 5 minutes in a stainless steel boiling pan

Cool the pulp

Add pectin-degrading enzyme according to instructions on the packet Keep the mixture at room temperature overnight

Filter the extract using a muslin cloth or stainless steel filter

Prepare a 50% sugar syrup solution at 90º C by dissolving 500 g sugar in a small amount of water and make the volume up to 1 litre.

Combine the fruit juice (30%) and sugar syrup (70%). To obtain 1 litre of the beverage mix 300 ml juice and 700 ml sugar syrup

Add a preservative such as sodium meta-bisulphite (concentration up to 0.05%) (optional)

Pour into pre-sterilised bottles by using either a jug and funnel or a stainless steel bucket with an outer tap.

Cap the bottles

Pasteurise the sealed bottles at 80-95ºC for 10-20 minutes

Cool the bottles to room temperature by immersing in cool water

Label

Candy (ICUC, 2005)

Candies can be prepared from ripe jackfruit pulp by putting them in sugar syrup and gradually raising its TSS to 70º Brix.

Ingredients

Pulp	500 g
Water	1250 ml
Sugar	750 g
KMS	2 g
Citric acid	3 g

Method

Cut the fruit in half lengthwise

Carve out the core of the fruit

Scoop out the bulbs

Cut the end of the bulbs to remove the seeds

Prepare a brine solution containing 15% salt (150 g/l) and 1% calcium chloride (10 g/l)

Soak the bulbs in a brine solution for 2 days. Place a wooden plate with a weight on top of the fruit to keep them submerged in the brine.

Remove the bulbs from the brine, wash them to remove the salt and drain using a stainless steel sieve. Check the flavour to ensure that all salt has been removed.

Prepare sugar syrup of 40º Brix.

Boil the deseeded bulbs for 5 minutes in the syrup.

Keep the mixture at room temperature (28-31º C) for 24 hours.

Remove the bulbs from the syrup. Add sugar to the syrup until it is 50º Brix (use a refractometer).

Immerse the bulbs in the syrup and keep at room temperature for 24 hours.

Remove bulbs from the syrup again. Add more sugar to the syrup until it is 62º Brix.

Re-immerse the bulbs in the syrup and keep at room temperature for 24 hours.

Remove the bulbs and quickly rinse in water to remove surface syrup. Drain off the syrup by spreading the bulbs on wire trays.

Dry drained fruits for about 1 day in a solar or tray dryer.

Pack the candies in jars, tins, cardboard cartons or in polythene pouches and seal them.

Label

N.B. Citric acid was added when strength of the syrup was 50° Brix.

Final TSS	70° Brix
Colour	yellow

Candying of bulbs is practised to extend their utilisation. It was prepared by conventional syruping at 70°C Brix, with subsequent oven drying at

60° Brix for one day. The moisture level of the fruit was reduced to 20% after drying.

Fruit bars

Jackfruit bars are prepared by mixing sugar and citric acid with pulp and drying to a moisture content below 30%.

Ingredients

Pulp	300 g
Sugar	60 g
Citric acid	0.6 g
KMS	a pinch
Essence	1.5 ml
Weight of the final product	150 g

Method

Three methods of drying for fruit bars were attempted - sun drying, drying in a cabinet drier at 60° C, and microwave dehydration. The product dried in a microwave oven had an undesirable dark colour. The colour of the product dried by sun drying and the cabinet drier were good.

Weight of the final product:	
Sun drying	155 g
Cabinet drying	150 g
Recover %	
Sun drying	43
Cabinet drying	42

Dehydrated products (ICUC 2005)

Jackfruit can be preserved by dehydration of the bulbs, seeds, perigones and used to make products like papads. Pectins can also be extracted for

use in processing (Jain and Lal, 1954). Jackfruit bulbs can be dried in the sun or in a cabinet drier at 50-55°C after sulphuring them in a closed chamber. Teaotia and Awasthi (1968) carried out detailed studies in the dehydration of jackfruit bulbs and reported that fruits harvested between 165-195 days from spike appearance with 0.2% SO_2 treatment for 15 minutes gave a good quality dehydrated product.

Method

Cut fruit in half lengthwise

Carve out the core of the fruit

Scoop out the bulbs

Cut the end of the bulbs to remove the seeds

Cut the deseeded bulb into 2 or 4 pieces

Blanch the fruit segments by plunging into boiling water for 2 minutes and cool them rapidly under clean cold water

Place the blanched segments in a single layer on mesh dryer trays. Put them close together but not touching to achieve the maximum capacity and an even rate of drying.

Load trays into the drying cabinet and dry at 55º C for 6-7 hours until the moisture content is reduced to 5%. Remove trays and pack dried fruits immediately in moisture proof containers e.g. 400 gauge polythene or polypropylene pouches, and heat-seal them. Label.

Jackfruit leather (ICUC 2005)

Ingredients

1 kg fruit bulbs

100-150 g/kg sugar

0.1 g/kg potassium or sodium meta-bisulphite

Method

Cut fruit in half lengthwise

Carve the sticky core

Scoop out the bulbs

Cut the end of the bulbs to remove the seeds

Add sugar (10-15% the weight of the bulbs = 100-150 g/kg) according to variety used and taste.

Blend the bulbs

Dissolve preservative e.g. potassium or sodium meta-bisulphite (0.1 g/kg) in water and add to the product

Concentrate mixture in a stream-jacketed pan.

Spread concentrate on stainless steel trays lined with grease proof paper in 3 mm thickness.

Dry leather using a solar (2 days) or mechanised dryer (18-20) hours. Turn it over after 1 day in a solar dryer or 5 hours in an artificial dryer until the moisture content is 9-12%.

Canning of raw jackfruit

Bhatia *et al.* (1956) described a procedure for canning raw jackfruit in brine in which tender jackfruit flesh cubes were used in 2% brine in cans. Bhatia *et al.* (1955) also described methods for canning of raw jackfruit packed in curried style, either alone or in combination with other vegetables like potato, tomato, cauliflower, beans etc. In this case, the product is canned in spiced gravy instead of brine.

Jackfruit seeds

Sun dried or oven dried (cabinet drier) seeds can be preserved in airtight containers for over a year. The dehydrated seeds after soaking in water for about 18 hours can be used as fresh seeds for canning or can be cooked and consumed (Bhatia *et al.,* 1956).

Flour prepared from dried jackfruit seeds mixed at a 25% level with wheat flour was found to be useful for “Chapati” making.

Jackfruit pectin

Good quality pectin can be prepared from jackfruit waste. Krishnamurthy and Giri (1949) reported that pericarps and kernels of jackfruit are rich in pectin. Bhatia *et al.* (1959) prepared pectin and also pectin extracts from jackfruit rind.

Jackfruit powder (ICUC, 2005**)**

Method

Cut fruit in half lengthwise.

Carve out the core of the fruit. Scoop out the bulbs

Cut the end of the bulbs to remove seeds

Cut the deseeded bulb into 2-4 pieces

Blanch fruit segments by plunging into boiling water for 2 minutes and cooling them rapidly under clean cold water.

Place the blanched segments in a single layer on the mesh dryer trays. Put them close together but not touching to achieve the maximum capacity and an even rate of drying.

Load trays into the drying cabinet and dry at 55º C for 6-7 hours until the moisture content is reduced to 5%.

Grind the pieces into a powder using a grinder or by pounding them using a pestle and mortar

Sieve the powder to remove lumps and unground material.

Pack powder in moisture-proof containers, e.g. 400 gauge polythene or polypropylene pouches, and heat-seal them.

Label

Further recipes are available at
www. fairchildgarden.org/horticulature/jackfruit-recipes.html

Chapter 7. Economics of production and marketing

7.1 Economics of production

7.1.1 Cost of cultivation

Jackfruit is not considered a major fruit by most national research programmes and because of this, actual production areas, total production and production cost data are difficult to obtain. As a result there is a lack of information on the economics of jackfruit, a situation which is rather surprising considering that the fruit is valued as a staple in times of scarcity in some countries particularly of South and Southeast Asia. From the information available, it is noted that production from Indonesia, Malaysia and Thailand exceeds 7.5 million tonnes (see Table 3.11).

Bangladesh produces over 250,000 metric tonnes of fruits from almost 25,000 hectares of land, with about 30% of fruits being grown as a monoculture. In India, the total area under jackfruit cultivation is thought to be approximately 102,000 hectares of which an estimated 100,000 trees are grown in backyards and as intercrops amongst other commercial crops. Jackfruit is also grown commercially in Sri Lanka over an area of about 4500 hectares, primarily for timber although the fruit is greatly appreciated and well-consumed.

A few orchards for commercial production are found elsewhere in South and Southeast Asia owned by large farmers and in some cases by multinational companies. An example of the latter is the Unilever Plantation in Malaysia (M. bin Osman, pers.comm.).

Farmers in some jackfruit producing countries are getting a good return from the crop. Many farmers claim that because of its regular and good fruiting habit and high market price, jackfruit is even more profitable than mango or other major fruits. Farmers get more return/income from early and late produce than from peak season production.

7.1.2 Tree establishment costs in household farms and small orchards

Since jackfruit trees are mostly grown in small farms/orchards, no estimates are available for the costs of establishment of jackfruit trees at the farm level. In general, little cost is incurred for establishment and management by farmers: some cost is incurred for harvesting, storing and transportation and marketing. However, based on the recommendation of Research Stations and Agricultural Universities regarding spacing, manuring and fertiliser application, the cost for planting 100 trees has been estimated to be around US$ 54 in India. However, this depends on the region as labour and planting material costs differ within the country (Table 7.1). This estimate is based on 100 plants grown in a hectare, following 10 x 10 m spacing, and pits of 1 x 1 m filled with a mixture of top soil and FYM or compost. The estimate also includes the cost for seedlings/ grafted plants.

Table 7.1 Estimated cost of establishment (in Indian Rs.) of a jackfruit orchard in India

Item	Quantity	Rate	Amount
Planting materials	100	20/plant	2000
FYM applied in pits (kg)	1000	0.3 kg	300
Labour cost for planting, manure application	-	-	400
Total			**Rs. 2700** (US$54)

7.1.3 Maintenance cost

No special care is taken by cultivators on small farms to maintain jackfruit trees and there is little maintenance cost incurred by the growers other than pruning costs.

7.1.4 Returns

Generally the trees start yielding well 7-8 years after planting and peak yield is obtained within 15-16 years. Grafted plants are expected to yield from 3-4 years onwards.

The exact yield varies greatly. For example, in India, the expected yield is around 250-300 fruits/plant in Kerala, whereas in Karnataka it varies from 50-250 fruits/plant. On an average one can expect 150-250 fruits per year per tree in India, however, a mature tree produces up to 700 fruits per year, each weighing from 0.5 kg to as high as 50 kg. On average one can expect a yield of around 10 t /ha.

7.2 Marketing

In a recent survey in Asia (ICUC, 2005), jackfruit marketing involved three groups: producers, traders (middlemen) including wholesalers, and retailers. The marketing of jackfruit hinges not only on the development of suitable cultivars, production, post-harvest management strategies, processing and utilisation systems but importantly on marketing and market development. A marketing programme should include:

(i) determining market channels, outlets and pricing

(ii) assessing supply and demand of market potentials and corporate marketing systems, and

(iii) establishing workable marketing information systems and quality standards.

7.2.1 Marketing channels

The marketing channels involved in the movement of jackfruit produce are complex. The channels may vary between large, medium and small farmers. Large farmers sell their produce long before fruits are mature. It helps cash flow and reduces risk. Wholesalers in the city and large towns are typical buyers who may assume all the risks associated with poor fruit production, including damage due to natural hazards (Anon, 1986). On the otherhand, medium sized farmers sell their fruits to local markets or sell surplus fruits to relatives and neighbours, or to small traders and local retailers.

A production to consumption chain for commercialisation of fruits is shown in Figure 7.1.

Where there is an export market, the exporters have designated suppliers or commission agents, who visit the production areas, examine the fruits and buy only those that meet the exporter's specification.

In general, the buyers purchase the entire fruit crop of a tree and take responsibility for protection of fruits and harvesting them at the time of required maturity.

7.2.2 Products

The following products of jackfruit are considered for marketing:

7.2.2.1 Planting materials

There is a shortage of quality planting materials although the demand for them has been increasing. As a result the number of saplings produced by farms and nurseries has been increasing. The price for a grafted sapling and for a tissue culture propagated plant is high (varying between US$ 0.75-2.0, depending on the country) and small farmers mostly plant seedlings because grafted planting materials are too expensive for them. It is estimated that a small nursery, selling seedlings and grafted planting materials, can earn on an average US$120-150 a month.

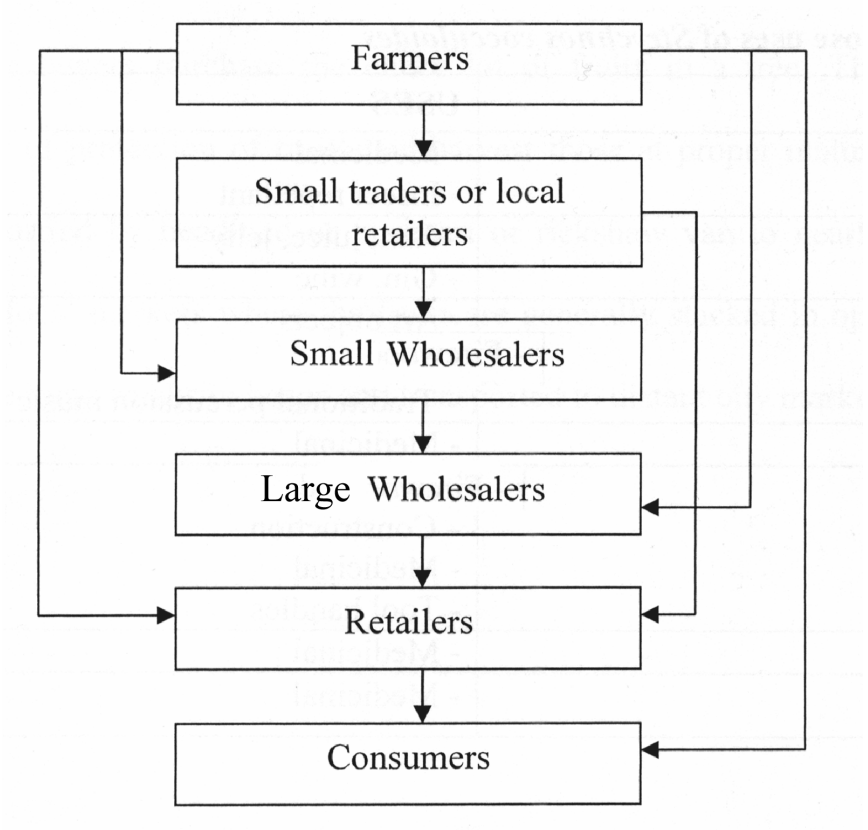


Fig. 7.1 Producer to consumer chain for commercialization of fruits
Source: Hossain, unpublished

7.2.2.2 Unripe fruits (green vegetables)

Tender raw jackfruit and seeds are popular products of the jackfruit tree. These are marketed mainly by the producers. In some countries, like Sri Lanka and Nepal these products are more popular than the ripe fruits and are sold either as whole fruits or in sliced form. Price is determined on the basis of size, weight and condition of fruits and varies (US$ 0.2-0.5 per kg) in these countries and fluctuates depending on season and localities. These products are also canned by industries in some countries (e.g. Thailand, Malaysia, Philippines) where the procurement of raw materials is mostly done by wholesalers. The mechanism of procurement

for unripe fruits is similar to ripe fruits for processed products. Price fluctuations are found to be very high depending on cultivars, season, localities and market demand. It was reported that in Nepal, 200 kg/day of jackfruit is sold in Illam as a vegetable, 650 kg/day in Dharan, and 800 kg/day in Biratnagar. The vegetable was marketed at the price of NRs 45 (US$ 0.9) per kg in Biratnagar, NRs35 (US$ 0.7) per kg in Dharan, and NRs 55 (US$ 1.1) per kg in Illum (AEC, 2003). The wholesalers make profits of 20-25% on wholesale trading.

7.2.2.3 Ripe fruits

In a large jackfruit producing country most of the owners sell their trees on a contract basis and the amount is fixed based on the number and size of fruits: it varies between US$ 8-20/tree (Hossain and Haq, 2006). On this basis, a mature jackfruit plantation can fetch on average US$ 1500 per hectare (based on 100 plants per hectare). The market chains (Fig. 7.1) for ripe fruits operate in two ways in many countries: either the producers bring their produce themselves to the market, or collectors assemble the farmers' produce. Sometimes wholesalers also perform a secondary role as collector.

In other cases the traders or their agents visit market centres for their requirements. These market centres include weekly markets (sometimes twice a week) which facilitate local trade (See Plate 13). Traders (collector, wholesaler, retailer and vendor) determine the price for producers by means of bargaining. Once the price is fixed an immediate cash payment is made.

Big traders/contractors generally sell the whole fruits to either consumers or to retailers and this fetches them a margin of about US$ 0.5 per fruit depending upon the size and quality.

The contractors/traders who have bought whole trees on a contract basis, harvest the fruits as and when they become mature, bring them to the market and sell them directly to retailers or consumers. Some small contractors around cities cut the whole fruit and sell individual bulbs. When the fruits are sold in this way, the profit margin for the whole fruit may total US$0.55 depending upon the size of the bulbs and the number of bulbs per fruit. Despite the strategy. during peak season wholesalers purchase fruits from the primary and secondary markets.

The supply and marketing of jackfruit largely depend on the fruiting season (Table 7.2) and the time of maturity which varies with the agro-climatic conditions and ecosystems. The jackfruit season is divided into: early, peak and off-peak depending on the availability in the market. This seasonality has also been noted in Australia, Zanzibar, Hawaii and Florida where the trees have been introduced.

Table 7.2 Availability of jackfruit in different countries

Countries	Main season(s) of availability
Australia	June-April
Bangladesh	June-August
Brazil	January-March, August-October
Colombia	January-December
India	April-July
Indonesia	August-January
Jamaica	January-July
Kenya	June-October
Malaysia	April-August, September-December
Philippines	March-August
Sri Lanka	February-November
Thailand	January-May, October-December
Uganda	January-December
USA (Florida)	May-August, September-October
Zanzibar	June-December

Source: Soepadmo, 1992; Crane *et al.,* 2003

7.2.2.4 Processed products marketing

Underutilised fruit products develop country-wide demand only when good marketing has been established. Products like chips and papads in India are produced at the village level and marketed by producers as either individuals or as cooperatives, such as self-help women's groups in India. Pickles, leather, candy, dry pulp and juice are also produced at the village level for local marketing. These products may have brand names of their own or be marketed through cooperatives under the cooperative brand name. The products do not in general follow strict

quality assessment or packaging systems for market channels. However, most countries now require certificates from Food Standards Departments, and cooperatives in India and Sri Lanka have started to market jackfruit products with certification.

Although there is recent interest in underutilised fruit products, the small scales of operation, irregular availability of raw material, limited markets, and continued use of traditional processing make this unorganised sector of minor economic importance. Therefore, marketing chains of growers-processors-wholesalers-retailers do not always exist. Sometimes processors have problems in marketing because of the limited outreach for products and concentration by processors in a small area. Nevertheless, the underutilised fruit products hold promise for expansion with appropriate promotional efforts which could include trade-fares, exhibitions, and door to door sales. In addition, value added products from the fruit, such as jacalin, will encourage industries to use the crop as a raw material.

Currently production of processed products is extremely small and utilises less than one tonne of fruit per month in total in most producing countries. This is due to several constraints, such as:

- Lack of technical know-how and training.
- Limited availability of raw materials, particularly in the off-season period resulting in processing units not being fully used.
- Non-availability of suitable machinery and equipment.
- Small entrepreneurs, with inadequate machinery and equipment, who do not want to take risks in new production ventures and marketing of products.
- Poor storability of fruits.
- Difficulties in sun drying due to the monsoon season occurring during peak fruit harvesting time.
- Lack of capital.
- Products are not yet known to consumers and there is risk in the market as well as a lack of marketing facilities.
- Lack of improved packaging materials for processed products.

7.2.2.5 Timber and leaves

Jackfruit timber is popular in many producing countries and is highly prized. The timber price in Bangladesh varies between Tk 900-1200 (US$ 18-26 per cubic feet or US$ 640-929 per cubic metre). India and Sri Lanka export jackfruit timber to Europe but trading prices are not known.

Timber has been sold particularly to make guitars in the Philippines but it was considered inferior to other species. In the chain, woodworkers make the parts of the instrument and these are sold to wholesalers/retailers/or factories for finishing.

The dried leaves are sold for fuel. A full sack is sold for Tk 30-50 (US$ 0.6-1.0) in Bangladesh, depending on the season and the production area. The green leaf is also sold for fodder by the small van load (rickshaw) for the price of Tk 120-150 (US$ 2.4-3.0), again depending on the season and the area.

7.2.2.6 Pricing

The pricing of jackfruit largely depends on demand and supply, with consumers paying higher prices for early and off-peak season fruits. Early and off-peak types may be of inferior quality and of a different size to the fruits from the main season. Pricing of jackfruit also depends on the quality and size of the fruits.

7.2.2.7 Packaging

Generally no packaging is used when transporting whole fruits. At the village level, processed products, both fresh and dried bulbs including chips and papads are packed in polythene bags. Pickles and jam are packed in glass bottles. Candies and leather are packed in plastic bags for local markets. Bulbs are canned in brine by industries for local and export markets. In some producing countries, pickles and jam are marketed in small sealed pouches but considerable promotion is needed to make the products popular in markets.

7.2.2.8 Transport

In many countries, jackfruits are brought to the market manually by carrying on the shoulder or head. Jackfruits are also transported loosely by tempoes (rickshaw van) or by loading them in available space on already loaded lorries. The transport cost is generally fixed by bargaining with the transport/truck drivers as only a small quantity is transported by contractors, and estimated to be US$ 0.06 per fruit depending on the size and the distance to market. In the Terai region of Nepal, as well as in Bangladesh and India, bicycles or bullock carts are used to transport the produce to the road-head, collection or market centres, whereas in the hills it is carried as a back-load in a "Doko" (basket). From the road-head, the local buses are mostly used as the preferred means of transport.

7.2.3 Domestic marketing

A study by Ahmed and Islam (1996) showed there are typically six types of middlemen involved in marketing jackfruits and seeds in domestic markets; (i) retailer, (ii) wholesaler-retailer, (iii) assembler-wholesaler, (iv) assembler-retailer, (v) wholesaler-shipper, (vi) wholesaler and processor. The retailers paid the highest prices for mature and immature fruits also receive the highest selling prices. The movement of jackfruits from producer to consumers passes through wholesalers and retailers. There are also commissioning agents of wholesalers who sometimes also act as wholesalers. They provide short-term finance, find buyers and sellers for wholesalers and retailers and provide storage. A fixed commission is charged, about 15% of the sale proceeds. In general, the stages of movement for jackfruits are as follows:

- producers sell to consumers at primary market
- producers sell to retailers at primary market
- producers sell to the wholesalers at primary and secondary market
- retailers sell to the consumers at primary market
- wholesalers sell to retailers at primary market
- wholesalers sell to retailers through commission agents
- wholesalers of one area sell to other areas or at terminal markets
- retailers sell to consumers at terminal markets.

Local industry in Bangladesh uses jackfruit for pickles at a rate of 500-1100 kg/month. In a market study in Bangladesh, it was shown that the marketing margin of retailers (Tk 571/100 fruits) was higher than that of wholesalers (Tk 164/100 fruits, US$ 1=Tk 55) (Ahmed and Islam, 1996).

In India, in addition to fresh fruit, processed products like chips and papads (sold locally for US$ 0.30-0.60) in a plastic bag of 100-300 g.

In Nepal, fruits are sold for the price of NRs 50-70/fruit (US$ 1=NRs 70) and the farmers earn a net income of NRs 6000-8000/tree (US$ 120-160) for ripe fruits (Chaudhary and Khatari, 1997).

In Bangladesh, the usual suppliers again are the middlemen and they collect orders from exporters, collect crops from farmers/local markets and deliver these to the exporters on the day of shipment. No standard post-harvest handling practices are followed. As a result, post-harvest loss is enormous in particular because the packaging materials are of very poor quality, generally consisting of bamboo baskets or second-hand cartons.

At present, there is no standard phytosanitary certificate, conformity certificate and food safety certificate, but as globalisation proceeds under WTO systems, the EU has already enacted a regulation including traceability norms. Many countries like Bangladesh are not yet ready to accord with this. Such regulating will also affect the production and marketing of jackfruit in other producing countries.

7.2.4 International marketing

Haq and Hughes (2002) estimated that the production of jackfruit will expand mostly due to an expanding market for processed products. It is also estimated that the demand for fresh fruits will expand in countries such as Japan, Malaysia, and the United Kingdom in addition to Singapore and Hong Kong and some Middle Eastern countries. Bangladesh exported 54,340 kg of jackfruit to the United Kingdom at a price of £1.23/kg. In the United Kingdom a fresh fruit is sold at £2.45 per kg and a medium size fruit may cost £16-£20. Canned tender raw jackfruit and seeds can be sold in international markets, mostly for ethnic consumers. One can containing 250 g of bulbs in brine is sold in the United Kingdom retail market for £1.39. In Bangladesh there is no

government support for exporters from the Export Promotion Bureau, but the Malaysian Government has recently signed a contract with Bangladesh to supply jackfruit which will be processed in Malaysia for re-export.

The main exporters of jackfruit in Asia are Thailand, China and Malaysia, and among them, Thai products are considered to be the market standard, followed in quality by Malaysia and China. Malaysia exports to Singapore (almost 85%) and Hong Kong, where grading for uniformity in shape is not required as strictly as in the United Kingdom. In Thailand, the jackfruit has a long season, April to October, and it exports to the USA year round.

Colombia, India, Malaysia, Uganda, Jamaica, Thailand, Sri Lanka, Bangladesh and Kenya export jackfruit to the United Kingdom market. Among these, Colombia, India, Malaysia and Uganda supply throughout the year. Thailand exports throughout the year except for July-September and Sri Lanka exports during all calendar months except December and January. The UK retailer Sainsbury is increasing its range of fruits as customers are prepared to try an increasing variety, and jackfruit has now reached 15 of its stores (www.just-food.com, 2002). The jackfruit is the most expensive fruit on sale in Britain costing about £25.00 per fruit.

The jackfruit has regional and international markets because it is available as a fresh fruit as well as a processed product. Malaysia exported more than 4633 tonnes of fresh fruits to Singapore and Hong Kong in 1995 (Azad, 2000) and earned about US$ 740,000. Jackfruit is popular in Hong Kong and the fruits are supplied from Thailand, Malaysia and particularly from other parts of China (Vinning and Moody, 1997). The Philippines has also exported jackfruit to the value of US$ 324,000 (Acedo, 1992).

The jackfruit is available in the wholesale markets of Australia, supplied from Queensland and the Northern Territory. The fruits are sold in the Sydney market, most frequently ranging from A$ 3-4 /kg. In addition to Sydney, jackfruit is traded in Melbourne and Brisbane. The fruits are consumed by ethnic groups such as Pacific Island communities and Southeast Asian communities resident in Australia.

Whereas the large, heavy and perishable fruits will have limited fresh export capacity from producing countries, there is a clear niche for canned and other processed products as exports and due attention should be focused on them.

7.3 Socio-economics and marketing

Socio-economic information relates to jackfruit being primarily a backyard crop whose fruits are mainly consumed fresh or processed (Espino, 1987; Gatchailan, 1978). Very little socio-economic information is available on the role of women or children or the results of added off-farm income.

As for marketing, little is known of the factors that affect consumers purchasing capability, user preferences, beliefs and consumption-related practices. Such information would help policy makers, researchers and development workers in formulating technological and non-technological interventions in the jackfruit industry. A continuing research effort must be undertaken to exploit the considerable potential of jackfruit and make the industry a viable component of economic development and socio-economic change.

There have been important studies on the role of *Artocarpus* in the rural economy of Nepal where two species, *A. heterophyllus* and *A. lakoocha* are cultivated on-farm in three of the six climatic zones of the country (Pandey, 1981; Jackson, 1987). Kaki and Kaki (1994) provided a socio-economic profile of *Artocarpus* growers (Table 7.3). All the areas are relatively well-developed with diverse rich agriculture and good roads. Selection by farmers of the species is based on (i) ease of propagation, (ii) site suitability, (iii) effect on milk yield of animals, (iv) market value of main and secondary products, (v) preferences for fruit, (vi) rapid tree growth, (vii) use in agroforestry, (viii) need for fodder and fruits in the dry seasons, (ix) ease of harvesting, and (x) multipurpose uses (Rustey and Gold, 1991). Jackfruit is of particular value for fodder as well as fruits.

Table 7.3 Socio-economic profile of *Artocarpus* growers in Nepal

Region	Family size	% Literacy	Size of holding (ha)	No. of Livestock	Per capita food production (kg)
Eastern	7.4	53	2.6	7.6	492
Central	8.7	62	1.5	4.8	234
Western	7.7	50	1.6	6.3	339

Kaki and Kaki (1994) showed, by survey and rapid rural appraisal that data were available for prices and marketing. Farmers sold fruits on a per tree basis or per 100 pieces or per wooden cart to dealers. Dealers then sold fruits by the mound in markets. Some fruits were sold to neighbours; some farmers also went to weekly markets. On the whole, marketing of jackfruit is dominated by contract buyers including agents. This system is entrenched in the sociocultural fabric of rural society where farmers get partial payment in advance and risks are transferred to buyers. Middlemen make the large profits and the price differential from farm gate to market is 1:6.

On being asked about production, farmers cited lack of land, lack of markets and lack of government support and proper prices as serious concerns about production, but there were differences between regions (Table 7.4)

Table 7.4 Farmer cited suggestions for market management
(from Kaki and Kaki 1994)

Item	Percentage of farmers citing the item by region		
	Eastern	Central	Western
Create markets	80	81	88
Form cooperative	33	25	29
Provide transport subsidies	93	85	75
Provide price guarantee	73	71	50
Provide cold storage facilities	67	48	83
Fix fodder prices	27	46	38

Price differentials per fruit were less when compared to local markets or nearby towns than for urban markets. The big difference from farm to market is seen for urban markets. This is similar for jackfruit timber where farmgate:weekly market:nearby town:urban market is 1:1.5:3:6.7.

A study in marketing was carried out in the Philippines and this was related to marketing of immature and mature fruits, dried fruits, seeds and wood (Salabao and Layola, 1994). Traders reported that fruit spoilage and high transportation costs were the major constraints. However at the farm level the lack of reliable price information and reliance on buyers was acute. Better market intelligence is a pre-requisite for farmers to take shorter routes to final consumers and keep consumer prices reasonable. For example, dried fruits were marketed directly to processing firms and a clear chain is therefore recognisable. However lack of grading standards for fresh fruit and poor packaging are conducive to current spoilage/waste.

Chapter 8. Conclusions and future research needs

Rapid increases in population growth coupled with limitations on resources are creating serious problems for the steady supply of food and adequate nutrition in many developing countries. Both the quality and quantity of food have become important international issues in view of widespread malnutrition. Carbohydrates, proteins and fat are in general supplied from cereals, pulses and oilseeds respectively but there are notable vitamin and mineral deficiencies in many regions. In this context, high levels of vitamins and minerals have been recorded in a number of underutilised fruits. Table 8.1 compares jackfruit (and ber or jujube, another underutilised fruit) to more widely grown tropical fruits. This table highlights the jackfruit as being nutritionally rich.

Table 8.1 Comparison of properties of tropical fruits

Fruits	Cal.	Prot. (g)	Ca (mg)	Fe (mg)	Vit. A (IU)	Thiam. (mg)	Vit. C (mg)
Orange	53	0.8	22	0.5	-	0.05	40
Banana	116	1.0	7	0.5	100	0.05	10
Mango	63	0.5	10	0.5	600	0.03	30
Pineapple	57	0.4	20	0.5	100	0.08	30
Papaya	39	0.6	20	0.5	1000	0.03	50
Ber	21	1.75	-	0.5-1	-	-	166
Ripe jackfruit	98	2.0	37	1.1	540	0.09	10
Tender jackfruit	50	2.0	53	0.4	30	0.12	12
Jackfruit seeds	139	7.04	50	1.5	17	0.25	11

Cal.- calorie, Prot.- protein, Ca - calcium, Fe - iron, Vit - vitamin, Thiam.-thiamine. Source: Azad (2000), Pareek (2001).

Recent commercial interest in several tropical underutilised fruits has resulted in an increased cultivated area in Asia and other regions of the

developing world. The export of fruits from Asia alone has been increasing by a little over 10% annually (Singh, 1993).

Jackfruit is grown mainly on homestead farms and produces multiple products for food, feed, and industry as well as contributing towards soil management for sustainable environments. Although the importance of jackfruit for these purposes has been recognised little research has been done. There is a lack of understanding of the taxonomy and origins of jackfruit, of the needs for quality planting materials, and in particular of the non-availability of appropriate technologies for propagation, production, post-harvest handling, processing of products and their marketing.

In recent decades, a number of scientific and economic interests have emerged to promote and commercialise jackfruit commodities. The primary reason for this is that the crop is already well-suited to the household and farming systems of small farmers vulnerable to food shortages and nutritional deficiencies. Diversification within these systems, through enhanced use of jackfruit could lead to increased production of new products which can be sold to raise income as well as satisfying subsistence needs.

The following sections highlight the approaches needed by policy makers, researchers, extension workers, food processors and traders to improve the crop. Suggestions are made in particular for research requirements and for technology transfer to remove the constraints which have been identified in the earlier chapters.

8.1 Taxonomy

Chaper 1 pointed out the lack of knowledge related to the taxonomy of the genus *Artocarpus*, although the work of Jarrett (1959a, 1959b, 1960) has helped to clarify some confusion. More recent molecular research has provided important pointers as to which species might form the primary and secondary genepools of jackfruit. (Kanzaki *et al*., 1997; Schnell *et al*., 2001).

It is thought that jackfruit originated in the Western Ghats region of India, whether it is still found wild or not is debatable. We are thus not sure of the original progenitor of the cultigen and precisely whether truly wild material of this still exists.

8.2 Genetic resources and crop improvement

Scientists are interested in studying genetic diversity of a species for its efficient utilisation and conservation. Underutilised crops have been overlooked for improvement by scientists possibly due to lack of knowledge of the crop. In jackfruit, collecting, characterisation, documentation and evaluation from the region of origin and centres of diversity have been sporadic and are far from complete. There is an urgent need to establish targeted collections from the Indian sub-continent and other jackfruit growing countries of Southeast Asia to use to improve germplasm. In terms of genetic resources, collecting of wild species will not be justified unless the genetic resources and the cultivated material are better understood and are likely to be used in crop improvement. However, pointers can be derived from data recorded on local knowledge and ethnic uses.

To initiate improvement, a basic understanding of the existing clones is required. Some trees produce sweet aromatic fruits; others are nearly dry and sour. Better selection and vegetative propagation of clones is practicable and efforts should also be made to extend the fruiting season. Although little work has been done on rootstock and scion compatibility the evidence so far is that there is a wide variability in scion performance with different rootstocks.

To the present, selection in jackfruit has not been rigorous. Farmers' selection criteria include high yield, fruit quality, sweetness, early fruiting types and off-season types. However there are no true cultivars developed as such, but local types have been identified which have been given names. Little is known about the breeding of jackfruit. This may be due to it being a long-lived tree and a minor fruit. Any attempt to produce improved jackfruit cultivars needs to be targeted both for commercial production and for their value in homegardens and for small growers, thus adding substantially to the latter's income generation and food requirement.

There is a lack of strategic planning by official agencies for improvement of jackfruit for different purposes, localities, environments and cultural practices.

The wealth of genetic diversity of jackfruit is the basis for present and future use. Due to its dispersal over very wide areas of Asia it is important that an assessment is made of the patterns of genetic diversity that exist. Such a study will help planning for national genetic conservation activities, either in natural ecosystems or on-farm sites, or in well-known, well-described and focused *ex situ* collections.

8.3 Crop management

For homestead gardens and small orchards land preparation requires few skills (Coronel, 1983) but for commercial or large scale plantations land preparations require much more attention to attain the desired tilth.

Most cultivated material is of seedling origin which often represents relatively inferior genetic material. There is a need to promote vegetatively propagated material thus improving uniformity and also earlier coming-into-bearing. Extension to improve nursery techniques and provision of better planting materials is urgent.

Agronomic practices for jackfruit are not well established as little research has been carried out in this area. Systematic experimentation is needed to develop optimum agronomic packages for jackfruit in different agroecological areas. The potential of the crop in different cropping systems has not yet been adequately investigated. The crop can be more widely grown once the combination of crops in agroforestry systems has been established.

8.4 Post-harvest and processing

Possibilities and opportunities exist for small food producers to process jackfruit for local income generation and employment. In rural areas of jackfruit producing countries, food processing is a major source of

employment. It is not only important to the national micro-economy but also is one of the fastest growing sectors and is particularly relevant to marginalised and vulnerable women. Added income allows this group of women to spend extra on education, nutrition, and health. As a result it increases their income capacity and raises their status so that women command increased respect from families and communities.

The present status of post-harvest handling and processing of jackfruit is very poor. There is high wastage because seasonal production causes gluts in the market and low prices. A major constraint is the lack of accessible practical information, in particular on post-harvest handling and processing. Individual problems have been identified in Chapter 7. However, the policy environment is also important. Agro-processing sectors involved with major crops receive government support in the form of subsidies, foreign exchange allowances, price stabilisation or guarantees, and access to specialists and consultants. Small-scale processors involved with underutilised fruits do not have such advantages.

8.5 Future research

As a result of the recognition that jackfruit is underutilised but has considerable potential for alleviating malnutrition, income generation and contributing to sustainability, ICUC has organised a series of meetings over the last five years in Asia with researchers, farmers (in particular smallholders) and stakeholders, including industries, to promote and commercialise underutilised tropical fruits including jackfruit. The specific focus has been on the utilisation of this tree for rural improvement. The following suggestions and recommendations emerged from these meetings:

Table 8.2 Suggestions for research requirements and technology transfer

Disciplines	Requirements
Taxonomy	1. Identify close relatives and species relationships and throw light on the taxonomy of the genus, *Artocarpus.*
	2. Location of putative progenitors could lead to better improvement of the crop.
Genetic resources and crop improvement	1. Strategic plans based on the results of research and cooperation between neighbouring countries or regions, for genetic conservation of the jackfruit genepool.
	2. Collect, characterise (including use of DNA markers as a tool), evaluate, and document the genetic diversity. Through farmer's participatory studies identify quality planting materials, in particular to meet the needs of marketing.
	3. Suitable types for specific needs for fruit and timber production could be developed including those for multipurpose use.
Agronomy	1. Develop optimum and standard vegetative methods of propagation for the use of small farmers who can develop small businesses through the establishment of nurseries.
	2. Development of appropriate methods for *in vitro* propagation to multiply promising planting materials.

Discipline	Requirements
	3. Systematic study of wild species to assess grafting compatibility to identify vigorous and genetically stable rootstocks.
	4. Continued cultivar selections to be carried out.
	5. Investigate agronomic requirements (including irrigation) to develop agronomic packages including organic production techniques for better crop management.
Post-harvest and processing	1. Appropriate methods for post-harvest handling, processing and product development for local and regional markets should be considered.
	2. At the local level, technology needs to be transferred to promote products, packaging techniques and better long distance transport.
Marketing	1. To improve income of growers and product producers. Government agencies and institutions should carry out policy research and stimulate the formation of co-operatives, women's self help groups, or other such associations so that they can reach regional and international markets.
	2. Systematic information gathering and its dissemination to all concerned, including those involved in rural development, growers, product producers and small entrepreneurs.

References

Abraham, K.O. (1971) *Fruit flavours: Preliminary studies on jackfruit (*Artocarpus integrifolia L.*) flavour*. M.Sc. Dissertation, Mysore University, India.

Acedo, A.L. (1992) *Jackfruit biology, production, use and Philippine research*. Multipurpose Tree Species Network Series. Winrock International Institute for Agricultural Development, Thailand. 51.

Agro-enterprise Centre, (AEC) (2003) *A report on marketing of underutilised fruits in Nepal*. UTFANET, Southampton University, UK.

Ahmad, K. and Quasem, A. (1969) A trial on the propagation of jackfruit through vegetative means. *Pakistan Journal of Biology for Arid Science* 12(1):12-16.

Ahmed, M.R. and Islam, A. (1996) Marketing pattern of some multipurpose tree species production in Bangladesh. *Bangladesh Journal of Forest Science* 24(2):41-48.

Alexander, D.M.P., Scholefield, P.B. and Frodsham, A. (1983) Jackfruit. In: *Some Tree Fruit from Tropical Australia*. Commonwealth Scientific and Industrial Research Organisation, Australia. 27.

Alia, P., Sanyal, D. and Kar, P.L. (1997) Propagation of jackfruit by mound layering. *Crop Research* (HISAR) 14(3):433-436.

Amin, M.N. and Jiswal, V.S. (1993) *In vitro* response of apical bud explants from mature trees of jackfruit (*Artocarpus heterophyllus*). *Plant Cell Tissue and Organ Culture* 33:59-65.

Anand, L. (1998) Assessing diversity using molecular and other techniques in tropical fruit crops. In: Arora, R.K. and Rao, V.R. (eds.) *Tropical Fruits in Asia: Conservation Maintenance and Use*. IPGRI-South Asia, New Delhi, India: 79-89.

Angeles, D.O. (1983) *Cashew and jackfruit research*. Research Technical Report. Laguna, Philippines. Department of Horticulture, University of Philippines at Los Banos (UPLB).

Anon (1986) Increase in average sale in jackfruit. A special article of jackfruit of Panruti. *The Hindu*, June 6. 20.

Arkroyd, W.R., Gopalan, C. and Balasubramanuyam. S.C. (1966) *The nutritive value of Indian food and the planning of satisfaction diet*. Sept. Rep. Ser. 42 Indian Council of Medical Research, New Delhi.

Arora, R.K. (1985) *Genetic Resources of Less Known Cultivated Food Plants*. National Bureau of Plant Genetic Resources, New Delhi: 45.

Azad, A.K. (1989) *Studies on floral biology, pattern of fruit set and quality of fruit borne in different sections of jackfruit plants*. M.Sc. (Ag.) Thesis. Faculty of Agriculture, BAU, Mymensingh, Bangladesh.1-77.

Azad, A.K. (2000) *Genetic diversity of jackfruit in Bangladesh and development of propagation methods*. Ph.D. Thesis, University of Southampton. UK.

Azad, A.K. and Haq, N. (1999) *Germplasm Catalogue of Jackfruit in Bangladesh*. ICUC, University of Southampton, UK.35.

Azad, A.K., Jones, J.G. and Haq, N. (2006) *Diversity of jackfruit*, submitted for publication.

Bailey, L.H. (1942) *The Standard Encyclopedia of Horticulture*. The Macmillan Co. New York: 401-402.

Bailey L.H. (1949) *Manual of Cultivated Plants*. Macmillan Co. New York: 338.

Baltazar, E.P. (1984) *A Handbook of Philippine Crops*. San Fernando, La Union, Philippines: 76-80.

BARI (1990) Annual Report (1990-91) BARI, Joydebpur, Bangladesh: 306-308.

Barrau, J. (1976) Breadfruit and its relatives. In: Simmonds, N.W. (ed.) *Evolution of Crop Plants*, Longman Inc., New York. 201-202.

Bashar, M.A. and Hossain, A.K.M.A. (1993) *Present status of jackfruit in Bangladesh*. ICUC, University of Southampton, UK. 1-21.

Bhag Mal and Rao, V.R. (2001) Conservation and use of native tropical fruit species biodiversity in Asia. In: Bhag Mal, Ramamani, Y.S. and Rao, V.R. (eds.) *Proceedings of the First Annual Meeting of Tropical Fruit Genetic Resources Project*. Pattaya, Thailand: 7-15.

Bhattacharjee, S. (1981) *Chemistry and technology of some minor fruits*. M.Sc Dissertation, University of Mysore, India.

Bhatia, B.S., Siddappa, G.S. and Lal, G. (1955) Development of products from jackfruit - canned jackfruit, frozen canned jackfruit and jackfruit jam. *Indian Food Packer* 9(11):7.

Bhatia, B.S., Siddappa, G.S. and Lal, G. (1956) Development of products from jackfruit. V. Dried jack seeds, flour, roasted nut and jack papad and toffee. *Indian Food Packer* 10:9.

Bhatia, B.S., Siddappa, G.S. and Lal, G. (1959) Preparation of pectin, pectin extract and syrup from jackfruit rind. *Indian J. Agric. Sci*. 29:75.

Biswas, M. and Kobayashi, K.D. (1989) Propagation of jackfruit stem cuttings. American Society for Hort. Sci. Annual Meeting Programme and Abstracts (No. 137): 75.

Biswas, M. and Hossain, A.K.M.A. (1984) Successful method of vegetative propagation of jackfruit. *Bangladesh Journal of Agricultural Resesearch* 9(2):145-146.

Blasco, E., Lien-BS-Ngoc, Aucouturier, P., Preud-Homme, J.L. and Barra, A. (1996) Mitogenic activity of new lectins from seeds of wild *Artocarpus* species from Vietnam. Comptes-Rendus de l'Academie-des Sciences Serie III, *Sciences de la vie*, 319(5):405-409.

Bowe, C. (2006) *Modelling the Adaptation and Distribution of Underutilised Fruit Tree Species*. Ph.D. Thesis (in preparation). University of Southampton. UK.

BPI (1991) *Jackfruit (Nangka).* BPI Circular. Manila. Bureau of Plant Industry (BPI). Department of Agriculture, Philippines.

Burkill I.H. (1935) *Dictionary of the Economic Products of the Malay Peninsular*, 2 vols. Crown Agents, London.

Butani, D.K. (1978) Pests and diseases of jackfruit in India and their control (a review). *Fruits* 33(5):351-357.

Campbell, C.W. (1984) Tropical fruits and nuts. In: Martin, F.W. (ed.) *CRC Handbook of Tropical Food Crops*. CRC Press Inc., Boca Raton Florida.

Chandel, K.P.S., Rekha, C., Radhamani, J., Malik, S.K. and Chaudhury, R. (1995) Desiccation and freezing sensitivity in recalcitrant seeds of tea, cocoa and jackfruit. *Annals of Botany* 76(5):443-450.

Chandrika, U.G., Jansz, E.R. and Warabsuriya, N.D. (2005) Analysis of carotenoids in ripe jackfruit *Artocarpus heterophyllus* kernel and study of their bioconversion in rats. *Journal of the Science of Food & Agriculture*. John Wiley & Sons, Chichester, UK. 85(2):186-190.

Chatterjee, B.K. and Mukherjee, S.K. (1982) Studies on the efficacy of rates and methods of application of indole butyric acid (IBA) on rooting of cuttings of jackfruit (*Artocarpus heterophyllus*). *Science and Culture* 48(2):74-75.

Chatterjee, B.K. and Mukherjee, S.K. (1980) Stooling potential of clones of jackfruit (*Artocarpus heterophyllus*). *Science and Culture* 46(2):55-56.

Chaudhary, U.L. and Khatari, B.B. (1997) *A status report on jackfruit, pummelo and mangosteen*. UTFANET, Southampton University, UK.

Concepcion, R.F. (1990) Jackfruit: Aromatic money-maker. *Agrobusiness Weekly* 4(3):12-13.

Copeland, L.O. (1976) *Principles of Seed Science and Technology*, 15. Burgués Publishing Co., Minneapolis, Minnesota, USA.

Corner, E.J.H. (1938) Notes on the systematics and distribution of Malayan phanerogams II. The jack and the chempedak. *Gardener. Bull*. 10:56-81.

Coronel, R.E. (1983) *Promising fruits of the Philippines*. UPLB, College of Agriculture. Laguna, Philippines: 251-274.

Costa, W.A.J.M. and de Rozana, M.F. (2000) Effects of shade and water stress on growth and related physiological parameters of the seedlings of five forest tree species. *Journal of the National Science Foundation of Sri Lank.*, Colombo 28(1):43-62.

Crane, J.H., Balerdi, C.F. and Campbell, R.J.V. (2003) *The jackfruit (Artocarpus heterophyllus Lam.) in Florida.* University of Florida Extension Services. www.dis.ifas.ufl.edu/BODY_Mg370.

Darlington, C.D. and Wylie, A.P. (1956) *Chromosome Atlas of Flowering Plants*. George Allen and Unwin Ltd, London. 184.

Das, G.C., Rana, S. and Konhar, T. (1981) Effect of phosphoric acid on induction of flowering and gynoecium in jackfruit (*Artocarpus heterophyllus* Lam.) *Orissa Journal of Horticulture*. 9(1):49-52.

Deb, S., Arunachalam, A. and Arunachalam, K. (2005) Cell-wall degradation and nutrient release pattern in decomposing leaf litter of *Bambusa tulda* Roxb. and *Dendrocalamus hamiltonii* Nees. in a bamboo based agroforestry system in north-east India. *Journal of Bamboo and Rattan* 4:257-277.

Deshai, S.A. and Deshai, A.G. (1989) Effect of age length, defoliation and storage of scionstock on success of softwood grafting in jackfruit. *Artocarpus heterophyllus* Lam. *Proc. Indian. Acad. Sci. Plant Sci*. 99(6): 585-592.

Dhar, M. (1998) *Techniques of vegetative and in vitro propagation of jackfruit*. Ph.D. Thesis, Institute of Postgraduate Studies in Agriculture. Salna. Gazipur, Bangladesh.

Dhua, R.S. and Sen, S.K. (1984) Role of etiolation, auxinic and non-auxinic chemicals on root initiation of air-layers of jackfruit (*Artocarpus heterophyllus* Lam.). *Indian Journal of Horticulture* 41(1):116-119.

Dhua, R.S., Sen, S.K. and Bose, T.K. (1983) Propagation of jackfruit (*Artocarpus heterophyllus* Lam.) by stem cuttings. *Punjab Horticultural Journal* 23(1):84-91.

Dhua, R.S., Ghosh, D. and Mitra, S.K. (1996) *Propagation of jackfruit by cutting* (cited by Azad, 2000).

Dutta, P. and Mitra, S.K. (1992) Regeneration of jackfruit (*Artocarpus heterophyllus* Lam.) air layers by pretreatment of stock plant with cycocel and Ethrel. *Advances in Horticulture & Forestry* 2:77-83.

Espino, R.R.C. (1987) *Study on perennial cropping systems. Research and Progress Report.* Philippines Council for Agriculture, Forestry and Natural Resources Research and Development (PCARRD), Laguna, Philippines.

Falcao, M.D.A. and Clement, C.R. (2001) Phenology and yield of breadfruit (*Artocarpus altilis*) and jackfruit (*Artocarpus heterophyllus*) in Central Amazonia. *Acta Amazonica*. Manaus, Brazil. 31(2):179-191.

Fernando, M.R., Wickeramasinghe, S.D.N., Thabre, M.I., Ariyanada, P.L. and Karuanayakeefal, H. (1991) Effect of *Artocarpus heterophyllus* and A*steracanthus-longifolia* on glucose tolerance in normal human subjects on maturity-onset diabetic patients. *Journal of Ethnopharmacology* 31(3):277-282.

Fu, J.R. and Xia, H.Q. (1993) Effects of desiccation on excised embryonic axes of 3 recalcitrant seeds and studies on cryopreservation. *Seed Science and Technology* 21(1):85-95.

Gan, Y.Y., Zaini, S. and Idris, A. (1981) Genetic variation in the grafted vegetatively propagated mango (*Mangifera indica*) *Pertainida* 4:53-62.

Gatchailan, M.M. (1978) *Backyard fruit resources and their utilization in Luzon region. Research Technical Report*. Philippines Council for Agriculture, Forestry and Natural Resources Research and Development (PCARRD), Laguna, Philippines.

Ghosh, G.H. (1994) *Studies on flowering and prevalence of fruit drop in jackfruit*. Annual Report (1993-94). Horticulture Research Centre, BARI, Gazipur, Bangladesh: 4-9

Ghosh, S.P. (1996) *Technical Report for Use of Underutilised Tropical fruits in Asia Network*. UTFANET, Southampton University, UK.

Ghosh, S.P. (1998) Fruit wealth of India. In: R.K. Arora and V. R. Rao (eds.).*Tropical Fruits in Asia, Diversity, Maintenance and Use*. IPGRI-South Asia, New Delhi, India: 3-15.

Gopinath, R., Kumar, S.P. and Kumaran, K. (1983) Spike characteristics anthesis and pollen viability in jak. *South Indian Horticulture* 31(4/5): 178-180.

Gunasena, H.P.M., Ariyadasa, K.P., Wikramasinghe, A., Herath, H.M.W., Wikramasinghe, P. and Rajakaruna, S.B. (1996) *Manual of Jack Cultivation in Sri Lanka*. Forest Information Service, Forest Department: 48.

Gunjatee, R.T., Kolekar, D.T. and Salvi, M.J. (1982) (cited by Narasimaham P.) Breadfruit and Jackfruit. In: Nagy, S., Shaw, P.E. and Wardswoski, W.F. (eds.). *Fruits of Tropical and Sub-tropical origin. Composition Properties and Uses*. Florida Science Source Inc., Florida 1990.

Habib, A.F. (1965) (cited from Samaddar, 1990) *Mysore Journal of Agricultural Science* 6:200.

Hamrick, J.L., Godt, M.J.W. and Sherman-Broyles, S.L. (1992) Factors influencing levels of genetic diversity in woody plant species. *New Forests* 6:95-124.

Haq, N. (1995) Analysis of questionnaire to select priority species for research and development in Asia. In: Arora, R.K. and Rao, V.R. (eds). *Proceedings of Expert Consultation on Tropical Fruit Species of Asia*, IPGRI, Singapore.

Haq, N. (2002) *Improvement of Underutilised Fruits in Asia*. Annual Report, Community Fund, UK.

Haq. N. (2003a) *Report on Evaluation of Fruit Trees in Homesteads of Bangladesh and their possible marketing opportunities*. DFID-SHABJE project. CARE Bangladesh.

Haq, N. (2003b) *Improvement of Underutilised Fruits in Asia*. Final Report. Community Fund, UK.

Haq, N. and Hughes, A. (2002) *Fruits for the Future in Asia*. ICUC, Southampton University, UK. 236

Hayes, W.B. (1953) *Fruit Growing in India*. Kitabistan, Allahabad, India.

Hocking, D., Sarwar, G. and Yousuf, S.A. (1997) Trees on farms in Bangladesh 4. Crop yield underneath traditionally managed mature trees. *Agroforestry Systems* 35(1):1-13.

Hore, J.K. and Sen, S.K. (2004) Interaction of non-auxinic compounds with IBA in the regeneration of roots in air-layers of jackfruit. *Scientific Horticulture*. 9:47-52.

Hossain, A.K.M.A. (1996) *Status report on genetic resources of jackfruit in Bangladesh*. IPGRI Regional Office, Singapore, 30.

Hossain, A.K.M.A. and Haq, N. (2006) *Jackfruit,* Artocarpus heterophyllus, *Field Manual for Extension Workers and Farmers*, SCUC, Southampton University, UK.

Hossain, M. and Haque, A. (1977) Studies on the physical characteristics of jackfruit. *Bangladesh Horticulture* 5(1):9-14.

IBPGR (1986) *Genetic Resources of Tropical and Sub-tropical Fruits and Nuts (excluding Musa)*. IBPGR, Rome.

ICRAF (2003) Database http://www.worldagroforestry.org/Sites/TreeDBS/aft/speciesPrinterFriendly.asp?Id=239

ICUC (2005) *Training Manual on Processing and Small Business Development*. ICUC, University of Southampton, UK.

IPB (1990) *Breeding selected fruit crops II. Mango, cashew and jackfruit*. Research Annual Report, IBP, UPLB, Laguna, Philippines.

IPGRI (2000) *Descriptors forf jackfruit* (Artocarpus heterophyllus). IPGRI, Rome, Italy.

Islam, M.A. (1996) *Chemotaxonomy of persimmon (*Dispyros kaki L.*) by enzyme polymorphism and inorganic elements.* A thesis submitted to the United Graduate School of Agricultural Sciences, Iwate University, Japan.

Islam, S., Chowdhury, A. and Alam, M.R. (1997) The effects of supplementation of jackfruit leaves (*Artocarpus heterophyllus*) and maskalai (*Vigna mungo*) bran to common grass on the performance of goats. *Asian-Australian Journal of Animal Sciences* 10(2):206-209.

Jackson, J.K. (1987) *Manual of Afforestation in Nepal*. Nepal-UK Forestry Research Project, Kathmandu.

Jain, N.L. and Lal, G. (1954) Preparation of high grade pectins from papaya, jackfruit and woodapple. *Bulletin of the Central Food Technology Research Institute* 4:287.

Jarrett, F.M. (1959a) Studies in *Artocarpus* and allied genera III. A revision of *Artocarpus* subgenus *Artocarpus*. *Journal of Arnold Arboretum*. Harvard University. 40(4):329-338.

Jarrett, F.M. (1959b) Studies in *Artocarpus* and allied genera III. A revision*.of Artocarpus* subgenus *Artocarpus. Journal of Arnold Arboretum.* Harvard University. 40(2):120-155.

Jarrett, F.M. (1960) Studies in *Artocarpus* and allied genera, IV. A revision of *Artocarpus* subgenus *Pseudojaca*. *Journal of Arnold Arboretum. Harvard University*. 41(1):73-140.

Jose, M. and Velsalakumary, P.K. (1991) Standardization of epicotyl and soft wood grafting jack (*Artocarpus heterophyllus* Lam.) *South Indian Horticulture* 39(5):264-267.

Kabir, S. (1998) Jacalin: a jackfruit (*Artocarpus heterophyllus*) seed-derived lectin of versatile applications in immunological research. *J. Immn. Methods* 212(2):193-211.

Kaki, M. and Kaki, J. (1994) Strategies for improving market infrastructure and information for MPTS products case studies of *Artocarpus* species in Nepal. In: J.B. Rowntree and H.A. Francisco

(eds.) *Marketing of Multipurpose Tree Products in Asia.* Winrock International, USA. 159-165.

Kannan, K. and Nair, T.N. (1960) A note on the growth of jack on to rootstock. *South Indian Horticulture* 4(1/2):26-27.

Kanzaki, S., Yonemori, K., Sugiura, A. and Subhadrabandhu, S. (1997) Phylogenetic relationship between jackfruit, the breadfruit and nine other *Artocarpus* spp. from RFLP analysis of an amplified region of cpDNA. *Scientia Horticulturae* 70:57-66.

Kelaskar, A.J., Desai, A.G. and Salvi, M.J. (1991) Effect of rootstock leaf retention shade and tying materials on patch bud grafts of jackfruit. *Indian J. Plant Physiol*. 34(1):58-62.

Khan, K.F. (1946) Clones of jackfruit (*Artocarpus integrifolia*). *Indian Journal of Horticulture* 4(1/2):46-47.

Khan, M.L. (2004) Effect of seed mass on seedling success in *Artocarpus heterophyllus* L. a tropical tree species of Northeast India. *Acta Oecologia*. 25(1/2):103-110.

Khan, M.R., Omoloso, A.D. and Kihara, M. (2003) Antibiotic activities of *Artocarpus heterophyllus*. *Fitoterapia*. 75(5):501-505.

Krishnamurthy, C.R. and Giri, K.V. (1949) Preparation, purification and composition of pectins from Indian fruits and vegetables. *Proceed. Indian Acad. Sci*. 29B:155-167.

Komarayati, S. (1995) Development of prospect of jackfruit plant evaluated from charcoal properties and other aspects. *Journal Penelitian Hasil Hutum (Indonesia)* 13(2):45-51.

Konhar, T., Murmu, S. and Maharan, T. (1990) A study on the budding methods of propagation of jackfruit. *Orissa Journal of Agricultural Research* 3(2):115-119.

Lai, T.V. (2002) Improvement of Underutilised Tropical Fruits in Vietnam, UTFANET Annual Report. 15

Laserna, J.C. (1988) *Fruit abscission and its effect on yield and quality of jackfruit (*Artocarpus heterophyllus Lam*.)* B.Sc. Thesis. UPLB Laguna, Philippines.

Lavania, M.L., Jain, S.K. and Lavania S.K. (1995) Effect of indole butyric acid on air-layering in jackfruit. *Annals of Agricultural Research* 16(3):387-388.

Ly, J., Samkol, P. and Preston, R.R. (2001) Nutritional evaluation of tropical leaves for pigs: pepsin/pancretin digestability of thirteen plant species. *Livestock Research for Rural Development*. 13(5):1-6.

Maiti, C.S. and Sen, S.K. (1999) Effect of pretreatments of scion on grafting success in jackfruit (*Artocarpus heterophyllus* Lam.) *Horticultural Journal* 12(2):97-99.

Maiti, C.S.; Wangchu, L. and Sen, S.K. (2003) Effect of pre-sowing seed treatments with different chemicals on seed germination and seedling growth of jackfruit (*Artocarpus heterophyllus* Lam.). *Environment and Ecology* 21(2):290-292.

Manalo, M.L.A. (1986) *The relationship of growth and flowering habits of jackfruit (*Artocarpus heterophyllus Lam*.).* B.Sc. Thesis, UPLB, Laguna, Philippines.

Mandal, B.B. (1997) Application of *in vitro* cryopreservation techniques in conservation of horticultural crop germplasm. *Acta Horticulturae.* 447:483-490.

Manjunath, B.L. (1948) *Wealth of India*. Vol.1 CSIR Publications. New Delhi, 1-240.

Mannan, M.A. (2000) *Plant Biodiversity in the Homesteads of Bangladesh and its Utilization in Crop Improvement.* Ph.D. Thesis, Institute of Postgraduate Studies in Agriculture. Salna, Gazipur, Bangladesh.

Mathur, P.B., Singh, K.K. and Kapur, N.S. (1952) Cold storage of jackfruit. *J. Indian. Soc. Refrig. Engineers* 3(1):40-46.

Martin, F.W., Campbell, C.W. and Ruberte, R.M. (1987) *Perennial Edible Fruits of the Tropics, an Inventory*. USDA-ARS. Washington DC. Agric. 642.

Mitra, S.K. and Maity, C.S. (2002) A summary of the genetic resources of jackfruit (*Artocarpus heterophyllus* Lam.) in West Bengal, India. *Acta Horticulturae.* 575.

Mitra, S.K. and Mani, C.S. (2000) *Genetic resources of jackfruit (Artocarpus heterophyllus* Lam*.) in West Bengal, India*. Symposia Booklet, International Symposium on Tropical and Sub-tropical Fruits, Cairns, Australia. 45.

Moncur, M.W. (1985) *Floral ontogeny of the jackfruit, Artocarpus heterophyllus* Lam*. (Moraceae).* Division of Water and Land Resources, CSIRO, Canberra, Australia.

Morton, J.F. (1965) The jackfruit (*Artocarpus heterophyllus*). Its culture varieties and utilization. *Proceedings of the Florida. State Horticultural Science Society* 78:336-344.

Morton, J.F. (1987) *Fruits of Warm Climates*. Creative Resources System, Inc., Winterville, North Carolina, USA: 58-64.

Mowry, H., Toy, L.R. and Wolfe, H.S. (1941) *Miscellaneous tropical and sub-tropical Florida fruits*. Bulletin Of the Florida Agricultural Extension Service 109. 96.

Mukherjee, S.K. and Chatterjee, B.K. (1978) Effect of invigoration, etiolation and IBA on the rootage of jackfruit. *Science and Culture* 44(9) 414-415.

Mukherjee, S.K. and Chatterjee, B.K. (1979) Effect of forcing and indole butyric acid on rooting of cuttings of *Artocarpus heterophyllus* Lam. *Scientia Horticulturae* 10:295-300.

Murthy, B.N.S., Murch, S.J. and Saxena, P.K. (1998) Thidiazuron: A potent regulator of *in vitro* plant morphogenesis. In vitro *Cellular and Development Biology-Plant* 34(4):273-275.

Naik, K.C. (1952) *Jackfruit*. ICAR Bull. 33. New Delhi.

Naik, K.C. (1963) *South Indian Fruits and theirCculture*. P. Veradachary & Co. Madras, India. 434-537.

Narasimham, P. (1990) Breadfruit and jackfruit. In: Nagy, S., Shaw, P.E. and Wordowski, W.F. (eds.). *Fruits of Tropical and Sub-tropical origin - Composition, Properties and Uses*. Florida Science Source, Inc: 193-259.

Nataranjan, P.N. and Karunanithy, R. (1974) Synthetic flavour enhancers for *Artocarpus integrifolia*. *The Flavour Industry* 5(11):282-283.

Ochse, J.J., Soule (Jr.), M.J., Dijkman, M.J. and Welburg, C. (1961) *Tropical and Sub-tropical Agriculture*. Macmillan Co: 652-655.

Oliveros, B.L., Cardeno, V. and Perez, P. (1971) Physical properties of some Philippine essential oils. *The Flavour Industry* 2(5):305-309.

Palang, D.B. and Cajes, B.C. (2000) *Maturity indices of two types of jackfruit.* Agency inhouse Research & Review Report. EVIARC Balinsasayao, Abuyog, Leyte. Philippines.

Pandey, K.K. (1981) *Silvicultural characteristics of* Artocarpus lakoocha *in different altitudes of Dolakha district*. SATA, Kathmandu.

Pareek, O.P. (2001) *Ber.* International Centre for Underutilised Crops, Southampton University, UK.

Pelzar, K.J. (1948) *Pioneer Settlement in the Asiatic Tropics*. American Geographical Society, New York.

Popenoe, W. (1974) *Manual of Tropical and Sub-tropical Fruits*. Halfner Press Co., New York: 414-419.

Purseglove, J.W. (1968) *Tropical crops. Dicotyledons 2*. John Wiley and Sons, Inc., New York: 384-387.

Pushpakumara, D.K.N.G., Simons, A.J. and Gunasena, H.P.M. (1996) Reproductive biology and improvement of *Artocarpus heterophyllus* in Sri Lanka. *Domestication of Agroforestry Trees in Southeast Asia*, Yogyakarta, Indonesia: 203-208.

Quasem, A. (1982) *Propagation of jackfruit*. Annual Report. Regional Agricultural Research Station, Hathazari, Chittagong, Bangladesh.

Quasem, A. and Shakur, M.A. (1984) *Propagation of jackfruit*. Annual Report. Regional Agricultural Research Station, Hathazari, Chittagong, Bangladesh.

Querijero, N.L.B. (1988) *The flowering of jackfruit (Artocarpus heterophyllus* Lam*.)*. BSc Thesis. UPLB, Laguna, Philippines.

Rahman, A.K.M.M., Huq, E., Mian, A.J. and Chesson, A. (1995) Microscopic and chemical changes occurring during the ripening of two forms of jackfruit (*Artocarpus heterophyllus* L.). *Food Chemistry* 52(4):405-410.

Rahman, M.A. and Blake, J. (1988a) Factors affecting *in vitro* proliferation and rooting of shoots of jackfruit (*Artocarpus heterophyllus* Lam.) *Plant Cell, Tissue and Organ Culture* 13:79-187.

Rahman, M.A. and Blake, J. (1988b) Propagation of jackfruit (*Artocarpus heterophyllus*) by stem cutting effect of ringing. Etiolation and indole butyric acid treatment. *Bang. Hort.* 16(2): 25-29.

Rajmohan, K. and Mohanakumaran, N. (1988) Influence of explant source on the *in vitro* propagation of jack (*Artocarpus heterophyllus* Lam). *Agricultural Research Journal of Kerala* 26(2):169-174.

Raman, K.R. (1957) A note on the propagation of jack on individual jack tree selections as root stocks in grafting. *South Indian Horticulture* 5:31-32.

Rao, N.K.S., Narayanaswami, S., Chako, E.K. and Doreswame, R. (1981) Tissue culture of the jack tree. *Current Sciences* 50(7):310-313.

Rasmussen, P. (1983) Identification of volatile components of jackfruit by gas chromatography/mass spectrometry with two different columns. *Analytical Chemistry* 55:1331-1339.

Rawal, R.D. and Saxena, A.K. (1997) Design of dryland horticulture and their management. *Silver Jubilee National Symposium Arid Horticulture*, HSH/CCS HAU, Hisar, 5-7 December.

Reddy, B.M.C. (1998) Propagation Techniques for Tropical Fruits. In: Arora, R.K. and Rao, V.R. (eds.). *Tropical Fruits in Asia, Diversity, Maintenance and Use*. IPGRI- South Asia, New Delhi, India: 103-112.

Reddy, B.M.C., Prakash, P., Shashikumar, S., Sampathkumar, P. and Govindaraju, R. L. (2001) Exploration, collection of potential germplasm, elite clones and establishment of field genebank of *Artocarpus heterophyllus* Lam. *Proceedings of the National Symposium Biodiversity viz à viz Resource Exploration: An introspection*: 50.

Reddy, P.P. (1998) Nematodes and their control in Tropical Fruit Crops. In: Arora, R.K. and Rao, V.R. (eds.) *Tropical Fruits in Asia, Diversity, Maintenance and Use.* IPGRI- South Asia, New Delhi, India. 246-250.

Rehm, S. and Espig, G. (1991) *The Cultivated Plants of the Tropics and Subtropics*. Verlag Josef Margraf, Weikersheim, Germany.

Rowe-Dutton, P. (1985) *Artocarpus heterophyllus* – Jackfruit. In: Garner, J.R. and Chaudhury, S.A. (eds.). *The Propagation of Tropical Fruit Trees*. FAO/CAB, London: 269-290.

Roy, S.K. (2000) Promotion of underutilised tropical fruit processing and its impact on world trade. *Acta Horticulturae* 518:233-236.

Roy, S.K. and Hadiuzzaman, S. (1991) Micropropagation of two species of *Artocarpus* through *in vitro* culture. *Bangladesh Journal of Botany* 20(1):27-32.

Roy, S.K., Hossain, T. and Bilkis, S. (1991) Micropropagation of *Artocarpus heterophyllus* through *in vitro* shoot proliferation on nodal explants of mature trees. *Acta Horticulturae* 289:145-146.

Roy, S.K., Islam, M.S., Sen, J. and Hadiuzzaman, S. (1992) Effects of auxin sucrose and agar concentration on the *in vitro* rooting of callus induced microshoots of jackfruit *Artocarpus heterophyllus* Lam. *Bangladesh Journal of Botany* 21(1):93-98.

Roy, S.K., Islam, M.S., Sen, J. and Hossain, A.B.M.E. (1993) Propagation of flood tolerant jackfruit (*Artocarpus heterophyllus*) by *in vitro* culture. *Acta Horticulturae* 336:273-278.

Roy, S.K., Rahman, S.L. and Majumder, R. (1990) *In vitro* propagation of jackfruit (*Artocarpus heterophyllus* Lam.). *Journal of Horticultural Science* 65(3):355-358.

Ruehle, G.D. (1967) *Miscellaneous Tropical and Sub-tropical Florida Fruits.* Agric. Extension Survey, IFAS, University of Florida, Bull., 156a.

Rustey, E.P. and Gold, M.A. (1991) Understanding an indigenous knowledge system for tree fodder via a multi-method on-farm research approach. *Agroforestry Systems* 15:139-165.

Saha, M.C., Saha, M.G., Rahman, M.A., Nazrul, M.I., Quasem, A., Halder, N.K. and Haque, A.F.M.E. (1996) *Viability in jackfruit*. A paper presented at the Internal Research Review Workshop. Horticulture Research Centre, BARI, Gazipur, Bangladesh.

Sahadevan, P.C., Abdul, S.A. and Menon, K.C.P. (1950) Floral abnormalities in Jack. *Madras Agricultural Journal* 37:497-498.

Salabao, A.A. and Layola, J.B. (1994) Marketing of jackfruit in Central Visayas, the Philippines. In: Raintree, J.B. and Francisco, H.A. (eds.) *Marketing of Multipurpose Tree Products in Asia*. Thailand., Winrock International, USA: 153-158.

Samaddar, H.N. (1990) Jackfruit. In: Bose, T.K. and Mitra, B. (eds.). *Fruits of India, Tropical and Sub-tropical*. Naya Prakash, Calcutta, India: 638-649.

Samaddar, H.N. (1985) Jackfruit. In: Bose, T.K. and Mitra, B. (eds.). *Fruits of India. Tropical and Sub-tropical*. Naya Prakash, Calcutta, India: 494.

Samaddar, H.N. and Yadav, P.S. (1970) A note on the vegetative propagation of cashewnut, avocado, jackfruit and custard apples. *South Indian Horticulture* 18(1):47-49.

Samaddar, H.N. and Yadav, P.S. (1982) Cited from *Hortic. J.* 1:54-60.

Sambamurthy, K. and Ramalingam, V. (1954) Preliminary studies in blossom biology of the jak (*Artocarpus heterophyllus* Lam.) and pollination effects. *Indian Journal of Horticulture* 11:24-29.

Sastrapradja, S. (1975) Tropical fruit germplasm in South East Asia In: Williams, J.T., Lamoureux, C.H. and Soetjipto, N.W. (eds.) *Proceedings of Symposium on South east Asian Plant Genetic Resources*. LIPI: 33-46.

Sato, M., Fujiwara, S., Tsuchiya, S., Fujii, H.M., Linuma, T., Tosa, H. and Ohkawa,Y. (1996) Flavonoids with antibacterial activity against carcinogenic bacteria. *Journal of Ethnopharmacology* 54(2/3):171-176.

Schnell, R.J., Olano, C.T., Campbell, R.J. and Brown, J.S. (2001) AFLP analysis of genetic diversiy within a jackfruit germplasm collection. *Scientia Horticulturae* 91(3-4):261-274.

Selvaraj, Y. (1993) In: Chada, K.L. and Pareek, O.P. (eds.) Advances in Horticulture, vol.4. *Fruit Crops*, Part. 4, Malhotra Publ. House, New Delhi, India. (Cited from Ghosh, 1996. Technical Report for Use of Underutilised Tropical fruits in Asia Network. UTFANET, Southampton University, UK.)

Selvaraj, Y. and Pal, D.K. (1989) Biochemical changes during the ripening of jackfruit (*Artocarpus heterophyllus* Lam.) *Journal of Food Science and Technology* 26:304-307.

Sen, P.K. and Bose, T. (1959) Effects of growth substances on rooting of jackfruit (*Artocarpus integrifolia* Linn.) layering. *Indian Agriculturists* 3:43-47.

Shanmugavelu, K.G. (1971) Effect of plant growth regulators on jack (*Artocarpus heterophyllus* Lam.) *Madras Agricultural Journal* 58:97-103.

Siddappa, G.S. (1957) Effect of processing trypsin inhibator in jackfruit seed. *J. Sci. Ind. Res*. 16c:199-201.

Singh, A. (1986) *Fruit Physiology and Production*. Kalyani Publishers, New Delhi, India.1-210.

Singh, A.K. and Singh, G.N. (2004) Effect of IBA and NAA on rooting of airlayers of jackfruit (*Artocarpus heterophyllus* Lam.) *Scientific Horticulture.* Scientific Publishers, India: 9:41-46.

Singh, D.K. and Bhatacharya, B. (2003) Trials on the role of pre-sowing seed treatment with different chemicals on the seed viability of jackfruit (*Artocarpus heterophyllus* Lam.). *Orissa Journal of Horticulture* 31(1): 88-90.

Singh, I.P. and Sharma, C.K. (1995) Effect of position of airlayering on rooting jackfruit (*Artocarpus heterophyllus*). *Progressive Horticulture* 27(1/2):22-23.

Singh, K.K. and Mathur, P.B. (1954) A note on investigations on the cold storage and freezing of jackfruit. *Indian Journal of Horticulture* 11:149.

Singh, L.B. (1951) Propagation of jackfruit, *Artocarpus integrifolia*, by air layering with hormones. *Current Sciences* 20:102-103.

Singh, K. (1972) Farm Information Bull. 71, Directorate of Extension, Government of India, New Delhi, cited by Ghosh (1996)

Singh, M., Sharma, B.K. and Yadava H.S. (1995) Response of plant growth regulators and layering dates on air-layering of jackfruit (*Artocarpus heterophyllus* Lam.) *Advances in Plant Science* 8(1):130-133.

Singh, R. (1969) *Fruits*. National Book Trust, New Delhi, India. 115.

Singh, R. (1985) *Fruits.* National Book Trust, New Delhi, India.

Singh, R.B. (1993) *Research and development of fruits in the Asia-Pacific,* RAPA Publ. 93/9. FA)-RAPA, Bangkok, Thailand.

Singh, S.P. (1992) Budding in some fruit crops: a review. *Advances in Horticulture and Forestry* 2:84-97.

Singh, U.R., Pandey, T.C., Upadhaya, N.P. and Prasad, R.S. (1982) Propagation of jackfruit by budding. *Punjab Horticultual Journal* 22:103-105.

Sinha, M.M. (1973) Pollen viability and pollen storage studies in jackfruit (*Artocarpus heterophyllus* Lam.) *Progressive Horticulture* 3:69-73.

Sinha, M.M. and Sinha, S.M. (1968) cited by Samaddar (1990) 638-649. *Science and Culture* 34:372-373.

Soepadmo, E. (1992) *Artocarpus heterophyllus* Lamk. In: Verheij, E.W.M. and Coronel, R.E. (eds.) *Plant Resources of Southeast Asia No.2: Edible Fruits and Nuts.* PROSEA,Wageningen, Netherlands: 86-91.

Sonwalker, M.S. (1951) A study of jackfruit seeds. *Indian Journal of Horticulture* 8:27-30.

Soyza, A.M.T. (1973) Natural durability of twelve timbers found in Sri Lanka. *Sri Lanka Forester* 11(1/2):24-31.

Srinivashan, K. (1970) "Matton verkka" a promising jackfruit variety. *Agricultural Research Journal of Kerala* 8(1):51-52

Srivastava, H.C. (1953) J. Sci. Industr. Res. 12B:363-365. (Cited from Ghosh, 1996. *Technical Report for Use of Underutilised Tropical Fruits in Asia Network*. UTFANET, Southampton University, UK)

Srivastava, R.P. (1961) Preliminary studies in the sex determination, growth behaviour and the influence of α-napthalene acetic acid sprays on the size, seed number and weight of jackfruit (*Artocarpus heterophyllus* Lam.) *Journal of Science Research Banaras Hindu University* 11:213-221.

Sudiyani, Y. S., Horisawa, S., Chen KeLi Doi, and Imammural, Y. (2002) Changes in surface properties of tropical wood species exposed to the Indonesian climate in relation to mould colonies. *Journal of Wood Science*. Springer-Verlag, Tokyo, 486:542-547.

Susiloadi, A., Sunyoto, A. and Lukitariatis, S. (2002a) *Exploration and characterisation of jackfruit.* UTFANET Annual Progress Report, Southampton University, UK.

Susiloadi, A., Sunyoto, A. and Lukitariatis, S. (2002b) In vitro *propagation of jackfruit.* Research Institute for Fruits -UTFANET Annual Progress Report. Southampton University, UK.

Swaminathan, M.H. and Ravindran, D.S. (1989) Vegetative propagation of fruit yielding trees. *My Forest* 25(4):357-360.

Swords, G., Bobbio, P.A. and Hunter, G.L.K. (1978) Volatile constitution of jackfruit *Artocarpus heterophyllus. Journal of Food Science* 43(2):639-640.

Tandon, H.L.S. (1987) *Fertilizer Recommendations for Horticultural Crops in India - A Guidebook*. Fertilizer Development and Consultation Organisation, New Delhi, India.112.

Tandon, P.L. (1998) Management of Insect Pests in Tropical Fruit Crops. In: Arora, R.K. and Rao, V.R. (eds.) *Tropical Fruits in Asia, Diversity, Maintenance and Use.* IPGRI- South Asia, New Delhi, India:. 235-245.

Teaotia, S.S.K. and Awasthi, R.K. (1968) Dehydration studies in jackfruit (*Artocarpus heterophyllus* Lam.). *Indian Food Packer* 22(5):6-14.

Teaotia, S., Dayal, K. and Asthana, M.P. (1963) Propagation of jackfruit by budding. *Science and Culture* 29:46-47.

Thamsiri, K. (1999) Cryopreservation of embryonic axes of jackfruit. *Cryo. Let*. 20(1):21-28.

Thanh Van, Do Thi, Nguyen Thi Mui and Ledin, I. (2005) *Animal Feed Science & Technology.* 118(1/2):1-17.

Thomas, C.A. (1980) Jackfruit, *Artocarpus heterophyllus* Lam. (Moraceae) as source of food and income. *Economic Botany* 34:154-159.

Uniyal, S.G.B.M. (2003) Indian woods - their medicinal importance and identification. *Indian Forester*. 129(10):1225-1240.

Van Hintum, T.J.L. (1995) Hierarchical approaches to the analysis of genetic diversity in crop plants. In: Hodgkin, T., Brown, A.H.D., van

Hintum,Th.L. and Morales, E.A.V. (eds.) *Core Collection of Plant Genetic Resources.* John Wiley and Sons, UK. 23-34.

Vijayakumar, K., Shivashanker, G. and Gowda, V.N. (1991) Propagation of jack *Artocarpus heterophyllus* Lam. by green wood cleft grafting. *Crop Research*. 4(1):169-170.

Vilasachandran, T., Kumaran, K. and Gopikumar, K. (1982) Evaluation of jackfruit (type varikka) for pectin. *Agricultural Research Journal of Kerala.* 20(10):76-78.

Vinning, G. and Moody, T. (1997) *A Market Compendium of Tropical Fruit.* RIRDC Research Report No. 97/74, Rural Industries Research and Development Corporation, Barton, Australia. 110-120.

Weeden, N.F. and Lamb, R.C. (1987) Isozyme analysis of tree fruits. In: Soltis, D.E. & Soltis, P.S. (eds.) *Isozymes in Plant Biology*. Chapman & Hall, London. 195.

Wester, P.J. (1921) The food plants of the Philippines. Philipp. *Agric. Rev.* 14:211-384.

Wickramasinghe, A. (1992) *Agroforestry Systems and Trees Practices: A case study in Sri Lanka*. MTPS Network Research Series 17, Winrock International, USA.

Wickramasinghe, A. (1994) The pattern of timber supply and consumption in Sri Lanka. In: Rowntree, J.B. and Francisco, H.A. (eds.) *Marketing of Multipurpose Tree Products in Asia*. MPTS Network for Asia, Thailand. Winrock International, USA: 125-142.

Yap, A.R. (1972) *Cultural Directions for Philippine agricultural crops. Fruits.* BPI, Department of Agriculture, 1:137-141.

Zielenski, Q.B. (1955) *Modern SystematicPpomology*, WMC Bio.Co., Iowa, USA. 50.

Appendix 1. Specialists and institutions engaged in jackfruit research and development

Dr A.K. Azad
Principal Scientist
Bangladesh Agricultural Research Council
Framgate, Dhaka
Bangladesh

Dr Amzad Hossain
Former Director Horticulture Research Centre
Bangladesh Agricultural Research Institute (BARI)
Joydebpur
Gazipur 1701
Bangladesh

Dr S. Islam
Director General
Bangladesh Agricultural Research Institute (BARI)
Joydebpur
Gazipur -1701,
Bangladesh
00-8802-9252529
00-8802-9252713
Email: baridg@bttb.net.bd

Mr Alamgir Kabir
HRC, BARI
Joydebpur
Gazipur 1701
Bangladesh

Dr M.A. Mannan
Department of Extension
Khamarbari
Framgate, Dhaka
Bangladesh

Director
Horticultural Research Centre
Joydebpur, Gazipur-1701,
Bangladesh
00-8802-9252529
00-8802-9252713
Emails: hrcbari@citechco.net
baridg@bttb.net.bd

Ms S.S. Annapurna
Department of Biochemistry
Andhra University
Visakhapatnam
530 003
India
Tel: 91 891 284 4535

Mr A. Baruah
Department of Animal Physiology
College of Veterinary Science
Assam Agricultural University
Khanapara, Guwahati, 781 022
Assam
India
Tel: 03 763 40001
Email: rc@aau.ren.nic.in

Mr A. V. Bhat
Department of Biochemistry
Kasturba Medical College
Manipal 576 119
India

Mr Bijendra Singh
Division of Horticulture
ICAR Research Complex for NEH
Region
Shillong
India

Dr B. K. Chatterjee
Calcutta University
College of Agriculture
India

Dr V. Chikkasubbanna
Department of Horticulture
UAS
GKVK
Bangalore-65
India
Tel: 91 080 3330277

Mr R. T. Gunjate
Kinkan Krishi Vidyapeeth
Department of Horticulture
Dapoli
India
Tel: 02 358 82074
Email: root@kkv.ren.nic.in

Mr P. N. Gupta
Division of Horticulture
ICAR Research Complex for NEH Region
Shillong
India

Mr T. R. Guruprasad
Department of Horticulture
University of Agricultural Sciences
GKVK
Bangalore 560 003
India

Mr V. Jamaludheen
College of Forestry
Kerala Agricultural University
Vellanikkara
Thrissur, 680 654, Kerala
India
Tel: 04 873 370019
Email: kauhqr@ren.nic.in

Dr G. Kalloo (DDG, Hort)
Indian Council for Agricultural Research (ICAR)
Dr. Rajendrs Prasad Road
New Delhi-110001
India
00-9111-3382534
00-9111-3382534/3387293

Mr D. T. Kolekar
Kinkan Krishi Vidyapeeth
Department of Horticulture
Dapoli
India
Tel: 02 358 82074
Email: root@kkv.ren.nic.in

Mr B. M. Kumar
College of Forestry
Kerala Agricultural University
Vellanikkara
Thrissur, 680 654, Kerala
India
Tel: 04 873 370019
Email: kauhqr@ren.nic.in

Dr K. R. Melanta
Division of Horticulture
University of Agricultural Sciences
Gandhi Krishi Vignana Kendra
Bangalore-560 065
India
Tel: 91-080-3330153
Fax: 91 080 3330277

Prof. S.K. Mitra
B-10/284
Kalyani
Nadia - 741/235
West Bengal
India
Email: sisir@vsnl.net

Dr S. K. Mukherjee
Calcutta University
College of Agriculture
India

Dr P. Patil
Indian Institute for Horticulture Research (IIHR), Bangalore
Hessaraghatt
Lake Post 560 089
Bangalore
India

Dr B.M.C. Reddy
Director
Central Institute of Sub-tropical Horticulture
O.O. Kakori
Luchnow 227107, UP
India
+91-80-8466080
+91-80-8466420
+91-80-8466291

Dr. M. Winarno
Deputy Chairman
Directorate of Horticulture Production
JL Ragunan 19, Pasarminggu
Jakarta, Selatan
Indonesia
00-6121-7806570
00-6121-7806760
Emails: hortina@indo.net.id
M_Winarno@plasa.com

Mr Agus Susiloadi
Research Institute for Fruits,
Agency of Agricultural Research and Development
Department of Agriculture
Tln.Raya. Solok-Aripau
PO Box 5,
Solok 27301
Indonesia
Tel: 61-755-22444; 20137
Fax: 61-755-20592
Email: agususiloadi@plasa.com

Dr K. Budathoki
Chief, Horticulture Research Division
Nepal Agricultural Research Council (NARC)
PO Box 5459, Kathmandu
Nepal
00-9771-525708/525703/523716/523041
00-9721-521197
Email: hrdn@wlink.com.np

Mr Lajpat R. Akhani
Horticulture Research Institute
Mirpurkhas
Pakistan
Tel: 92-231-61843
Fax: 92-2231-5504

Mr. M. Hashim Laghari
Director
Pakistan Agricultural Research Centre (PARC)
Park Road
PO NIH
Islamabad
Pakistan
00-9251-9255027
00-9251-9255034
Email: laghari_pk@yahoo.com

Dr Hafeez U. Rehman
SSO, Fruits
PARC
Park Road
Islamabad
Pakistan
Tel: 92-51-9255027
Fax: 92-51-9255034

Mr Munir Sheikh
Sind Agriculture University
Tandojam
Pakistan
Tel: 92-2231-5505
Fax: 92-2231-5504

Dr. Jocelyn Eusebio
Director
Crops Research Division
Paseo de Valmayor
Los Banos
Laguna 4030
Philippines
Tel: 63-049-5360014/5360015/5360017/5360020/536-0024
Fax: 63-049-536-0016/536-0132
Email: jocelyneusebio@yahoo.com

Dr. Patricio S. Faylon
Executive Director
Philippine Council for Agriculture, Forestry and Natural Resources Research and Development (PCARRD)
Paseo de Valmayor, Los Banos, Laguna 4030
Philippines
63-049-5360014/5360015/5360017/5360020/536-0024
63-049-536-0016/536-0132
Emails: psfaylon@pcarrd.dost.gov.ph
psfaylon@pacific.net.ph

Mr Mario Martinez
DA-RIAC
Balisasayao
Abuyog
Leyte
Philippines
Tel: 63-53-325-7242
Email: daeviarc@tac.webling.com

Dr Kudagamage
Deputy Director Agriculture
Horticultural Research Development Institute (HORDI)
Makadura, Gonawila NWP
Sri Lanka
00-9431-99625
00-9431-99707
Email: hordi11@sltnet.lk

Dr. Songpol Somsri
Horticulture Research Institute
Department of Agriculture (HRI)
10900 Chatuchak
Bangkok
Thailand
00-662-9405484
00-662-5614667
songpol@doa.go.th

Dr Suphap Suntranon
Chanthaburi Horticultural Research Centre
Plew
Lamsing
Thailand

Dr Long Cao
Hanoi Agricultural University No. 1
Trauquy-Gialam-Hanoi
Vietman
Tel: 00 844 8675572
Fax: 00 844 8276149

Prof. Dr Vu Manh Hai
Director
Research Institute of Fruits and Vegetables (RIFAV)
Trauquy, Gialam
Hanoi
Vietnam
00-844-8765572
00-844-8276148
Email: vrqhnvn@hn.vnn.vn

Mr Danh Nguyen
Phuho Fruit Research Center
Phong Chau
Phu Tho
Vietnam
Tel: 84 2108 65278

Mr Hung Nguyen
RIFAV
Trauquy, Gialam
Hanoi
Vietnam
Tel: 84 482 76148
Email: vrqhnvn@hn.vnn.vn

Deputy Director
Tran
Hong Quan
Hue Beer Factory
Vietnam

Dr Ca Do
RIFAV
Trauquy, Gialam
Hanoi
Vietnam
Tel: 00844 8765573
Fax: 00 844 8276149
Email: vrqhnvn@hn.vnn.vn

Appendix 2. Institutions with collections of jackfruit germplasm

South Asia

Bangladesh
Horticulture Research Centre
BARI
Joydebpur

Horticulture Department,
Agricultural University
Mymensingh

Ramgar Research Centre
BARI
Chittagong Hill Tracts

India
IIHR
Bangalore

IIHR
Trichur

BCKV
West Bengal

Nepal
Horticulture Research Division
Kathmandu

Pakistan
NARC Research Centre
Karachi

Sri Lanka
HORDI
Gannurua

South East Asia

Indonesia
National Biological Institute
Bogor

Horticultural Research Institute
Solok

Malaysia
MARDI
Kuala Lumpur

Papua New Guinea
Lowlands Agriculture Experimental Station
Kevart

Philippines
Institute of Plant Breeding
Los Banos

Department of Agriculture Regional Field
Station
Babatngon
Leyte

Thailand
Plew Horticultural Experimental Station
Chantaburi Province

Vietnam
Research Institute of Fruits and Vegetables
Hanoi

Taiwan
Chiayi Agricultural Experiment Station
Chi-Yi

Africa

Ghana
Crop Research Institute
Bunso

Seychelles
Mahè

Tanzania
Tropical Pesticide Research Institute
Arusha

Americas

Brazil
Dept. de Horticultura
Instituto Nacional De Pesquisas Da Amazonia

Costa Rica
CATIE
Turrialba

Guadeloupe
Institute de Recherche sur les Fruits et Legumes

United States of America
Sub-Tropical Horticultural Research Unit
Miami
Florida

National Clonal Germplasm Repository
Hilo
Hawaii

Tropical Agricultural Research Station
Puerto Rico

Europe
Canari, Spain
Canarias Centre for Research and Agrarian Technology
La Laguna

Sources: IPBGR (1986), IPGRI database at
http://www.ipgri.cgiar.org/system/page.asp?theme=4,
UTFANET (2003), Campos (pers.comm.)

Appendix 3. Seed suppliers

The Borneo Collection
TreeFarm
El Arish
North Queensland 4855
Australia
Tel (61/7) 4068 5263
E-mail: dkchandlee@yahoo.com

KMPH Mitra Sesaot
Dusun Jurang Malang
Desa Lebah Sempage
Mataram Lombok 83231
Indonesia

Gautam Global
34 Old Cannought Place
Dehra Dun-248001
India
Tel (91/135) 656222
Fax (91/135) 651108, 650944, 652766
E-mail: npsonudd@nde.vsnl.net.in
Website www.garhwalhimalayas.com/gautamglobal

Neelkantheshwar Agro-Seeds and Plantations
Commercial complex, C Block - C-29/X3
Dilshad Garden,
Delhi-110 095
India
Tel 2274277, 2119790, 2119744
Fax (0091-11) 2112974

Shivalik Seeds Corporation
47 - Panditwari P.O.
Prem Nagar
Dehra Dun - 248007, U.P.
India
Tel 91-135 - 773348
Fax 91-135 - 773776
E-mail: hilander@vsnl.com

The Inland & Foreign Trading Co (Pte) Ltd.
Block 79A Indus Road #04-418
Singapore 169589
Tel (65) 2722711 (3 lines)
Fax (65) 2716118
E-mail: iftco@pacific.net.sg

Forestry Research Institute (FORI)
Address PO Box 1752
Kampala
Uganda
Tel (256-41) 255163-5, 244140, 251916/9
Fax (256-41) 234252, 255165
Telex 61186 SHIBSSC UG.

Glossary

A

acute - terminating with a sharp or well defined angle.

acuminate - the shape of a tip or base of a leaf or perianth segment where the part tapers gradually and usually in a concave manner.

adnate - joined to or attached to.

adventitious - describes an organ growing where it is not normally expected.

alternate - describes leaves that are not opposite to each other on the axis, but arranged singly and at different heights.

angiosperm - a plant producing seed enclosed in an ovary. A flowering plant.

annual - a plant that completes its life cycle from germination to death within one year.

anther - the pollen-bearing (terminal) part of the male organs (stamen), borne at the top of a stalk (filament).

anthesis - flower bud opening; strictly, the time of expansion of a flower when pollination takes place, but often used to designate the flowering period; the act of flower bud opening.

apex - the tip of an organ, the growing point.

apical - pertaining to the apex.

asexual - lacking sexual characteristics, or when referring to reproduction, occurring without the fusion of egg and sperm.

axil - the upper angle formed by the union of a leaf with the stem.

axillary - pertaining to the organs in the axil, e.g. buds, flowers or inflorescence.

axis - the main or central stem of a herbaceous plant or of an inflorescence.

B

basal - borne on or near the base.

biotic - refers to any aspect of life, but especially to characteristics of entire populations or ecosystems.

blade - the flattened part of a leaf; the lamina.

budding - method of propagating woody plants. A cutting of one variety, called the scion with buds attached, is joined onto another related species or variety called the rootstock. As the plant grows, the two parts graft together to form one plant.

C

calyx - the outer whorl of floral envelopes, composed of the sepals.

chlorosis - a yellowing of the leaves, reflecting a deficiency of chlorophyll and caused by waterlogging or a lack of nutrients, often iron.

clone - a group of plants that have arisen by vegetative reproduction from a single parent, and which therefore all have identical genetic material.

coriaceous - of leathery texture.

cotyledon - seed leaf; the primary leaf or leaves in the embryo.

cross pollination - the transfer of pollen from the anther of the flower of one plant to the flowers of a different plant.
cultivar - a race or variety of a plant that has been created or selected intentionally and maintained through cultivation.
cuneate - wedge-shaped; triangular with the narrow end at the point of attachment, as in the bases of leaves or petals.

D

deciduous - falling at the end of one season of growth or life, as do the leaves of non-evergreen trees.
decoction - herbal preparation made by boiling a plant part in water.
dehiscence - the method or process of opening a seed pod or anther.
derived - originating from an earlier form or group.
dicotyledon - a flowering plant with two cotyledons.
diploid - having two sets of chromosomes.
dorsal - upon or relating to the back or outer surface of an organ.
downy - covered with short and weak soft hairs.

E

ecosystem - an interacting complex of a community, consisting of plants and/or animals and functioning as an ecological unit.
elliptic - oval in outline.
endosperm - the starch and oil-containing tissue of many seeds.
explant - a plant part asceptically excised and prepared for culture in a culture medium.

F

filament - thread; particularly the stalk of the stamen, terminated by the anther.
filiform - thread-shaped, long, slender and terete.

G

genotype - the genetic constitution of an organism, acquired from its parents and available for transmission to its offspring.
genus - a group of related species, the taxonomic category ranking above a species and below a family.
glabrous - not hairy.
globose - globe-shaped.
glabrescent - becoming glabrous with age.
grafting - a method of propagation, by inserting a section of one plant, usually a shoot, into another, so that they can grow together into a single plant.
gynoecium - all the female parts of a flower.

H

hybrid - a cross-breed of two species, usually having some characteristics of both parents.

I

indehiscent - not regularly opening, as a seed pod or anther.
indigenous - native and original to the region.
inflorescence - the flowering part of a plant and especially the mode of its arrangement.

L

lamina - a blade, the leafy portion of a frond or leaf.
lanceolate - shaped like a lance head, several times longer than wide, broadest above the base and narrowed toward the apex.
lateral - side shoot, bud etc.
lamellae - a thin, flat plate or laterally flattened ridge.

M

membranous - thin in texture, soft and pliable.
mesocarp - the fleshy middle portion of the wall of a succulent fruit between the skin and the stony layer.
micro-propagation - propagation of plants thought tissue culture.

N

naturalised - to cause a plant to become established and grow undisturbed as if native.
nectar - sweet secretion of glands in many kinds of flower.

O

oblique - slanting, unequal sided.
obovate - inverted ovate; egg-shaped, with the broadest part above.
obtuse - blunt or rounded at the end.
orbicular - circular.
ovate - egg-shaped, with the broader end at the base.
ovule - the body which after fertilisation becomes the seed.

P

pedicel - a tiny stalk; the support of a single flower.
pendulous - more or less hanging or declined.
peduncle - a primary flower stalk supporting either a cluster or a solitary flower.
perianth - the floral envelope consisting of the calyx and corolla.
petal - a division of the corolla; one of a circle of modified leaves immediately outside the reproductive organs, usually brightly coloured.
petiole - the stalk of a leaf that attaches it to the stem.
phenology - the science of the relations between climate and periodic biological phenomena
phenotype - the morphological, physiological, behavioural, and other outwardly recognisable forms of an organism that develop through the interaction of genes and environment.

pinnate - a compound leaf consisting of several leaflets arranged on each side of a common petiole.
pistil - the seed-bearing organ of the flower, consisting of the ovary, stigma and style when present.
prolate - having flattened sides due to lengthwise elongation.
propagate - to produce new plants, either by vegetative means involving the rooting or grafting of pieces of a plant, or sexually by sowing seeds.
pubescent - covered with hairs, especially short, soft and down-like.

R

rachis - the main stalk of a flower cluster or the main leafstalk of a compound leaf.
radicle - the portion of the embryo below the cotyledons that will form the roots.
rootstock - the root system and lower portion of a woody plant to which a graft of a more desirable plant is attached.

S

scarify - to scar or nick the seed coat to enhance germination.
scion - a cutting from the upper portion of a plant that is grafted onto the rootstock of another plant, usually a related species.
self pollination - the transfer of pollen from the anther of a flower to the stigma of the same flower, or different flowers on the same plant.
sepal - a division of a calyx; one of the outermost circle of modified leaves surrounding the reproductive organs of the flower.
sheath - a tubular envelop.
stamen - one of the male pollen-bearing organs of the flower.
stigma - that part of a pistil through which fertilistion by the pollen is effected.
stipule - an appendage at the base of a petiole, often appearing in pairs, one on each side, as in roses.
style - the usually attenuated portion of the pistil connecting the stigma and ovary.
syncarp - an aggregate or multiple fruit produced from coherent or fused pistils, the small single fruits massing and growing together into a single fruit.

T

tetraploid - having four sets of chromosomes (twice the normal number of chromosomes).
terete - cylindrical but usually slightly tapering at both ends, circular in cross section, and smooth-surfaced.
testa - the outer seed coat.
transverse - cross-wise in position.
triploid - having three sets of chromosomes.

Index

A. brasiliensis, 4
A. champeden, 11
A. integer, 2, 3, 4, 77, 97
A. *integrifolia*, 11
A. integrifolius, 4
A. maxima, 4
A. philippinensis, 4
A. polyphema, 11
active compounds, 22
agroforestry, i, 26, 156, 164, 169
  bamboos, 27
  black pepper, 26, 29
  citrus, 26, 36
  durian, 26
  mango, 26, 36, 61, 127, 154
  palm, 27
  rambutan, 27
amino acids, 108
anthocyanins, 22
artocarpin, 24, 25
Bangladesh, v, 10, 15, 16, 26, 27, 29, 41, 44, 53, 54, 57, 58, 60, 65, 78, 80, 83, 93, 94, 95, 96, 97, 99, 101, 127, 133, 135, 137, 138, 149, 150, 151, 153, 154, 155, 156, 159, 162, 164
budding
  chip, 43, 44
  flute, 43
  forked, 43
  patch, 43, 44, 158
  ring, 8, 36, 43, 59
  shield, 43, 44, 61
cattle, 21, 22
Cauliflori, 3
characteristics, v, vi, 3, 6, 7, 33, 78, 80, 82, 95, 98, 99, 100, 103, 155, 156, 161, 186, 187
Chempedak, 11, 12
chlorophenoxyacetic acid, 31
compost, 29, 48, 49, 53, 128
conservation, i, 26, 77, 99, 100, 101, 144, 145, 147, 159
cultivar, 57, 83, 84, 97, 98, 103, 187
disease, 52, 64, 65, 66, 67, 68, 69, 100, 101
diversity, i, 13, 77, 78, 79, 82, 96, 97, 99, 144, 145, 147, 149, 150, 155, 168
Duricarpus, 3
export, 130, 135, 138, 143
fertilizer, 49, 53, 54, 55, 128
flavonoids, 22
Florida, v, 15, 16, 18, 51, 55, 56, 60, 65, 78, 83, 102, 133, 152, 153, 155, 160, 161, 164
freezing, 100, 111
furniture, vi, 13, 24
germplasm, 59, 78, 82, 95, 97, 99, 101, 144, 159, 163, 165, 180
gibberellic acid, 31
goats, 21, 157
grafting
  approach, 40, 164
  cleft, 40, 41, 44, 169
  epicotyl, vi, 40, 41, 44, 88, 89, 157
  inarching, 40, 41, 44
  splice, 40, 41
  veneer, 40, 41
grazing, 30
homegardens, 24, 53, 95, 100
Hong Kong, 137, 138
ideotype, 98
India, v, 1, 2, 10, 11, 13, 14, 15, 16, 18, 24, 26, 27, 28, 38, 40, 43, 44, 54, 57, 58, 60, 61, 70, 78, 83, 84, 93, 94, 95, 96, 97, 100, 101, 102, 104, 105, 127, 128, 129, 133, 135, 136, 137, 138, 144, 153, 155, 156, 159, 160, 161, 163,

164, 166, 168, 171, 172, 173, 174, 184, 185
indole-3-acetic acid, 35
Indole-3-butyric acid, 35
inflorescence, 3, 5, 8, 9, 64, 67, 71, 74, 103, 186, 188
isozymes, 96
jacalin, 24, 134
lectins, 24, 151
lipids, 109
local medicine, v, 22, 23
mahogany, 24, 25
market, v, 24, 25, 92, 107, 127, 129, 130, 132, 133, 134, 136, 137, 138, 139, 140, 141, 146, 157, 169
marketing, 28, 107, 128, 129, 130, 133, 134, 136, 137, 139, 140, 141, 143, 147, 148, 155
maturation, 75, 102, 103, 104
minerals, 20, 21, 109, 142
naphthalenacetic acid, 31
Nepal, v, 2, 10, 14, 15, 16, 28, 44, 57, 58, 70, 78, 83, 95, 96, 103, 131, 136, 137, 139, 140, 157
Pakistan, 16, 44, 83, 95, 96, 175, 176
perianth, 3, 8, 9, 71, 73, 74, 75, 111, 186, 188
pest, 33, 61, 101
Philippines, 2, 10, 12, 14, 15, 16, 26, 44, 50, 54, 58, 78, 83, 94, 95, 96, 101, 110, 133, 135, 138, 141, 149, 150, 153, 154, 156, 159, 161, 164, 169
phytochemical, 22
poly-embryony, 31
proanthocyanidin, 22
products, i, vi, 12, 19, 20, 24, 86, 99, 102, 104, 110, 111, 123, 130, 131, 133, 134, 135, 137, 138, 139, 143, 148, 157, 169
  beverages, 19, 120
  candy, 121
  canning, 125
  curry, 112, 115, 116, 117, 118
  jam, 119
  jelly, 120
  leather, 124, 125, 133, 135
  pickles, 118, 133, 135
  powder, 19, 20, 111, 112, 113, 115, 116, 117, 118, 119, 126
propagation
  air layering, 36
  budding, 43, 166
  cuttings, 34
  grafting, vi, 34, 40, 41, 42, 43, 44, 48, 88, 95, 148, 153, 157, 159, 169, 187, 189
  growth regulators, v, 31, 35, 37, 38, 39, 45, 165
  In vitro, 45, 100, 149, 164, 168
proteins, 108
Pseudojaca, 3, 157
pulp, 1, 2, 3, 12, 13, 19, 20, 23, 33, 72, 73, 74, 81, 84, 93, 107, 108, 109, 114, 115, 116, 119, 121, 123, 133
retail, 107, 137
rooting, v, 35, 36, 37, 38, 39, 45, 47, 152, 160, 162, 165, 166, 189
rootstocks, 30, 34, 40, 41, 48, 94, 99, 144
seed, 9, 23, 30, 31, 34, 48, 49, 70, 73, 74, 75, 78, 83, 100, 101, 109, 111, 157, 166, 167, 184, 186, 187, 188, 189
Singapore, 57, 70, 83, 137, 138, 156, 185
Soccus arboreus major, 4
Southeast Asia, 1, 11, 12, 79, 99, 127, 144, 167
sowing, 30, 31, 166, 189
spikes, 5, 8, 65, 70, 71, 72, 75
Sri Lanka, 2, i, 10, 14, 15, 16, 18, 24, 27, 28, 30, 44, 57, 72, 78, 83, 84, 93, 94, 95, 96, 101, 102, 127, 131, 133, 134, 135, 138, 153, 155, 169
stipules, 5, 11
sugars, 108
syncarp, 2, 3, 9, 74, 189

tannin, 109
tannins, 22
taste, 11, 12, 57, 78, 84, 93, 103, 104, 110, 111, 117, 125
teak, 24, 25
termites, 13, 24
Thailand, 1, 10, 12, 14, 15, 16, 41, 44, 58, 70, 78, 83, 93, 94, 95, 96, 101, 127, 133, 138, 158, 164, 166, 169
thinning, 52, 72
timber, 24, 25, 30, 34, 50, 52, 98, 99, 127, 135, 141, 147, 169
transplanting, 32
trypsin, 21
vegetable, 19, 132
Vietnam, 10, 15, 16, 44, 57, 58, 78, 83, 95, 96, 101, 151, 178, 179
vitamins, 109
Western Ghats, 1, 11, 15, 97, 100, 144
wholesale, 107, 132, 138
yield, 24, 25, 27, 57, 58, 98, 99, 103, 104, 110, 129, 139, 144, 154, 156, 159