1. INTRODUCTION

1.1. THE PAPAYA INDUSTRY IN MALAYSIA

Papaya (*Carica papaya* L.) is also sometimes called papaw. It is a herbaceous, short-lived perennial usually cultivated for its large melon-like fruits. Ripe papaya fruits have a delicate aroma and sweetness and have very high vitamins A and C. Papaya is also sometimes cultivated for papain, a proteolytic enzyme widely used for tenderising meat, beer clearing and in paint, textile and leather industries. It is also used in the pharmaceutical field for suppression of wound inflammation and as a laxative.

1.1.1. Status of the industry

The papaya industry in Malaysia is relatively insignificant compared with the overall agricultural sector of the country. Indeed, it is relatively minor even in comparison with just the fruit sector. The total area of fruits in Peninsular Malaysia in 1989 was 145 546 ha and papaya with 2 026 ha, was a mere 1.4% of the national fruit acreage (Abd. Jamil, 1993). However, this small acreage contributed significantly to the export earnings from fresh fruits. In 1990, about 32 000 tonnes of papaya were exported with a value of RM 21 million, a contribution of about 15% of the total fruit export value (Mukhtiar, 1994).

The position of Malaysia as a papaya-producing country in the world is also not prominent. The total production of papaya in Malaysia was estimated to be about 40 000 tonnes in 1993 (FAO, 1993). This was about a mere 0.7% of the world production of 5 863 000 tonnes in 1993 (*Table 1.1*). Malaysia's position as a papaya-producing country in Asia was ranked seventh, after India (1 200 000 tonnes), Thailand (545 000 tonnes), Indonesia (358 000 tonnes), Taiwan (125 000 tonnes), Philippines (97 000 tonnes) and Yemen (56 000 tonnes).

There are, however, encouraging signs regarding the rapid growth of the local papaya industry. The acreage for example, had increased 234% in 1989 from a mere 600 ha in 1985 (Abd. Jamil, 1993). The rise in export earnings around that same period was an equally dramatic six-fold increase from RM 3.3 million in 1985 to RM 21 million in 1990 (Mukhtiar, 1994).

Table 1.1. World production of papaya (1991 - 1993)

Country	1991 (1 000 t)	1992	1993
World	**5024**	**5421**	**5863**
South America	**1737**	**1934**	**1963**
Brazil	1515	1709	1750
Colombia	71	74	62
Peru	61	62	62
Venezuela	35	35	35
Ecuador	16	16	15
Asia	**2043**	**2250**	**2463**
India	805	1000	1200
Thailand	539	542	545
Indonesia	353	355	358
Taiwan	123	122	125
Philippines	95	96	97
Yemen	53	55	56
Malaysia	37	38	40
North and Central America	**447**	**454**	**448**
Mexico	342	342	343
Cuba	32	30	30
USA	25	33	29
Africa	**782**	**768**	**774**
Nigeria	500	500	500
Zaire	208	210	210
Mozambique	44	35	40
South Africa	28	21	22
Oceania	**14**	**15**	**16**

Source: FAO (1993)

1.1.2. S.W.O.T. analysis of the industry

The strengths, weaknesses, opportunities and threats (S.W.O.T.) of the Malaysian papaya industry will be discussed as follows:

1.1.2.1. *Strengths*

(i) The advent of the Eksotika variety in 1987 had given the industry the necessary impetus for accelerated development in cultivation, production and export of papaya. Dramatic increases in papaya acreage and export earnings were evident after the release of this new variety. Malaysia is still the only country that grows the Eksotika on commercial scale, and enjoys the market monopoly in Singapore and Hong Kong.

(ii) The Malaysian government has identified fruits as the fourth crop option in the agricultural sector after rubber, oil palm and cocoa (Mohamad and Chan, 1992). Papaya was also identified as the fruit to be given top priority in research because of its potential as an export revenue earner.

(iii) Unlike most other tropical fruits, the papaya is a well-known and accepted fruit in international markets and there is less necessity for market promotion and advertisement.

1.1.2.2. *Weaknesses*

(i) The Eksotika is very susceptible to malformed top disease (MTD) caused by *Cladosporium oxysporum* (Lim, 1989) and papaya ringspot virus disease (PRSV) (Chan, 1993b). The outbreak of PRSV in Johor in 1991 had effectively curbed papaya cultivation in that state.

(ii) Papaya, like most tropical fruits, has very poor keeping quality. Harvested at Index 2 (a show of yellow), the Eksotika can be kept for 3-4 days under ambient temperatures and for about 2-3 weeks at 10^{0} C (Rohani and Siti, 1994).

(iii) Inconsistency in production and fruit supply has been the main concern of exporters who sometimes have to sign contractual agreements regarding supply of fruits to the clients. However, papaya, although generally classified as a non-seasonal fruit, does have peaks and troughs in production. The fluctuations in production are largely influenced by environmental factors (Chan *et al.*, 1991).

1.1.2.3. *Opportunities*

(i) New markets like the Middle East and Japan appear attractive and hold promise for expansion of the papaya industry. Interest and demand for Malaysian papayas have soared in the Middle East in recent years. From 1989 to 1990, a 65% increase in import of Malaysian papayas was recorded. For the Japanese market, however, certain postharvest disinfestation procedures must be followed in order to satisfy their strict quarantine regulations. At the Malaysian Agricultural Research and Development Institute (MARDI), various methods for disinfestation of fruit flies such as vapour heat treatment, irradiation, fumigation and cold treatments are actively pursued for fruit types which have export potential such as papaya, starfruit, mango, ciku and mangosteen (Mohamad and Chan, 1992).

(ii) Malaysia exports papaya to Hong Kong, the Middle East countries and Europe by air. The high air-freight costs and limited air cargo space have effectively diminished the export potential of the fruit. Opportunities exist for export of papaya by sea using refrigerated reefer containers which will drastically cut transportation costs. However, the storage life of the Eksotika variety, presently around 2-3 weeks if stored at 10 ^{o}C (Rohani and Siti, 1994) is insufficient to meet the duration of the sea journey to distant markets.

(iii) Papaya appears to adapt well on some soils such as peat, acid sulphate and tin-tailings which are normally considered marginal for crop cultivation (Raveendranathan and Chan, 1994). Eksotika was reported to yield about 60 - 65 t/ha on peat and acid sulphate when the low soil pH was redressed with suitable applications of lime. It was estimated that about 1.2 million hectares of these soils exist in Peninsular Malaysia (Mohd. Tamin *et al.*, 1982).

1.1.2.4. *Threats*

(i) Threats of competition from neighbouring countries like Indonesia and Thailand loom over the local papaya industry. The costs of production in these countries are lower than Malaysia because of cheaper and readily available manpower. Although Malaysia presently enjoys more or less a monopoly of the papaya export markets in Singapore and to a large extent, Hong Kong, this may not hold out much longer if the Eksotika variety is also widely cultivated by the competitors.

(ii) The industrialisation programme (Vision 2020) will make Malaysia a developed nation, but it will also worsen the labour shortage situation in the agricultural sector. This is exacerbated by the fact that workers in papaya orchards must be fairly skilled because unlike the plantation crops, papaya is more fastidious and requires great care in management for production of fruits with high quality and good cosmetics (Yee *et al.*, 1994). There is an urgent need for mechanisation of farm operations to reduce labour dependency.

1.2. STATUS OF PAPAYA RESEARCH

Papaya research can be divided into three era, namely, pre-1955, 1955 - 1975 and post-1975. In these three periods, the differences in emphasis and priority areas in research for papaya may be seen.

Active papaya research can be traced back more than five decades ago. During the pre-1955 era, research on papaya was carried out by several countries, notably USA (Hawaii), India, Puerto Rico, South Africa, Brazil and Venezuela. Most of the research was related to crop introduction, description and crop husbandry. In Hawaii, research on postharvest storage and disinfestation for export was initiated and gathered momentum in the late 1930's (Jones, 1939). However, the most active area of research in this era was focused on the complicated sexual forms of the papaya flower and other related traits. It was during this time that the genetics of sex inheritance of papaya was first determined (Hofmeyr, 1938; Storey, 1941). It was also during this time that studies on reversal of flower sexes, carpellody of stamens, male sterility, inheritance of dwarfness, height of bearing and other traits were carried out.

Papaya research in the second era from 1955 - 1975 can be said to be dominated by the team of scientists from the University of Hawaii. An integrated approach was adopted to develop the technology package for the papaya industry. This encompassed many disciplines of research including breeding and selection, agronomy, physiology, pest and disease management and postharvest ripening and handling. This was the era that saw the development of Line 10 Solo (Hamilton and Izuno, 1965), Sunrise Solo (Hamilton and Ito, 1968), Waimanalo (Nakasone *et al.*, 1972) and Higgins and Wilder (Nakasone *et al.*, 1974). Interspecific hybridisation between *Carica* species was also initiated (Mekako and Nakasone, 1975). In physiology, the effects of moisture, nitrogen and temperature on yield were established and fertiliser recommendations made based on uptake studies and petiole contents. In diseases, the major thrust was on control of *Phytophthora palmivora* stem and fruit rot which was also related to the replant problem of papaya in Hawaii. Soil replacement in the planting hole, soil fumigation and selection of tolerant lines were some methods to combat the disease. During this period too, great strides were made in the area of postharvest handling and fruit ripening. At the threshold of being an important exporter of papaya provided the motivation for research in extending the shelf life of the fruits and development of storage conditions for maintaining quality and cosmetics of the fruit.

The post-1975 era saw the participation of many other countries and research agencies in papaya research. The notable ones are the Queensland Department of Primary Industries (QDPI), University of Florida, Taiwan Agricultural Research Institute (TARI) and Chung Hsing University in Taiwan, EMBRAPA in Brazil, Kasetsart University in Thailand, Indian Institute of Horticultural Research and the Malaysian Agricultural Research and Development Institute. The major research areas, particularly in the third countries, were focused on breeding and selection to develop varieties adapted to the specific country. Many of the areas of work carried out in the 1955 - 1975 era in Hawaii, were repeated in these countries in the effort to find the suitable technology best suited for the local variety and environment.

In terms of progress, the third era witnessed the successful and important development of in-vitro propagation for papaya (Mehdi and Hogan, 1976; Yie and Liaw, 1977; Litz and Conover, 1978). This breakthrough not only promised rapid mass propagation of the crop but also spawned related experiments such as haploid breeding (anther culture), embryo rescue of interspecific progenies from otherwise incompatible crosses, rapid progeny screening for disease resistance and genetic engineering. The most obvious thrust during this era is on the control of the papaya ringspot virus disease (PRSV). Tolerant varieties like Cariflora (Conover *et al.*, 1986) and Tainung no. 5 (Lin *et al.*, 1989) were developed and cross-protection of seedlings using mild strains was commercially used in Taiwan (Yeh *et al.*, 1988). The more recent advancement is the development of PRSV resistant plants with coat protein-mediated protection by gene transfer using microprojectile-mediated transformation (Fitch *et al.*, 1992).

In Malaysia, papaya research was started in 1969, with the advent of the Malaysian Agricultural Research and Development Institute (MARDI). The institute has, since its inception, released improved cultivars like Subang and Batu Arang through mass selection and the popular Eksotika from the backcross breeding programme (Chan, 1987). A more recent variety, Eksotika II was developed from hybridisation of Line 19 and Eksotika and it has higher yields and more attractive fruit cosmetics (Chan, 1993a). MARDI has also developed the complete technology package for growing Eksotika and this includes fertiliser and water use, pest and disease management and postharvest ripening, handling and storage.

The present thrust areas of the papaya research in Malaysia are on the breeding of varieties with high yields, good fruit qualities and long shelf life for export and resistance to papaya ringspot virus and malform top disease. Research on agronomy includes development of cost-effective production systems with efficient use of fertilisers, water and management of pests, diseases and weeds. In postharvest research, emphasis is now given to postharvest disinfestation of fruits to meet the quarantine regulations for papaya export to potential markets like Japan (Mohamad and Chan, 1994).

Other agencies in Malaysia which are also involved in papaya research include Universiti Pertanian Malaysia which conducts research on nutrient requirements, postharvest ripening and handling and fruit transport mechanics; Universiti Sains Malaysia which does research on in vitro culture of papaya and Universiti Kebangsaan Malaysia which focuses research on postharvest ripening and extension of storage life of papaya.

1.3. BASIS FOR RESEARCH ON F_1 HYBRIDS OF PAPAYA

1.3.1. Conventional cultivars

The most important papaya cultivars in the world today, for example Kapoho, Waimanalo, the widely popular Sunrise Solo and the Eksotika, are purelines which are propagated from generation to generation from seeds obtained by selfing hermaphrodite flowers of gynodioecious varieties. Pureline varieties have the advantages of homozygosity and genetic uniformity and their seeds can be reproduced quite easily. In papaya, pureline selection is feasible because there is no inbreeding depression during selfing of gynodioecious populations (Hamilton, 1954) or dioecious populations (Aquilizan, 1983). There is growing evidence, however, that there may be other breeding techniques for producing higher yielding and more stable varieties.

1.3.2. Potential of F_1 papaya hybrids

In the past, there has been very little interest in F_1 hybrids of papaya with the exception of the work reported by Chang and Wu (1974) and Subramanayam and Iyer (1984) who demonstrated marked heterosis in crosses between varieties, and Mekako and Nakasone (1975) who reported heterosis from interspecific crosses. More recently, Chan (1992) reported heterosis in yield and fruit quality in F_1 hybrids developed from closely related sib crosses. In spite of these supporting evidence for the potential of hybrids, heterosis in papaya is still not fully exploited because there are no commercial F_1 papaya hybrid varieties in the market today.

In research for development of efficient production system for papaya, emphasis should be given to high production per unit area per unit time. With such a space-time increase in yield, the cost of production per unit weight of produce will also be lowered and this will bring about a favourable impact on the industry. The evidence gathered from heterosis breeding in other crops gives encouraging support that early and high yields can be realised in papaya. However, the prospects of using F_1 varieties on commercial scales depend, to a considerable extent, on the economic feasibility in the production of hybrid seeds.

Production of F_1 seeds requires that the seed-bearing parent be devoid of pollen to prevent production of self-pollinated seeds that would contaminate the purity of the hybrid stock. This can be achieved by using female flowers which obviate emasculation or hermaphrodite flowers which require emasculation. Hand emasculation has to be performed in papaya because no male sterile has yet been found to facilitate hybridisation. Production of hybrid seeds using female flowers which do not require emasculation appears attractive, but they also produce a higher percentage of undesirable female trees. On the other hand, hermaphrodite flowers produce seeds which have a high proportion of the more desired hermaphrodite trees. However, high costs are incurred in emasculation work to produce these seeds. This additional input can only be economically justified if the margin of returns of the F_1 hybrids over conventional varieties are higher than the added costs involved in their production. This forms the basis for the present studies on development of F_1 hybrids for papaya.

1.3.3. Scope of study

There are two major parts in the present studies. The first part investigates the seed production behaviour and trends of six inbred lines of papaya using a complete diallel cross system. This part of the study provides information on the seed production capabilities of the inbreds both as maternal (seed-carrying) or paternal (pollen) parent, and the variation in seed yields as affected by the age of trees, location and sex of the flowers (hermaphrodite v female). The results from this part of the study allow an estimation of the pricing of hybrid seeds based on the cost of production of the seeds and the seeding rate for papaya.

The second part evaluates the performance of the F_1 hybrids over six environments. This part of the study provides information on the relative superiority of hybrids over their parents in terms of mean performance (heterosis) and stability. It will answer the question related to the economic justification for added costs in the production of F_1 hybrids for papaya.